THE OYSTER FISHERY OF THE GULF OF MEXICO UNITED STATES:
A Regional Management Plan

2012 Revision

Gulf States Marine Fisheries
Commission

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THE OYSTER FISHERY OF THE GULF OF MEXICO, UNITED STATES:

A Fisheries Management Plan

2012 Revision

by the

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Preface

The Gulf States Marine Fisheries Commission (GSMFC) was established by the Gulf States Marine Fisheries Compact under Public Law 81-66 approved May 19, 1949. Its charge is to promote better management and utilization of marine resources in the Gulf of Mexico.

The GSMFC is composed of three members from each of the five Gulf States. The head of the marine resource agency of each state is an ex officio member. The second is a member of the legislature. The third is a governor-appointed citizen with knowledge of or interest in marine fisheries. The offices of the chairman and vice chairmen are rotated annually from state to state.

The GSMFC is empowered to recommend to the governor and legislature of the respective states action on programs helpful to the management of marine fisheries. The states, however, do not relinquish any of their rights or responsibilities to regulate their own fisheries as a result of being members of the GSMFC.

One of the most important functions of the GSMFC is to serve as a forum for the discussion of various problems and needs of marine management authorities, the commercial and recreational industries, researchers, and others. The GSMFC also plays a key role in the implementation of the Interjurisdictional Fisheries (IJF) Act. Paramount to this role are the GSMFC's activities to develop and maintain regional fishery management plans for important Gulf species.

The Oyster Fishery Management Plan is a cooperative planning effort of the five Gulf States under the IJF Act. Members of the task force contributed by drafting individually assigned sections. In addition, all members contributed their expertise to discussions that resulted in revisions and led to the final draft of the plan.

The GSMFC made all necessary arrangements for task force workshops. Under contract with the National Marine Fisheries Service (NMFS), the GSMFC funded travel for state agency representatives and consultants other than federal employees.

Throughout this document, metric equivalents are used wherever possible with the exceptions of reported landings data and harvest limits which, by convention, are reported in English units. A glossary of fisheries terms pertinent to this FMP is provided in the appendix (Section 16.1).

Abbreviations and Symbols

ADCNR/MRD	Alabama Department of Conservation Natural Resources/Marine Resources Division
CCP	Critical Control Point
DMS	Data Management Subcommittee
DO	dissolved oxygen
EEZ	exclusive economic zone
EFH	essential fish habitat
FMP	fishery management plan
FWC/FMRI	Florida Fish and Wildlife Conservation Commission/Florida Marine Research Institute
ft	feet
g	gram
GMFMC	Gulf of Mexico Fisheries Management Council
GSI	gonadal somatic index
GSMFC	Gulf States Marine Fisheries Commission
ha	hectare
HAB(s)	Harmful Algal Bloom(s)
HACCP	Hazard Analysis Critical Control Point
hr(s)	hour(s)
IJF	interjurisdictional fisheries
ISSC	Interstate Shellfish Sanitation Conference
kg	kilogram
km	kilometer
lbs	pounds
LDWF	Louisiana Department of Wildlife and Fisheries
m	meter
MDMR	Mississippi Department of Marine Resources
MFCMA	Magnuson Fishery Conservation and Management Act
min(s)	minute(s)
mm	millimeters
MO	Model Ordinance
MOA(MOU)	Memorandum of Agreement (Understanding)
MRFSS	Marine Recreational Fisheries Statistical Survey
mt	metric ton
NMFS	National Marine Fisheries Service
NSSP	National Shellfish Sanitation Program
n	number
PPI	producer price index
ppm	parts per million
ppt	parts per thousand
SAT	Stock Assessment Team
sec(s)	second(s)
SFFMC	State-Federal Fisheries Management Committee
SPR	spawning potential ratio
TCC	Technical Coordinating Committee
TPWD	Texas Parks and Wildlife Department
TTF	technical task force
TTS	Texas Territorial Sea
TW	total weight
USDOC	United States Department of Commerce
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
YOY	young-of-the-year
yr(s)	year(s)

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1.0 Summary

Eastern oysters (Crassostrea virginica) are distributed throughout the coastal area of the United States and occur naturally in a great diversity of habitats along the western Atlantic Ocean from the Canadian Maritime Provinces to the Gulf of Mexico, Panama, and the Caribbean Islands. Eastern oysters have been moved by humans between bay systems along the east coast of the United States since the late 1800s, and oysters from the Gulf of Mexico have also been used to supplement oyster populations in the Chesapeake Bay in response to population collapse.

Recent genetic analysis of eastern oysters along the east coast and oysters from the Gulf of Mexico suggests the existence of separate Atlantic and Gulf populations, with a transition zone along the eastern coast of Florida. There is evidence for some structuring of populations within the Gulf. Texas, Louisiana, and northwest Florida populations almost always show some differentiation, although the level of statistical confidence varies.

Eastern oysters are dioecious, with the sexes separate, and protandrous, first maturing as males, then changing to female later in life, while retaining the ability to revert to male. Under optimal environmental conditions, some oysters in Gulf bays can become sexually mature and reproductively active four weeks after setting. Environmental parameters such as temperature, salinity, and food availability affect the time required for oysters to mature. The number of gametes released during each spawn is directly correlated with oyster size and gonadal development as well as physiological condition. Fecundity of oysters in the Gulf of Mexico is difficult to determine due to prolonged spawning seasons, with intermittent spawning and redevelopment throughout the year. Oysters may spawn throughout the Gulf in all but the coldest months. Spawning peaks are usually clearly defined and typically occur several times throughout the year. Spawning may peak in the spring, summer, fall, or more than once depending on environmental conditions. Under natural conditions, mature individuals of each sex must simultaneously release sperm and eggs into the water in relatively close proximity for successful reproduction.

As sessile, non-motile organisms, oysters must rely on food-laden water being moved past the oyster in order to extract food from the water column. Water flow across oyster reefs has been shown to influence growth rate. Early larvae depend on naked (without rigid cell walls) phytoplankton as a food source, while older larvae can also feed on phytoplankton that possess cell walls. Juvenile and adult oysters feed primarily on planktonic organisms and organic detritus.

Oyster growth is influenced by temperature, salinity, and other environmental factors and can vary seasonally throughout the species range. In the Gulf of Mexico, growth has been reported as continuous throughout the year with the fastest growth occurring during periods of high water temperature. Oysters exposed to salinities that fluctuate within normal ranges (14-28 ppt) grow faster than those held at a relatively constant salinity but growth is stunted at 7.5 ppt and ceases below 5 ppt. When exposed to air for short periods, oysters exhibit growth rates similar to continually submerged individuals; however, long exposure periods of the reef will inhibit growth.

Oyster reefs are natural accumulations of oyster shell and living oysters that result from the successive growth of generations of oysters in the same place. Oyster shell provides a substrate for a variety of sessile organisms and a physical structure that provides cover and food for numerous other estuarine species including commercial and recreational bay and offshore fishery species. Oysters are capable of withstanding a wide range of environmental conditions but are most abundant and productive when optimal environmental conditions exist. Beginning their life as a free-swimming organism, oysters settle and quickly attach themselves to hard surfaces. While their preferred attachment substrate is other oyster shells, they will also attach to bulkheads, pilings, concrete, and almost any hard substrate. Larvae attaching to the shell of other oysters results in a natural accumulation of oyster shell within an area. The successive growth of generations of oysters in the same place results in a consolidated reef that is usually elevated above the surrounding bay bottom. Oysters can also survive on stiff mud surfaces, firm enough to support the oyster's weight. Soft mud and shifting sand are typically unsuitable substrates for the establishment of oyster reefs.

Larval survival, successful development into spat, growth into market size, and health and condition are greatly dependent on ambient environmental conditions. The ambient air temperature which influences water temperature can also vary greatly from the water temperature which the oysters inhabit. Water temperatures in the bays and estuaries of the Gulf vary with season and water depth, both of which influence the water temperature over a reef's surface. Oysters can survive a wide range of salinities, tolerate fresh water for brief periods, and grow in water saltier than the Gulf. The optimum salinity range for oysters is between 15-30 ppt. The ability of an oyster to tolerate higher salinities is inversely correlated to the ambient water temperature; increased water temperature reduces the ability of the oyster to tolerate high salinities, while lower ambient water temperature allows oysters to tolerate lower salinity waters longer. However, prolonged exposure to fresh water during flood events, known as 'freshets', can result in severe oyster mortalities. Finally, the oyster's euryplastic physiology allows them to use available oxygen over a wide range of temperature and salinity combinations, thereby maintaining an energy gain from a constantly changing environment.

Like most species, oysters are dependent on habitat for their survival. Oysters are vulnerable to many types of habitat destruction, including overfishing, altered fresh water flow, physical removal, and burial by sediments. These types of reef destructions can lead to shortages of accessible oyster substrate, poorer water quality due to less filtration, impaired habitat quality, increased predation, increased competition for resources, and increased exposure to diseases. The destruction of oyster reef habitat is two-fold, impacting the oyster's habitat and also impacting the habitat of numerous other marine species.

As a renewable resource, oyster reefs can replenish and sustain themselves when properly managed. The combined effects of harvesting, fluctuating environmental conditions, manmade perturbations, and natural mortality from disease and predation make it difficult to isolate the specific contributions of individual factors on total mortality. Certainly, man has been the most serious threat to oyster populations. Anthropogenic stressors, including habitat destruction (sedimentation), physical disruption (dredging), alteration of hydrologic regimes (freshwater diversion, impoundment, and channelization), pollution burdens, and overharvesting have resulted in long-term population losses. Oysters, however, have exhibited a remarkable capacity to reestablish thriving populations when mortalities have resulted from natural phenomena, such as floods, drought, or hurricanes.

Oysters suffer from numerous biological and anthropogenic sources of stress and mortality. Many competitors, parasites, predators, diseases, and pollutants have been identified, and the manner in which they infect or kill oysters has been described. In the Gulf, the oyster drill (Stramonita haemastoma) is among the most serious natural predators along the Gulf and was distributed wherever oysters were found at salinity levels averaging above 15 ppt. It has been reported that losses to oyster drills were incalculable and, with their voracious feeding habits, high reproductive capacity, and widely distributed larval stages, this snail is the most destructive oyster predator in the Gulf environment.

The pathogenic protozoan, Perkinsus marinus or 'Dermo', is widely distributed throughout the oyster-producing waters of the Gulf, and the prevalence of the parasite is high among oyster populations. Intensive Dermo infections have been associated with massive mortalities throughout the Gulf, especially during the summer, when high water temperatures and salinities exacerbate disease conditions.

Oysters are filter feeders which can bio-accumulate contaminants and microorganisms, including human pathogens and toxigenic micro-algae when these organisms are present in the overlaying waters of the growing area. There are several commonly occurring bacteria, enterovirulents, parasites, and viruses which can be contracted from the consumption of raw or under-processed foods. Since oysters are commonly eaten live, whole, and raw, these contaminants and organisms put immune-compromised individuals at a much higher risk than the normal, oyster-eating population. Therefore, public health controls for shellfish, including oysters, became a national concern in the U.S. in the late nineteenth and early twentieth centuries, and the U.S. Public Health Service responded by developing control measures through the National Shellfish Sanitation Program (NSSP) to reduce the risk of disease associated with the consumption of raw shellfish (oysters, clams, and mussels). Much of the management of oysters today is directly related to the concern for public health and prevention of disease outbreaks and illness.

The earliest records of oyster consumption in colonial America can be dated back to the mid-1700s when early French settlers harvested oysters. By the 19th century, the market for oysters expanded, and they became somewhat of a delicacy. Many tons of oysters were shipped to the east coast and Midwest as more people were able to afford them. Consumer demand fueled the efforts to maximize early oyster harvests. Oyster canning technology and railroad development during the mid-1800s opened markets for eastern oysters as far west as St. Louis and the increased harvests reduced oyster prices lower than those for beef, poultry, and fish. It is not clear when the commercial fishery for oysters in the Gulf was first developed. It is likely that commercial fishing was first developed by aboriginal Americans who established trade for smoked oysters in many areas of North America. As the early Europeans began to rely more on native foodstuffs and develop local economies, the industry evolved into its modern form. Management efforts with regulatory agencies are recorded back to the late 19th century.

The Gulf oyster fishery likely began with harvesters using tongs or picking oysters by hand. In the mid-1800's, schooners and sailed luggers pulled dredges to increase production in the Gulf. Eventually, the widespread use of the steam-powered dredging boats replaced sailing vessels and, by 1940, powered oyster luggers had replaced sailed schooners almost completely on the Gulf's oyster grounds. Traditionally, the Atlantic coast has provided the majority of the country's oysters while the Gulf held a small share of the market. However, in the mid-1950s, a serious decline in oyster populations began in the New England region and another decline began in the Chesapeake in the early 1980s. The Gulf's share of U.S. eastern oyster production averaged about 40% until 1980. Since then, it has increased from 50% in the early 1980s, 60% through the mid-1990s, and represents 80-90% of the total U.S. production today. Louisiana is the largest producer of oysters among the Gulf States and its average annual production of 11.9 million lbs represents close to 60% of the total Gulf production during 1986-2005. Historically, production in Louisiana comes primarily from leased bottoms; however, the public seed grounds exhibited sizable increases in production during the 1990s and early 2000s.

U.S. oyster production represented almost 3% of the total $4.4 billion U.S. seafood (edible and non-edible) dockside value. Considering the product only at dockside, however, provides an incomplete picture of the value of oysters as additional value is generated at each step along the marketing channel as the harvested product is transported and transformed to meet the demands of the consuming public. While less obvious, but also of importance, oysters and associated reef communities provide a multitude of ecological services (e.g., improved water quality) that benefit society and, hence, are of value.

Effective management of oyster resources requires an understanding of how many oysters occur within each defined management unit, the locations of those resources, and recruitment and mortality rates within each unit. Considering the fundamental importance of effectively modeling population status and suitability for harvest, there remains a surprising dearth of information regarding the stock status of oysters in the Gulf of Mexico. Population assessments of oyster stocks represent a special challenge, due to fundamental differences in data availability and population biology between shellfish and other fishery resources. In most states, an annual survey of oyster abundance is conducted but with high variability in coverage among states and years. The survey results provide the best time series from which to generate abundance estimates. Derivation of abundance estimates, combined with size-specific estimates of wet or dry weight, then allows an estimation of size-specific biomass. At present, there is not an assessment model that estimates the fishing mortality rate and abundance of the fishable stock or helps determine the population reference points for any Gulf of Mexico oyster fishery. In this document, we test the Constant Abundance/Surplus Production (CASP) model which is used successfully in Delaware Bay. Two populations of Gulf oysters were examined to determine the value of this approach on assessing Gulf oyster populations.

Finally, a history of cultch planting and an oyster aquaculture primer have been provided as appendices in the plan, as well as an atlas of the primary producing reefs currently identified in the Gulf of Mexico. These maps are not meant to represent all the known oyster habitats in each state but to indicate those known at the time of this publication. In addition, some historical reef areas are included even if they are no longer considered public or open to harvest.

2.0 INTRODUCTION

On March 15, 2006, the State-Federal Fisheries Management Committee (SFFMC) agreed that the Oyster Fishery Management Plan (FMP) which had been completed in 1991 was out-of-date and would be the next species (fishery) designated for revision under the IJF Program. Because of the age of the information in the original FMP, it was generally agreed that this would essentially be a major rewrite. The Oyster Technical Task Force (TTF) was subsequently formed, and an organizational meeting was held June 27, 2006 in Pensacola, Florida. Several experts outside the normal roster were added due to the extensive management of this fishery and the concern with both human health and the prevalence of cultured products.

2.1 IJF Program and Management Process

The Interjurisdictional Fisheries Act of 1986 (Title III, Public Law 99-659) was approved by Congress to: (1) promote and encourage state activities in support of the management of interjurisdictional fishery resources and (2) promote and encourage management of interjurisdictional fishery resources throughout their range. Congress also authorized federal funding to support state research and management projects that were consistent with these purposes. Additional funds were authorized to support the development of interstate FMPs by the GSMFC and other marine fishery commissions. The GSMFC decided to pattern its plans after those of the Gulf of Mexico Fishery Management Council (GMFMC) under the Magnuson Fishery Conservation and Management Act of 1976. This decision ensured compatibility in format and approach to management among states, federal agencies, and the GMFMC.

After passage of the act, the GSMFC initiated the development of a planning and approval process for the profiles and FMPs. The process has evolved to its current form outlined below:

DMS						
↕						
TTF	↔	**TCC**	↔	**SFFMC**	↔	**GSMFC**
↕				↕		
SAT				**Outside Review**		

DMS = Data Management Subcommittee
SAT = Stock Assessment Team
TTF = Technical Task Force
TCC = Technical Coordinating Committee
SFFMC = State-Federal Fisheries Management Committee
GSMFC = Gulf States Marine Fisheries Commission
Outside Review = standing committees, trade associations, general public

The TTF is composed of a core group of scientists from each Gulf state and is appointed by the respective state directors who serve on the SFFMC. Also, a TTF member from each of the GSMFC standing committees (Law Enforcement, Habitat Advisory, Commercial Fisheries Advisory, and Recreational Fisheries Advisory) is appointed by the respective committee. In addition, the TTF may include other experts in economics, socio-anthropology, population dynamics, and other specialty areas when needed. The TTF is responsible for development of the Profile/FMP and receives input in the form of data and other information from the DMS and the SAT.

Once the TTF completes the document, it may be approved or modified by the Technical Coordinating Committee (TCC) before being sent to the SFFMC for review. The SFFMC may also approve or modify the document before releasing it for public review and comment. After public review and final approval by the SFFMC, the document is submitted to the GSMFC where it may be accepted or rejected. If rejected, the document is returned to the SFFMC for further review.

Once approved by the GSMFC, Profile/FMPs are submitted to the Gulf States for their consideration for adoption and implementation of management recommendations.

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Section 17.0	All

2.5 Profile Objectives

The objectives of the Oyster Fishery Management Plan are:

1. To summarize, reference, and discuss relevant scientific information and studies regarding the management of Gulf of Mexico oysters in order to provide an understanding of past, present, and future efforts.

2. To describe the biological, social, and economic aspects of the Gulf oyster fishery.

3. To review state and federal management authorities and their jurisdictions, laws, regulations, and policies affecting oysters in the Gulf of Mexico.

4. To ascertain optimum benefits of the oyster fishery of the United States Gulf of Mexico to the region while perpetuating these benefits for future generations.

3.0 Description of Stocks Comprising the Management Unit (MU)

The management unit is comprised of eastern oyster (*Crassostrea virginica*) populations on the natural and artificially propagated oyster reefs occurring in the coastal waters of the Gulf of Mexico, including Florida, Alabama, Mississippi, Louisiana, and Texas. The management unit can be subdivided into oyster reefs in individual states, estuarine systems, shellfish harvesting areas, and reef complexes. For the purpose of this management plan, the overall management unit is the U.S. Gulf of Mexico.

3.1 Geographic Distribution of Genetic Stocks

Eastern oysters (*Crassostrea virginica*) are distributed throughout the coastal area of the United States Gulf of Mexico and are most abundant in shallow, semi-enclosed water bodies (< 12 m in depth) with salinities moderated by freshwater outfalls (Figure 3.1). Distribution maps for key reef areas in the U.S. Gulf of Mexico can be found in Section 17.0.

The eastern oyster occurs naturally in a great diversity of habitats along the western Atlantic Ocean from the Canadian Maritime Provinces to the Gulf of Mexico, Panama and the Caribbean Islands (Carlton and Mann 1996, Abbott 1974, MacKenzie 1997, Jenkins et al. 1997, FAO 1978). Eastern oysters have also been described from Panama, Venezuela, Brazil, and Argentina along the Caribbean Sea and the western Atlantic Ocean in Central and South America (Wallace 2001). Carriker and Gaffney (1996) report eastern oysters are distributed in the western Atlantic from Brazil northward through the Caribbean, and Gulf of Mexico to the St. Lawrence River estuary in

Figure 3.1 The distribution of the eastern oyster (*Crassostrea virginica*) throughout the Atlantic, Gulf of Mexico, Caribbean, and Pacific. Hatch pattern indicates the native range of eastern oysters (Atlantic coast) while stippling represents introductions outside their native range (Pacific coast).

eastern Canada, a range of some 8,000 km. Gaffney (pers. comm.) now reports that the southern distribution of *C. virginica* can only be verified genetically to the northern Yucatan Peninsula of the Gulf of Mexico at present, and other genetically distinct *Crassostrea* species might occur in the Caribbean.

Eastern oysters have been transplanted outside of the species natural range. Ruesink et al. (2005) listed many transplanted *C. virginica* populations that have appeared to have survived to present in the areas to which they were transplanted or continue in mariculture operations. According to Ruesink et al. (2005), surviving, out-of-range eastern oyster transplantations (with source in parenthesis) are found in: western Canada (North American east coast, since 1883); western US (US east coast since 1860s); western Mexico (unknown); Hawaii (unknown, since 1860s); Fiji (from Hawaii, 1970); Tonga (US west coast, 1973); Japan ("USA", 1968); Mauritius-Indian Ocean (US west coast, 1972); and possibly England (North American east coast, since 1870s).

It had been assumed that eastern oysters, with a prolonged larval stage, were capable of considerable movement and thus capable of expanding the species' geographic range. Additionally, eastern oysters have been moved by humans between bay systems along the east coast of the United States since the late 1800's (Carlton and Mann 1996). Oysters from the Gulf of Mexico have also been used to supplement eastern oyster populations in the Chesapeake Bay through stocking and selective breeding programs in response to population collapse.

More recent genetic analysis of eastern oysters along the east coast and oysters from the Gulf of Mexico suggests the existence of separate Atlantic and Gulf populations, with a transition zone along the eastern coast of Florida (Reeb and Avise 1990, Karl and Avise 1992, Hare and Avise 1996, Hoover and Gaffney 2005). There is evidence for some structuring of populations within the Gulf. Texas, Louisiana, and northwest Florida populations almost always show some differentiation, although the level of statistical confidence varies (Hoover and Gaffney 2005). With the addition of novel genetic methodologies, finer resolution in population structure is being discerned. For instance, Gaffney (2006) found that when using restriction fragment length polymorphism (RFLP) analysis, most Gulf populations clustered together but separately from southern Atlantic populations. The exception was Cedar Key, FL, which was hypothesized to have retained some genetic traits from the Suwannee Strait closure. When the same populations were assessed using single nucleotide polymorphisms (SNPs), some localized populations within the Gulf were as distinct as the difference between Atlantic and Gulf of Mexico groupings. Several studies comparing eastern oysters from Laguna Madre, Texas to eastern oysters from other locations throughout the Gulf of Mexico and east coast found the Laguna Madre populations to be genetically distinct (Buroker 1983, Hedgecock and Okazaki 1984, Groue and Lester 1982, King et al. 1994).

Galindo-Sánchez et al. (2008) found that in the Mexican state of Veracruz, *C. virginica* populations in neighboring lagoons could have higher genetic divergence than the most geographically separated populations. Those authors hypothesize that over short time periods, there is limited gene flow. Periodic fluctuations in local population size influenced by an oyster's high fecundity and short generation time would amplify these short-term genetic differences. Thus, isolated bays can function similar to islands, creating chaotic localized patchiness within a large-scale homogeneity (Johnson and Black 1982).

In a study of Chesapeake Bay oysters, small-scale patchiness, often on the scale of tributaries and within-estuary regions, was greater than temporal changes on any given reef. These observations suggest that so called sweepstakes events are of minimal impact (Rose et al. 2006). The authors hypothesize that local retention of larvae may be a fundamental trait among *C. virginica*. As an example of the implications of small-scale variability, Encomio et al. (2005) found that regional variation in susceptibility to both *Perkinsus marinus* (aka: Dermo) and *Haplosporidium nelsoni* (aka: MSX) within Chesapeake Bay sub-populations could be as high as variation between Gulf and Atlantic oysters.

These populations and genetic findings, however, have not been described in the published literature as subspecies even though the data suggest *C. virginica* may be in the process of incipient speciation. Additional genetic structure both between and among Gulf estuaries seems likely to be described in the near future.

3.2 Classification and Morphology

It is believed that oysters were perhaps first described by Linnaeus (1758) but grouped with other bivalves. Numerous other biological descriptions and taxonomic distinctions of oyster species have followed. Galtsoff (1964) provided an excellent historical account and biological treatise of oysters. More recently, Kennedy et al. (1996) have compiled a comprehensive review of the biology of the eastern oyster.

3.2.1 Classification

- Kingdom: Animalia
  - Phylum: Mollusca
    - Class: Bivalvia (Linnaeus 1758)
      - Subclass: Pteriomorphia (Beurlen 1944)
        - Order: Ostreoida
          - Family: Ostreidae (Rafinesque 1815)
            - Genus: *Crassostrea* (Sacco 1897)
              - Species: *virginica* (Gmelin 1791)

The valid scientific name for the eastern oyster is *Crassostrea virginica* (Gmelin 1791)

Synonyms include:

Crassostrea brasiliana (Lamarch)
Crassostrea floridensis (Sowerby)

Eastern oyster is the valid common name endorsed by the American Fisheries Society (Turgeon et al. 1998). Over 90 regional or marketing names have been identified and are being used for the eastern oysters. A partial list can be found in Table 3.1. Many of these names identify the waters or region from which the oysters are harvested. Other common, regional or market names include American oyster (former accepted common name), Atlantic oyster (East Coast US), Virginia oyster (Chesapeake Bay), Common oyster, and Coon oyster.

3.2.2 Morphology

Throughout this management plan, ‘shell length’ is the maximum distance from umbo to ventral margin or bill. ‘Shell width’ is the maximum anterior/posterior dimension (Figure 3.2).

3.2.2.1 Gametes

The following descriptions of gametes generally come from Quast et al. (1988).

Table 3.1 Regional and marketing names used for eastern oysters, *Crassostrea virginica*, in the United States.

Regional/marketing name	**Region**
Acadian oyster	St. George's Bay, Nova Scotia, Canada
Alba Bras d'Or oyster	Bras d'Or Lakes, Nova Scotia, Canada
Beau Soleil oyster	Neguac, New Brunswick, Canada
Bedeque Bay oyster	Salutation Cove, Prince Edward Island, Canada
Blackfish Creek oyster	Massachusetts, USA
Blue Point oyster	Long Island Sound, Connecticut and New York, USA
Canada Cup oyster	Prince Edward Island, Canada
Chesapeake oyster	Chesapeake Bay, Massachusetts, USA
Conway Cups oyster	Conway Narrows, Prince Edward Island, Canada
Cuttyhunk oyster	Buzzards Bay, Massachusetts, USA
Caraquette oyster	New Brunswick, Canada
Duxbury Bay oyster	South Shore, Massachusetts, USA
Falmouth oyster	Buzzard's Bay, Massachusetts, USA
Hog Island Virginica	Hog Island, California, USA
Horseshoe Shoals oyster	Cape Cod, Massachusetts, USA
Island Pride oyster	Prince Edward Island, Canada
Katama Bay oyster	Martha's Vineyard, Massachusetts, USA
Malpeque oyster	Prince Edward Island, Canada
Marionport oyster	Buzzard's Bay, Massachusetts, USA
Martha's Vineyard oyster	Martha's Vineyard, Massachusetts, USA
Mashpee Indian oyster	Mashpee, Massachusetts, USA
Mill Point oyster	Prince Edward Island, Canada
Moonstone oyster	Point Judith, Rhode Island, USA
Nauset Marsh oyster	Town Cove, Massachusetts, USA
Newport Cups oyster	Narragansett Bay, Rhode Island, USA
Ninigret Cups Oyster	Ninigret Pond, Rhode Island, USA
Nobsquassitt oyster	Cape Code Bay, Massachusetts, USA
Northumberland oyster	Salutation Cove, Prince Edward Island, Canada
Parramores	Motompkin Bay, Virginia, USA
PEI Select oyster	Prince Edward Island, Canada
Pickle Point oyster	Prince Edward Island, Canada
Piper's Point oyster	Salutation Cove, Prince Edward Island, Canada
Pleasant Bay oyster	Ocean Side Cape, Massachusetts, USA
Plum Island oyster	Ipswich, Massachusetts, USA
Prudence Island oyster	Narragansett Bay, Rhode Island, USA
Quonset Point oyster	East Passage, Narragansett Bay, Rhode Island, USA
Rappahannock oyster	Virginia, USA

Table 3.1 Con't.

Raspberry Point oyster	Prince Edward Island National Park, Canada
Red Point oyster	Malpeque Bay, Prince Edward Island, Canada
Rhode Island Wild oyster	Narragansett Bay, Rhode Island, USA
Rome Point oyster	Narragansett Bay, Rhode Island, USA
Salt Aire oyster	Prince Edward Island, Canada
Salute oyster	Salutation Cove, Prince Edward Island, Canada
Savage Harbour oyster	Prince Edward Island, Canada
Sea Cow Head oyster	Prince Edward Island, Canada
Smith Point oyster	Galveston Bay, Texas, USA
Spinney Creek	Southern Maine, USA
St. Simon oyster	New Brunswick, Canada
Sunnyside oyster	Prince Edward Island, Canada
Tatamagouche oyster	Tatamagouche, Nova Scotia, Canada
Tomahawk oyster	Menemsha Pond, Martha's Vineyard, Massachusetts, USA
Totten Virginica oyster	Totten Inlet, Washington, USA

Eggs: Oyster eggs are spherical, non-motile, unpigmented cells which have a large germinal vesicle and are approximately 40-50µm in diameter.

Sperm: Oyster spermatozoa are small, flagellated cells which become motile after release. Spermatozoa range in total length from 29 - 43µm.

3.2.2.2 Larvae

The following descriptions of larvae generally come from Quast et al. (1988).

Trochophore: Trochophore larvae, the first post-hatch larval stage, have an oval-shaped body, a single shell plate and a girdle of cilia for swimming.

Veliger: Early veliger larvae are oval shaped, bilaterally symmetrical and 70-80 µm in length. The single shell plate of the trochophore is folded along the midline to form two shell halves (valves). They are called "straight-hinge" larvae because the hinge (fold line) of the shell is straight. As larvae grow, their valves become deeper and protuberances (umbos) develop near the hinge of each valve. At the end of the 'umbo' stage, a pair of pigmented eye spots develops and larvae are then referred to as 'eyed veligers'. Development of the eye spots is an indication that metamorphosis is approaching. During the last veliger stage (i.e., pediveliger stage), larvae develop a foot containing a large byssal gland which produces cement used to attach the organism to substrate. Prior to metamorphosis and setting, the larvae are approximately 275-320 µm long.

Eastern oyster larvae can be differentiated from other species by the arrangement and number of hinge teeth on the valves. Differences among genera and species are slight. Though hinge complexity increases with development and age, differences among species remain evident. The hinge line of five to six day old eastern oyster larvae has two groups of rectangular teeth. The difference between right and left valves is slight at this stage but becomes more pronounced as larvae develop.

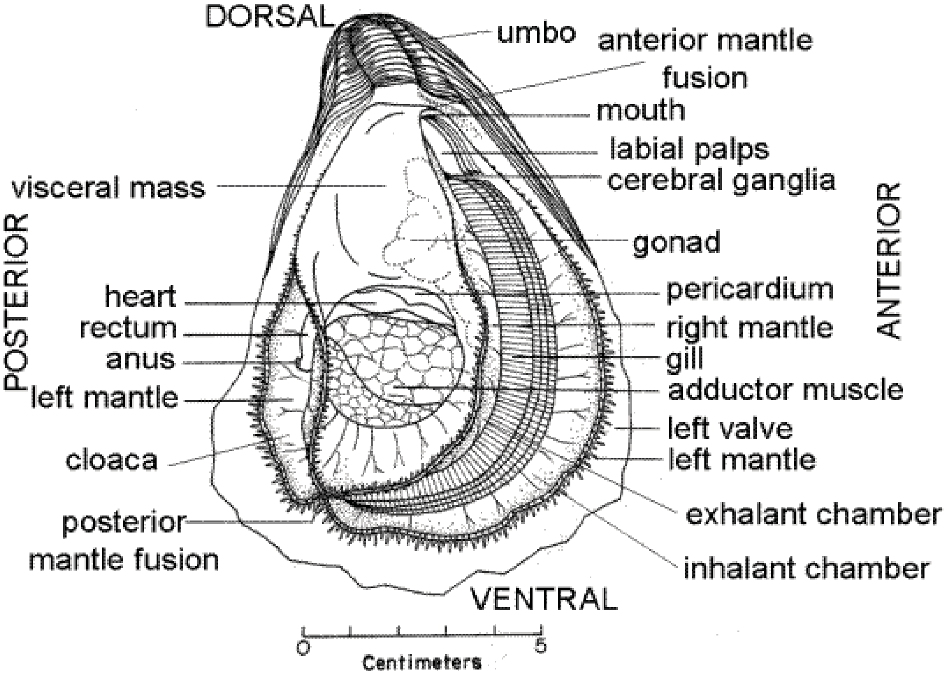


Figure 3.2 General anatomy of an oyster viewed from the right side with the right valve removed (*from* Galtsoff 1964).

3.2.2.3 Juvenile or 'Seed' Oysters

The following descriptions generally come from Quast et al. (1988). ***Note:*** *for the purposes of this section, juvenile oysters will be termed 'seed' oysters and are classified based on size rather than reproductive condition.*

Larval life ends when the oyster pediveliger attaches itself to a substrate. After setting, the change from larvae to 'spat' begins immediately. Spat usually refers to a recently metamorphosed (immature) oyster, but the term may be applied to any small oyster between approximately 0.3 mm and 25.0 mm shell length. The left valve of the spat, which is attached to the substrate, usually grows deeper and thicker than the right valve, which functions as a lid. Eastern oyster spat can be differentiated from other spat by the arrangement and number of the rectangular hinge teeth. Oysters >25 mm and <75 mm shell length are called seed oysters and their morphology reflects that of the adult.

3.2.2.4 Adults

The following descriptions of adults generally come from Stanley and Sellers (1986).

Adult oysters are usually categorized as >75mm in shell length. The left valve is almost always thicker and heavier than the right, and more deeply cupped (Yonge 1960, Galtsoff 1964). Hinge teeth are absent, but a buttress on the right valve fits into a depression on the left. There is no gap between the valves when fully closed. Shell shape is variable. On hard bottoms, beaks (umbones) usually are curved and point toward the posterior, whereas in silty environments or on reefs, umbones are usually straight. Solitary oysters from hard substrates are rounded and ornamented with radial ridges and foliated processes, whereas those from soft substrates or reefs are more slender and sparsely ornamented.

Shell thickness also depends on environment. Oysters on hard substrates have thicker and less fragile shells than those on soft substrates. The 'index of shape'

$$((height + width)/length)$$

varies from 0.5-1.3 in southern populations and from 0.6-1.2 in northern populations. The shell grows along a dorsal-ventral axis, but the angle of the axis is not permanent and may change several times over the lifespan of an individual, resulting in a zigzag pattern. The growth axis may change as much as 90°. Although tissue mass reaches an upper limit, the shell continues to grow over the lifespan of an oyster (Stenzel 1971).

The eastern oyster is monomyarian (anterior adductor muscle has been lost). The interior of the shell has a purple-pigmented adductor muscle scar situated slightly posterior and ventral. A second muscle scar, of the Quenstedt's muscle, is situated ventral to and a short distance from the hinge. The purple pigmentation on the adductor muscle scar distinguishes the eastern oyster from similar species such as the mangrove oyster (*C. rhizophorae*), Pacific oyster (*C. gigas*) and Suminoe oyster (*C. rivularis* or *ariakensis*) (Figure 3.3A-C). In Florida, *Ostreola equestris* occurs sympatrically with the eastern oyster and can only be confidently distinguished by the structure of the hinge teeth (Figure 3.3D).

3.3 Life History

3.3.1 Reproduction

Eastern oysters are dioecious, with the sexes separate, and protandrous, first maturing as males, then changing to female later in life (Galtsoff 1964, Bahr and Lanier 1981, Thompson et al. 1996). There is also evidence that suggests the process can be reversed throughout the oyster's life (Thompson et al. 1996). The factors determining sex and subsequent changes in sex are varied and complex. Sex reversal has been shown in response to environmental, nutritional and/or physiological stresses (Coe 1936, Tranter 1958, Bahr and Hillman 1967, Davis and Hillman 1971, Ford et al. 1990). There is also evidence suggesting sex determination may be influenced by the sex and proximity of nearby oysters (Burkenroad 1931, Needler 1932, Smith 1949, Menzel 1951). For example, in Louisiana, a higher ratio of females to males (> 4 cm) was observed growing unattached, while an equal distribution was found for smaller oysters growing in clumps (Burkenroad 1931). Similarly, Andrews (1979) found populations of three and four year old oysters to be 80% female. Thompson et al. (1996) noted that sex reversal usually occurred between spawning seasons when the gonad was undifferentiated.

Under optimal environmental conditions, some oysters in Gulf bays can become sexually mature and reproductively active four weeks after setting (Menzel 1951). Environmental parameters such as temperature, salinity, and food availability affect the time required for oysters to mature. Therefore, maturation periods fluctuate with changing environmental conditions (Soniat and Ray 1982).

Oysters that spawn shortly after setting generally do not contribute significantly to the year class because of low gamete production (Hayes and Menzel 1981). As oysters grow larger, more energy is allocated annually to gamete production than to somatic growth (Dame 1976, Cox and Mann 1992, Thompson et al. 1996). The number of gametes released during each spawn is directly correlated with oyster size and gonadal development (Davis and Chanley 1955, Galtsoff 1964, Thompson et al. 1996). Among oysters of the same size, variability of fecundity is due primarily to differences in the physiological condition of the oysters (Galtsoff 1964).

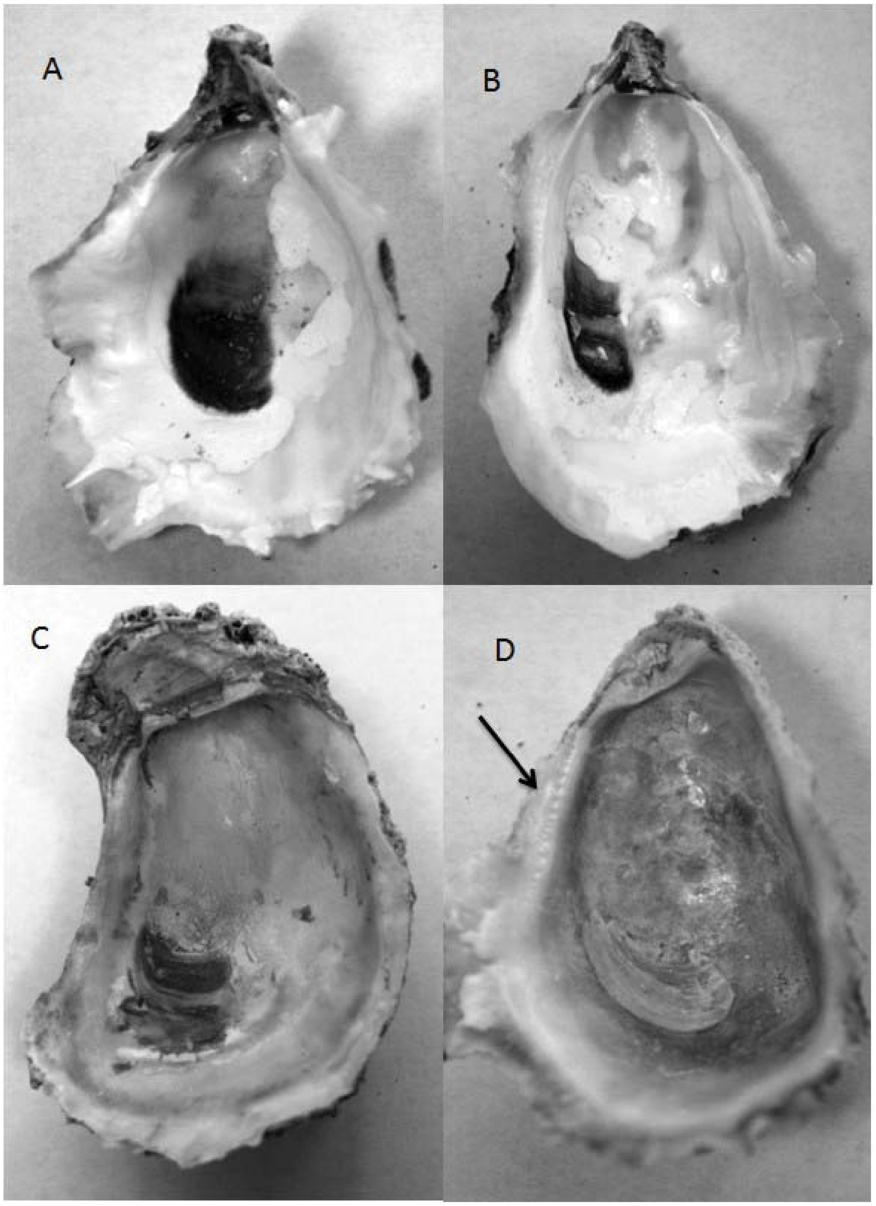


Figure 3.3 Internal shell of three oysters that may be found in GOM. **A & B**. *Crassostrea virginica* with dark muscle scar shapes may range widely; **C.** *C. rhizophora* with paler muscle scar and slightly squared hinge (this shell from South America - may occur in GOM keys); **D.** *Ostrea equestris* with almost no purple coloration and a series of fine indentations along the margin of the shell.

Fecundity of oysters in the Gulf of Mexico is difficult to determine due to prolonged spawning seasons, with intermittent spawning and redevelopment throughout the year (Hayes and Menzel 1981, Thompson et al. 1996). Also, it is difficult to differentiate gonadal tissue as it is diffuse and integrated into surrounding tissue (Thompson et al. 1996). However, Galtsoff (1964) estimated a range of 10-20 million eggs per female per spawn and as many as 100 million eggs produced per female in a season. The number of eggs is proportional to the size of the individual

(Davis and Chanley 1955). Thompson et al. (1996), utilizing only the highest fecundity estimates for females from specific weight classes for data from Cox (1988), reported fecundity estimates from 2 million eggs (4 cm adult) to 45 million eggs (7 cm adult).

3.3.2 Spawning

Oysters may spawn throughout the Gulf in all but the coldest months. Spawning peaks are usually clearly defined and typically occur several times throughout the year. Spawning may peak in the spring, fall, or both depending on environmental conditions.

A variety of environmental factors may initiate spawning in oysters. Some field observations suggest that gonad maturation and spawning are associated with rising water temperatures (Medcof 1939, Butler 1956), while other studies point to a sharp decline in water temperature as the stimulus for fall spawning (Hayes and Menzel 1981). Regardless of the trigger, most spawning is initiated and maintained when water temperature reaches and stays at or above 20ºC (Butler 1949, Loosanoff 1953, Schlesselman 1955, Hofstetter 1977, 1983). Salinity fluctuations do not appear to play a significant role in controlling spawning in oysters, however, salinities below 5-6 ppt can inhibit gametogenesis (Butler 1949, Loosanoff 1953). Chemical stimuli produced by phytoplankton may also play a role in triggering spawning activity in oysters (Nelson 1955, 1957, Starr et al. 1990).

Under natural conditions, simultaneous release of sperm and eggs into the water is essential for successful reproduction. Females may be less responsive to rising temperature than males (Dupuy et al. 1977) and require stronger stimulation in the form of specific chemical stimulation from male sperm to ensure that eggs are not discharged without the presence of sperm.

Fertilization is external, and its success is dependent on the close proximity of the sexes and their simultaneous response to spawning stimuli. Although there are no estimates on the densities of broodstock required to ensure spawning and fertilization success, Galtsoff (1930) estimated that more than 6×10^4 oysters (> 8 cm shell length) per hectare are needed for a successful spawning bed. Thompson et al. (1996) suggests that fertilization occurs within the mantle cavity of the female as a result of sperm entrained by the inhalant water currents and coming in contact with eggs being discharged from the gonad.

The duration and intensity of any spawning event depends on the physiological state of the oysters and the ambient water conditions. The number of spawns per individual is also variable; however, male oysters may spawn more often than females.

The egg stage can be brief (Figure 3.4). Embryological development begins immediately after fertilization leading to the first free-swimming larval form (Galtsoff 1964).

3.3.2.1 Larval Development

Following fertilization and early development, the trochophore stage is attained in 4-6 hours, depending on temperature. During this stage, a powerful ciliated girdle is formed, and larvae begin to swim (Figure 3.4). The trochophore stage is short, approximately 24-48 hrs at 22-24º C (Carriker 1996). Development to the veliger stage is accompanied by the development of the velum, the principal swimming and feeding organ (Newell and Langdon 1996). When swimming, the velum projects between the shell halves. Larger cilia around the margin of the velum are for swimming; smaller cilia covering the base carry food particles to the mouth (Elston 1980). As development continues, descriptive names are used that refer to the most conspicuous morphological changes associated with each stage (i.e. umbo larva, eyed larva, and pediveliger).

Pediveliger larvae represent the last stage of larval development and possess a well developed foot, which is projected outward while swimming.

The planktonic larvae of oysters act to distribute the species and will remain in the water column for 2-3 weeks after hatching (Bahr and Lanier 1981). During this free-swimming stage, larvae are distributed by currents and tidal conditions, but show a pronounced affinity for salinity, concentrating in the vicinity of the halocline (Nelson 1927, Nelson and Perkins 1931). Just prior to settlement, the veliger develops two eye spots (that aid in selecting an acceptable location for attachment), an actively crawling foot and byssal gland and is termed an eyed-pediveliger. The pediveliger's role is to search for a suitable substrate to which it will attach and metamorphose into a spat (Nelson 1924, Prytherch 1934, Carriker 1986) (Figure 3.4).

As the pediveliger nears the end of its planktonic development, it uses tidal currents, the salt wedge, and its ability to migrate vertically to 'select' the optimal environment for metamorphosis. Finally, it ceases to swim and creeps over the substrate with its foot, until locating a suitable attachment point. Larvae are normally sensitive to strong light and are slightly negatively phototactic. They set in an area of reduced light (inside an empty shell, or the underside of a piece of cultch, or low in the water column). During metamorphosis, the newly attached oyster (spat) loses its velum, foot and eye spots and begins a sedentary life.

3.3.2.2 Settling Cues

Transformation from a free-swimming larval stage to a completely sessile stage appears to be stimulated by various physical and chemical factors. Peaks in spat settlement appear to occur in warmer temperatures (Nelson 1909, Hidu and Haskin 1971, Lutz et al. 1970). High salinities appear to suppress settlement responses (Mackin 1946, Loosanoff 1953, Menzel 1955, Hidu and Haskin 1971, Kennedy et al. 1996) while exposures to some bacterial surface films on cultch materials have been shown to induce settlement and metamorphosis (Coon et al. 1985). Laboratory experiments showed that the gregarious nature of oyster larvae is enhanced by pheromones (a constituent of shell liquor) produced during the larval attachment process (Keck et al. 1971).

There are several triggering mechanisms that can influence oyster larvae to become competent to settle and some may function in combination with others. Salinity (Mackin 1946, Loosanoff 1953, Menzel 1955), temperature (Hidu and Haskin 1971, Lutz et al. 1970), biofilms (Crisp 1967), and specific chemicals (Coon et al. 1985) have been shown to play a role in larval settlement. Oyster larvae also exhibit gregarious settling behavior that suggests a water-borne pheromone produced by other oysters is involved (Keck et al. 1971, Veitch and Hidu 1971, Hidu et al. 1978, Zimmer-Faust and Tamburri 1994). Additionally, oyster larvae have been shown to exhibit negative phototaxis, whereby pediveligers tend to settle on undersurfaces of cultch, presumably to avoid light and silt (Kennedy et al. 1996). There is some evidence to suggest that oyster larvae also respond to the rugosity of the cultch surface, settling in the small pits and irregular surfaces (Nelson 1953, Galtsoff 1964).

At metamorphosis, the pediveliger attaches its left valve (shell) to the cultch with cementing fluid (mucopolysaccharide), from its pedal byssal gland that sets in a few minutes. Settling oyster larvae tend to attach in large groups on common cultch where other larvae have already attached or in the presence of mature oysters (Keck et al. 1971, Veitch and Hidu 1971, Hidu et al. 1978).

3.3.2.3 Feeding

Oyster larvae are filter feeders. Early larvae depend on naked (without rigid cell walls) phytoplankton (e.g. *Isochrisis* spp. and *Pavlova* spp.) as a food source, while older larvae can also feed on phytoplankton that possess cell walls (e.g. *Chaetoceros* spp.) (Davis 1953, Davis and Guillard 1958). Though more research is needed, there is some evidence to suggest oyster larvae exhibit some selectivity in particle size (1-30 μm) and nutritional content (Mackie 1969, Newell and Langdon 1996).

Langdon and Newell (1996) note there is no evidence to suggest that oyster larvae are food limited in the wild while other studies have shown that oysters consuming low protein food sources had better growth rates than those exposed to high protein food sources (Flaak and Epifanio 1978, Utting 1986). As sessile, non-motile organisms, oysters must rely on food-laden water being

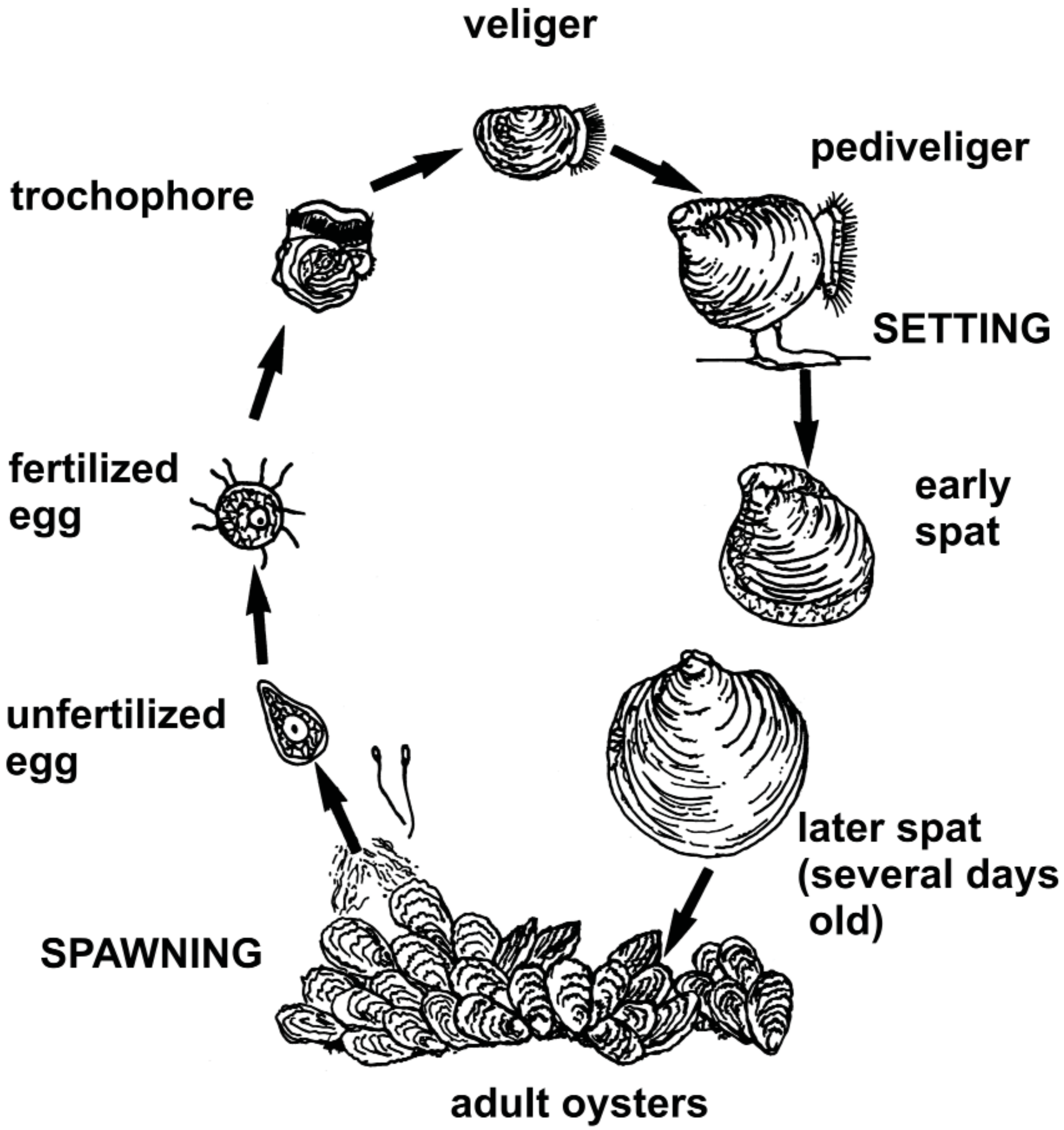


Figure 3.4 Life cycle of the eastern oyster, *Crassostrea virginica* (from Wallace 2001).

moved past the oyster in order to extract food from the water column. Water flow across oyster reefs has been shown to influence growth rate (Newell and Langdon 1996). In particular, if flow is too slow, there may not be enough food particles available to support growth (Grizzle et al. 1992).

Juvenile and adult oysters are filter feeders, feeding primarily on planktonic organisms and organic detritus. Results of gut content analyses indicate oysters ingest algae, dinoflagellates, ostracods, eggs and larvae of marine invertebrates, pollen grains from terrestrial plants, and detritus (Morse 1944, Flint 1956). Laboratory experiments indicate oysters survive and grow when fed various algal species [e.g., *Isochrysis galbana*, *Platymonas suecica* and *Thalassiosira pseudonana* (Epifanio 1979, Romberger and Epifanio 1981, Langdon and Newell 1996); *Skeletonema* sp. and *Chaetoceros* sp. (Epifanio 1979); and *Tetraselmis macula* (Wilkfors et al. 1984)]. In their review of research on larval and adult feeding, Newell and Langdon (1996) reported that oysters can ingest and utilize particles from 1-30 µm, depending on the structure (gills or labial palps) where the particle is captured.

Estimates of filtration rates of bivalves are affected by two inter-related activities, true feeding and production of pseudofeces. Both of these activities may occur when water for respiration is passed over the gills and both may result in removal of particles from the water column. Most of the particles passing over the gills are retained and passed towards the mouth, but only some particles are actually ingested, a process controlled by the activity of cilia on the labial palps (Ward et al. 1994). Pseudofeces are those particles that are not ingested, but are packaged in mucous and rejected. Most particles that are ingested are digested, resulting in conversion of some of the nutrients into oyster tissue and some fraction of the material being refractory and defecated. The feces may settle to the bottom as deposits or may be processed by reef resident fauna resulting in either growth of faunal biomass or recycling of nutrients. Similarly, pseudofeces may settle to the bottom to be utilized by resident fauna or may become incorporated to the sediment. Finally, those nutrients that are digested, but which are not incorporated to tissue, those which are used to fuel energetic demands, result in recycling of mainly nitrogenous waste to the water column. One benefit the oyster provides is that it modulates the amplitude of nutrient dynamics in an estuary by cropping the phytoplankton (and thereby nutrient load) during times of high productivity, resulting in oyster growth, and then slowly releasing nutrients via metabolic processes during times of low productivity.

Oyster filtration rates, or more appropriately clearance rates, based on a single volume filtered per unit time are almost certainly over generalized [e.g., Galtsoff (1964) lists 8 liter/hour as a mean filtration rate]. However, as early as 1970, Haven and Morales-Alamo (1970) recognized that many factors, such as particle size, affected the filtration rate. Dame et al. (1980) estimated that oysters can filter approximately 120 ml/gram dry mass/minute and that the entire population of one coastal embayment could filter approximately the same volume of water as the volume of the tidal prism. Riisgård (1988) listed a more complex allometric relationship for filtration rates (F) as:

$$F = 6.79W^{0.73}$$

where F = liters/h^{-1} and W = grams body dry weight

and describes some of the shortfalls of laboratory based methodology in measurement. Other factors that influence filtration rate include life-history stage and hypoxia (Baker and Mann 1994), temperature (Riisgård 1988), salinity (Galtsoff 1964), turbidity (Galtsoff 1964), flow or current velocity (see discussion in Newell and Langdon, 1996), and food type (Cognie et al. 2003) and concentration (Higgins 1980, Haven and Morales-Alamo 1970). In a salt marsh estuary in South Carolina, Wetz et al. (2002) examined the preferential feeding of eastern oysters on microbial communities *in situ* and in flume experiments. They indicated that the eastern oyster is able to 'sort' particles from the environment and seems to prefer phototrophic nanoflagellates over heterotrophic nanoflagellates. In other words, the oysters successfully grazed down the bacteria and small-sized phytoplankton and microprotozoan out of the summer plankton blooms in coastal South Carolina. Most of the above estimates are based in individual clearance rates. One measurement of the clearance of a water mass as it passes over a bivalve reef indicated oysters may clear from 2.7 to 37.3% of the chlorophyll (Grizzle et al. 2006) and a second that about 25% of the chlorophyll *a* was removed (Cressman et al. 2003). Further studies will be needed to clarify the role of reefs in filtering estuarine water masses.

3.3.2.4 Growth

During the spat stage, shell growth is rapid and generally follows the contour of the surface upon which it is attached. Shells are thin and spat are susceptible to predation by a variety of organisms during this time (Kennedy 1996). Following the initial rapid growth phase, the shell starts to thicken and cups, and the shape of the young oyster begins to resemble that of an adult.

Oyster growth is influenced by temperature, salinity, and other environmental factors and can vary seasonally throughout the species range (Shumway 1996). In the Gulf of Mexico, growth has been reported as continuous throughout the year with the fastest growth occurring during periods of high water temperature (Ingle and Dawson 1950a, 1950b, and 1952, Copeland and Hoese 1966). Loosanoff (1953, 1965) and Shaw (1966) reported that oysters adapt rapidly to changes in salinity, but growth is stunted at 7.5 ppt and ceases below 5 ppt. Oysters exposed to salinities that fluctuate within normal ranges (14-28 ppt) grow faster than those held at a relatively constant salinity (Pierce and Conover 1954, Quast et al. 1988, Shumway 1996). Oysters also grow faster in areas with higher phytoplankton densities (Manzi et al. 1977) and areas with flowing water (Incze et al. 1981, Manzi et al. 1986, Grizzle and Lutz 1989). When exposed to air for short periods, oysters exhibit growth rates similar to continually submerged individuals; however, long exposure periods inhibit growth (Gillmore 1982).

The growth rate of *C. virginica* is initially as high as 10 mm/month, but decreases with age. Growth is highest during the first six months after setting and gradually declines throughout the life of the oyster (Heffernan 1962, Hofstetter 1962, 1977, Galtsoff 1964, Berrigan 1988). The maximum age reported for the eastern oyster is 25 to 30 years (Martin 1987).

Oysters expend as much as 48% of their annual energy budget on germinal production (Dame 1976, Thompson et al. 1996). In the Gulf, oysters typically reach harvest size (76 mm or 3 inches) in 18-24 months from setting (Hofstetter 1977, Berrigan 1988, 1990) and may reach 150 mm in 5-6 years (Andrews 1981). The maximum size of eastern oysters is reported to be approximately 300 mm (Abbott and Alcolado 1978, Martin 1987).

3.3.2.5 Spatial Distribution and Movement of Larvae

Oysters are mobile only during planktonic larval stages, and although not well understood, larval movement appears to be primarily dictated by salinity and water currents (Kennedy 1996). Andrews (1983) concluded, based on plankton samples collected during all tidal stages, that larvae swim continuously, and their dispersal and ultimate fates are strongly dependent on current regimes and flushing rates of estuaries. He also found that these forms of hydrographic transport predominate over larval movement in reaction to physical and chemical stimuli. Throughout larval development, veligers are passively transported horizontally via water currents within the estuary, and their dispersal is basically controlled by the hydrographic forces of the estuarine system (Carriker 1947, 1951, Manning and Whaley 1954, Pritchard 1953, 1989).

Though horizontal movement within an estuary is passive, some studies suggest larvae are capable of vertical migration within the water column in response to specific stimuli. Nelson and Perkins (1931) were able to demonstrate increased swimming activity in response to increases in salinity. Similar results were observed by other researchers (see the review in Kennedy 1996). Vertical swimming speeds up to 14 cm/min have been calculated in laboratory studies which would result in 7-8 m vertical movement in an hour (Hidu and Haskin 1978).

The ability of oyster larvae to control their position within the water column in response to stimuli would minimize, to a certain extent, the dispersive effects of currents. However, the abundance and planktonic dispersal of oyster larvae ensure the species' survival in favorable areas of an estuary, even if traditional reef areas become unacceptable because of adverse conditions. Planktonic dispersal also ensures oyster survival in the event of adverse climatological conditions such as flooding and drought.

4.0 DESCRIPTION OF THE HABITAT OF THE STOCK(S) COMPRISING THE MANAGEMENT UNIT

4.1 Gulf of Mexico General Description

Galtsoff (1954) summarized the geology, marine meteorology, oceanography and biotic community structure of the Gulf of Mexico. Later summaries include those of Jones et al. (1973), Beckert and Brashier (1981), Holt et al. (1982), and the Gulf of Mexico Fishery Management Council (GMFMC 1998). In general, the Gulf is a semi-enclosed basin connected to the Atlantic Ocean and Caribbean Sea by the Straits of Florida and the Yucatan Channel, respectively. The Gulf has a surface area of approximately 1,600,000 km^2 (GMFMC 1998), a coastline measuring 2,609 km, one of the most extensive barrier island systems in the United States, and is the outlet for 33 rivers and 207 estuaries (Buff and Turner 1987). Oceanographic conditions throughout the Gulf are influenced by the Loop Current and major episodic freshwater discharge events from the Mississippi/Atchafalaya rivers. The Loop Current directly affects species dispersal throughout the Gulf while discharge from the Mississippi/Atchafalaya Rivers creates areas of high productivity that are used by many commercially and recreationally important marine species.

The Gulf coast wetlands and estuaries provide habitat for an estimated 95% of the finfish and shellfish species landed commercially in the Gulf and 85% of the recreational catch of finfish (Thayer and Ustach 1981). Three of the ten largest commercial fishing ports in the United States are located in the Gulf and accounted for an estimated 1.2 billion lbs of harvested fish and shellfish in 2006 or 13% of the nation's total commercial landings (USDOC 2006). In 2006, the total U.S. production of eastern oysters was 21.9 million lbs of which 89% was harvested from the Gulf region. On a national scale, the total oyster production in that same year (including Eastern, Pacific, European flat, and Olympia oysters) was 34.4 million lbs with the Gulf comprising 43% of this total. Louisiana alone accounted for 42% of the total Gulf landings in that year although total Gulf production would have been much higher had Mississippi reefs not been closed as a result of Hurricane Katrina in 2005. Gulf coast wetlands, estuaries, and barrier islands also provide important feeding, breeding and cover habitat to wildlife species such as waterfowl, shorebirds and wading birds, improve water quality, and play a significant role in lessening flood and storm surge damage and minimizing erosion.

4.1.1 Circulation Patterns and Tides

Hydrographic studies depicting general circulation patterns of the Gulf of Mexico include those of Parr (1935), Drummond and Austin (1958), Ichiye (1962), Nowlin (1971), and Jones et al. (1973). Circulation patterns in the Gulf are dominated by the influence of the upper-layer transport system of the western North Atlantic. Driven by the northeast trade winds, the Caribbean Current flows westward from the junction of the Equatorial and Guiana currents, crosses the Caribbean Sea, continues into the Gulf through the Yucatan Channel, and eventually becomes the eastern Gulf Loop Current. Upon entering the Gulf through the Yucatan Channel, the volume transported by the Loop Current is 25-30 million ft^3/sec (Cochrane 1965).

Moving clockwise, the Loop Current dominates surface circulation in the eastern Gulf and generates eddies that move into the western Gulf. During late summer and fall, the progressive expansion and intrusion of the Loop may reach as far north as the continental shelf off the Mississippi River Delta. Nearshore currents are influenced by shelf circulation dynamics, tides, and local wind patterns. The orientation of the shoreline and bottom topography also affect the speed and direction of shelf currents.

Gulf tides are small and noticeably less developed than along the Atlantic or Pacific coasts. Normal tidal ranges in the Gulf are 0.3-0.6 m. Despite the small tidal range, tidal current velocities are occasionally high, especially near the constricted outlets that characterize many of the bays and lagoons. Tide type varies widely throughout the Gulf with diurnal tides (one high tide and one low tide each lunar day of 24.8 h) existing from St. Andrew's Bay, Florida, to western Louisiana. The tide is semi-diurnal in the Apalachicola Bay of Florida and mixed in western Louisiana and in Texas.

The presence, quantity, and health of oysters in Gulf of Mexico estuaries are directly affected by tides, prevailing currents, and freshwater inflow from inland areas. The extent of disease and predation on oysters is driven by salinity and river discharge. Periods of high salinity can increase predation on reefs by oyster drills and increase susceptibility to diseases such as Dermo (Section 4.5.2.2), while low salinities can exacerbate Vibrios and fecal coliforms in the meats of oysters and limit oyster growth.

4.2 Regional Description

4.2.1 Eastern Gulf

The eastern Gulf of Mexico extends from Florida Bay northward to Perdido Bay on the Florida/Alabama boundary and includes 40 estuarine systems covering 1.2 million ha of open water, tidal marsh, and mangroves (McNulty et al. 1972). Considerable changes occur in the type and area of submergent and emergent vegetation from south to north. Mangrove tidal flats are found from the Florida Keys to Naples. Sandy beaches and barrier islands occur from Naples to Anclote Key and from Apalachicola Bay to Perdido Bay (McNulty et al. 1972). Tidal marshes are found from Escambia Bay to Florida Bay and cover 213,895 ha with greatest area occurring in the Suwannee Sound and Waccasassa Bay. The coast from west of Apalachee Bay to the Alabama border is characterized by wide sand beaches situated either on barrier islands or on the mainland itself. Beds of mixed seagrasses and/or algae occur throughout the eastern Gulf with the largest areas of submerged vegetation found from Apalachee Bay south to the tip of the Florida peninsula. Approximately 9,150 ha of estuarine area, principally in the Tampa Bay, have been filled for commercial or residential development.

Coastal waters in the eastern Gulf may be characterized as clear, nutrient-poor, and highly saline. Rivers which empty into the eastern Gulf carry little sediment load. Primary production is generally low except in the immediate vicinity of estuaries or on the outer shelf when the nutrient-rich Loop Current penetrates into the area. Presumably, high primary production in frontal waters is due to the mixing of nutrient rich, but turbid, plume water (where photosynthesis is light limited) with clear, but nutrient poor, Gulf of Mexico water (where photosynthesis is nutrient limited) creating good phytoplankton growth conditions (GMFMC 1998).

4.2.2 North-Central Gulf

The north-central Gulf includes Alabama, Mississippi, and Louisiana. Total estuarine area for Louisiana includes 29 major water bodies covering 2.9 million ha of which 1.3 million ha is surface water and 1.5 million ha is marsh (Perret et al. 1971). The eastern and central Louisiana coasts are dominated by sand barrier islands and associated bays and marshes. The most extensive marshes in the United States are associated with the Mississippi/Atchafalaya River deltas. The loss of wetlands along the Louisiana Coastal Zone is estimated to be 6,600 ha/yr (USEPA 1994a). The shoreline of the western one-third of Louisiana is made up of sand beaches with extensive inland marshes. A complex geography of sounds and bays protected by barrier islands and tidal marshes acts to delay mixing resulting in extensive areas of brackish conditions. The Alabama and

Mississippi coasts are bounded offshore by a series of barrier islands which are characterized by high energy sand beaches grading to saltmarsh in the interior. The mainland shoreline is made up of saltmarsh, beach, seawall, and brackish-freshwater marsh in the coastal rivers. Approximately 26,000 ha of mainland marsh existed in southern Mississippi in 1968 (Eleuterius 1973). Salt marsh on the barrier islands covers 860 ha.

Approximately 2,928 ha of submerged vegetation, including attached algae, have been identified in the Mississippi Sound and in the ponds and lagoons on Horn and Petit Bois islands (C. Moncreiff pers. Comm.) Approximately 4,000 ha of mainland marsh along the Mississippi Coastal Zone have been filled for industrial and residential use since the 1930s (Eleuterius 1973). Seagrass coverage in the Mississippi Sound has declined 40%-50% since 1969 (Moncreiff et al. 1998). The Alabama coastal zone contains five estuarine systems covering 160,809 ha of surface water and 14,008 ha of tidal marsh (GMFMC 1998). An estimated 4,047 ha of submerged vegetation exists in the Alabama Coastal Zone.

In general, estuaries and nearshore Gulf waters of Louisiana and eastern Mississippi are low saline, nutrient-rich, and turbid due to the high rainfall and subsequent discharges of the Mississippi, Atchafalaya, and other coastal rivers. The Mississippi River deposits 684 million metric tons of sediment annually near its mouth (Holt et al. 1982). Average daily discharge for the Mississippi and Atchafalaya rivers is 464,400cfs and 223,800cfs, respectively (USEPA 1994b). As a probable consequence of the large fluvial nutrient input, the Louisiana nearshore shelf is considered one of the most productive areas in the Gulf of Mexico.

4.2.3 Western Gulf

The shoreline of the western Gulf consists of salt marshes and barrier islands. The estuaries are characterized by low but extremely variable salinities and reduced tidal action. Eight major estuarine systems are located in the western Gulf and include the entire Texas coast. These systems contain 620,634 ha of open water and 462,267 ha of tidal flat and marshlands (GMFMC 1998). Submerged seagrass coverage is approximately 92,000 ha. Riverine influence is highest in Sabine Lake and Galveston Bay. Estuarine wetlands along the western Gulf decreased 10% between the mid 1950s and early 1960s with an estimated loss of 23,840 ha (Moulton et al. 1997).

4.3 General Estuarine Habitats

Gulf estuaries provide essential habitat for a variety of commercially and recreationally important species, serving primarily as nursery grounds for juveniles but also as habitat for adults during certain seasons. The Cooperative Gulf of Mexico Estuarine Inventory (McNulty et al. 1972) reported 5.62 million ha of estuarine habitat in the five Gulf States including 3.2 million ha of open water and 2.43 million ha of emergent tidal vegetation. Emergent tidal vegetation includes 174,000 ha of mangrove and 1.0 million ha of salt marsh; submerged vegetation covers 324,000 ha of estuarine bottom throughout the Gulf. The majority of the Gulf's salt marshes are located in Louisiana (63%) while the largest expanse of mangroves (93%) is located along the southern Florida coast (GMFMC 1998).

4.3.1 Sediments

Since substrate, sedimentation, and freshwater flow determines where and to what extent oyster reefs occur, a brief overview of the Gulf sediments is essential. Two major sediment provinces exist in the Gulf of Mexico: 1) carbonate sediments found predominantly east of Desoto Canyon and along the Florida west coast and 2) terrigenous sediments commonly found west of Desoto Canyon and into Texas coastal waters (GMFMC 1998). Bottom sediments are coarse in nearshore waters extending northward from the Rio Grande River to central Louisiana and are the dominant bottom type in deeper waters of the central Gulf. Fine sediments are common in the northern and eastern Gulf and south of the Rio Grande due to riverine influence, particularly the Mississippi and Rio Grande Rivers. Fine sediments are also found in deeper shelf waters (>80 m).

4.3.2 Submerged Vegetation

While oysters occur primarily in areas of open bottom, they can be found in limited numbers in association with areas of submerged vegetation. Submerged vegetation comprises an estimated 1,475,000 ha of seagrasses and associated macroalgae in the estuarine and shallow coastal waters of the Gulf (MMS 1983). Turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), star grass (*Halophila engelmanni*), and widgeon grass (*Ruppia maritima*) are the dominant seagrass species (GMFMC 1998). Distribution of seagrasses in the Gulf is predominantly along the Florida and Texas coasts (MMS 1983) with 910,000 ha of seagrass (98.5%) located on the west Florida continental shelf, in contiguous estuaries, and in embayments. Macroalgae species including *Caulerpa*, *Udotea*, *Sargassum*, and *Penicillus* are found throughout the Gulf but are most common on the west Florida shelf and in Florida Bay.

4.3.3 Emergent Vegetation

Irregularly distributed and unevenly apportioned along the Gulf coast, emergent vegetation is classified into habitat types depending upon where on the landscape they are located, hydrologic influence, and their vegetative composition. Generally, over 247,670 ha of fresh, brackish, and salt marshes occur along the Texas coastline (Diener 1975, GMFMC 1998). Louisiana marshes comprise more than 1.5 million ha or over 60% of the marsh habitat in the Gulf of Mexico. Mississippi and Alabama have a combined 40,246 ha of mainland marsh habitat (26,237 and 14,009 ha, respectively) and about 860 ha of saltmarsh habitat associated with the Mississippi Sound barrier islands. Florida’s west coast and Panhandle include 213,895 ha of tidal marsh (GMFMC 1998) and an additional 159,112 ha of Florida’s west coast is covered by three species of mangroves.

4.3.4 Oyster Reefs

The extent of oyster reefs in the five Gulf states is summarized in Table 4.1 through Table 4.5 and provides detailed descriptions of the type and area coverage of the various sediments, which include oysters. Distribution maps for key reef areas in the U.S. Gulf of Mexico can be found in Section 17.0.

4.4 General Description of Oyster Habitat

Oyster reefs are natural accumulations of oyster shell and living oysters that result from the successive growths of generations of oysters in the same place. Oyster reefs, whether they consist of live oysters or shell material, are an important estuarine habitat. In addition to sustaining oyster populations, oyster reefs often support diverse and complex biological communities. Oyster shell provides a substrate for a variety of sessile organisms and a physical structure that provides cover and food for numerous other estuarine species including commercial and recreational bay and offshore fishery species. Oyster reefs are typically discrete, distinguishable structures that have been formed by live oysters, and contain oyster shell and other living or dead organisms. Oyster reefs can be intertidal or sub-tidal.

Table 4.1 Oyster acreages and sedimentary characteristics of Florida estuarine systems (DN = Data Needed).

Hydrologic Unit	Oyster Reef (consolidated) (hectares)[1]	Shelly Sediment (unconsolidated) (hectares)	Oyster Reef and unconsolidated Shelly Sediments (hectares)	Sediment Type[2]	Surface Area[2] (hectares)	Bay Commercially Harvesting	Restoration Activities
Pensacola Bay System (Escambia, East Bay)	3,144	DN	DN	Sand, sand/shell	51,005	Yes	Fisheries
Choctawhatchee Bay	89	DN	DN	Sand, sand/shell, mud	34,924	Minimal	Fisheries
St. Andrews Bay System (West, North, East Bay)	890	DN	DN	Sand, silt, clay	27,972	Yes	Fisheries
St. Joseph Bay	0	DN	DN		17,755	No	None
Apalachicola Bay System	3,491	DN	DN	Sand covered with silt and clay	68,788	Yes	Fisheries
Apalachee Bay	1,535	DN	DN	Sand	24,817	Yes	Fisheries
Ochlocknee Bay	263	DN	DN			Yes	Fisheries
Suwannee Sound, Waccasassa, and Withlacoochee Bay	2,138	DN	DN	Sand	35,618	Yes	Fisheries
Tampa Bay	183	DN	DN	Sand, sand/clay, clay/silt	110,338	No	Habitat
Sarasota Bay (City Island Park to Blackburn Bay)	23	DN	DN	Sand, sand/shell	14,061	No	Habitat
Donna Bay and Roberts Bay	9	DN	DN			No	Habitat
Charlotte Harbor	97	DN	DN	Sand/shell, mud/shell	49,290	Minimal	None
Caloosahatchee River	1	DN	DN	Sand/shell	15,180	No	Habitat
Florida Bay	DN	DN	DN	Coral, sand/shell, sand/mud	225,631	No	None

[1] FWC/FWRI, [2] McNulty et al. 1972

Table 4.2 Oyster acreages and sedimentary characteristics of Alabama estuarine systems (DN = Data Needed).

Hydrologic Unit	Oyster Reef (consolidated) (hectares)	Shelly Sediment (unconsolidated) (hectares)	Oyster Reef and Unconsolidated Shelly Sediments (hectares)	Sediment Type[3]	Surface Area[1] (hectares)	Area Commercially Harvested	Restoration Activities
Mobile Bay	684[2,3]	DN	DN	Sand, clay, mud	107,030	Yes	Yes
Mississippi Sound (including Dauphin Island and Peavy Island Bays)	561[2,3]	DN	DN	Sand, clay, mud	37,516	Yes	Yes
Perdido Bay	0	DN	DN	Sand, clay, mud	6,989	No	No

[1]Crance 1971, [2]May 1971, [3]Tatum et al. 1995

Table 4.3 Oyster acreages and sedimentary characteristics Mississippi estuarine systems (DN = Data Needed).

Hydrologic Unit	Oyster Reef (consolidated) (hectares)	Shelly Sediment (unconsolidated) (hectares)	Oyster Reef and Unconsolidated Shelly Sediments (hectares)	Sediment Type[1]	Surface Area[2] (hectares)	Area Commercially Harvested	Restoration Activities
Pascagoula River	235[2]	DN	DN	Sandy and muddy, Sandy deposits	53,110	No	No
Biloxi Bay	216[2]	DN	DN	Sandy and muddy, Sandy deposits	60,896	No	Shoreline Stablization
St. Louis Bay	2,974[2]	DN	DN	Sandy and muddy, Sandy deposits	66,568	Yes	Cultch Plants and Relays
Pearl River	299[2]	DN	DN	Sandy and muddy, Sandy deposits	22,335	Yes	Cultch Plants and Relays

[1] Otvos 1973, [2] Christmas and Langley 1973

Table 4.4 Oyster acreages and sedimentary characteristics of Louisiana estuarine systems (DN = Data Needed).

Hydrologic Unit	Public Seed Grounds (total hectares)	Private Leases (hectares)	Oyster Reef (consolidated) (hectares)	Sediment Type[1]	Area Commercially Harvested (hectares)	Restoration Activities
Pontchartrain Basin	401,729	49,572	DN	Clayey silt, silty clay, sand	DN	Cultch planting, freshwater diversion
Barataria / Mississippi Delta	15,167	55	DN	Clayey silt, sand	DN	Cultch planting, freshwater diversion
Timbalier / Terrebonne	6,840	41,342	DN	Sandy silt, clayey silt	DN	Cultch planting
Vermillion / Atchafalaya	219,253	10,651	DN	Clayey silt, silty clay, sand clay	DN	None
Calcasieu	23,577	0	DN		DN	Cultch planting
Sabine	13,786	0	DN		Presently closed, awaiting updated Health	None

[1] Barrett et al. 1971

Table 4.5 Oyster acreages and sedimentary characteristics of Texas estuarine systems (DN = Data Needed).

Hydrologic Unit	Oyster Reef (consolidated) (hectares)	Shelly Sediment (unconsolidated) (hectares)	Oyster Reef and Un-consolidated Shelly Sediments (hectares)	Sediment Type	Surface Area[1] (hectares)	Area Commercially Harvested	Restoration, Experimental, or Artificial Reef Activities
Sabine Lake	308 [10]	68 [10]	DN	Mud, silt, shell	17,799	Yes Historically [2]	No
*Galveston Bay	6,441 [10]	4,376 [10]	10,795 [3]	Mud, shell, clay, sand	141,676	Yes Presently	Yes
East Matagorda Bay	11 [2]		583 [4]	Mud, sand	15,308	Yes Periodically	No
**Matagorda Bay	Lavaca Bay 1,315 [5] Matagorda Bay 100 [9]	Lavaca Bay 2,414 [5] Colorado R. Delta 59 [6]	DN	Mud, shell, clay, sand	98,984	Yes Presently	Yes
San Antonio Bay	DN	DN	2,260 [10]	Silty clay, mud, sand, shell	55,158	Yes Presently	Yes
***Aransas Bay	490 [10]	1,321 [10]	DN	Mud, sand	45,296	Yes Presently	Yes
Corpus Christi Bay	DN	DN	229 [8]	Mud, sand	43,316	Yes Historically [2]	Yes
Upper Laguna Madre	0 [10]	0 [10]	0.4 [10]	Sand, silt, shell	41,040	No	Yes
Lower Laguna Madre	50 [10]	13 [10]	DN	Sand, silt, clay	72,688	Yes Historically [7]	Yes

[1]Matlock and Osborn 1982, [2]Diener 1975, [3]Powell et al. 1995, [4]Moore 1907, [5]Simons et al. 2004, [6]Oborney pers. Comm., [7]Breuer 1962, [8]Martinez 1961, [9]Culbertson 2008, [10]TPWD unpublished data.

NOTES:

*__Galveston Bay__ acreages include Trinity Bay, Galveston Bay, Red Bluff/Morgan Point Embayment, Clear Lake Embayment, Dickinson Embayment, East Bay, Pelican Island Embayment, and West Bay.

**__Matagorda Bay__ acreages include Lavaca (includes Lavaca, Keller, and Cox) and Matagorda Bay.

***__Aransas Bay__ acreages include St. Charles, Aransas, Carlos and Mesquite, Copano, Port and Mission Bays.

4.5 Habitat Requirements

The habitat requirements of the eastern oyster, *Crassostrea virginica,* include suitable substrate, estuarine waters, and nutrition. However, there are a variety of environmental factors, many of them interrelated, that affect the abundance and health of the eastern oyster. Oysters are capable of withstanding a wide range of environmental conditions but are most abundant and productive when the ideal environmental conditions exist.

4.5.1 Substrate and Reef Types

The minimal habitat requirements of the eastern oyster, including estuarine water, nutrition, and hard substrate, provide the oyster with numerous opportunities and locations to colonize. Beginning their life as a free-floating organism, oysters settle and attach themselves to hard surfaces. While their preferred attachment substrate is other oyster shells, they will also attach to bulkheads, pilings, concrete, and almost any hard substrate. This ability to attach to a variety of substrates and thrive provides the oyster with limitless opportunities to colonize and expand their range and numbers. It also makes this species a prime candidate for habitat creation and restoration activities. Regardless of the substrate type, the surface must be clean and stable or the spat will not survive. Established oyster reefs generally contain the greatest abundance of clean, un-encrusted oyster shell and therefore commonly provide the best surface for spat sets (Quast et al. 1988). Larvae attaching to the shell of other oysters results in a natural accumulation of oyster shell within an area. The successive growth of generations of oysters in the same place results in a consolidated reef that is usually elevated above the surrounding bay bottom. Oysters can also survive on stiff mud surfaces firm enough to support the oyster's weight. Soft mud and shifting sand are typically unsuitable substrates for the establishment of oyster reefs.

Oyster reefs are typically discrete, distinguishable structures which have been formed by live oyster, and contain oyster shell and other living or dead organisms. Classified by their configuration and location relative to the nearest shoreline, the eastern oyster forms three fundamental reef types: 1) fringe reefs are located adjacent to shoreline and situated parallel to the shore and prevailing tidal currents; 2) string reefs or linear ridge reefs form a series of long and narrow reefs located perpendicular to tidal currents at the confluence of a river, bay or sound; 3) patch reefs or toe-head reefs are fairly compact reefs with irregular edges varying in shape and size (Price 1954). Reefs that are not solid expansive reefs have various regionally or colloquially terms and may be referred to as: 1) pancake reefs, which are broad in shape with only a thin layer (<1m) of shell and oysters (Scott 1968); 2) salt-and-pepper or shell-on-mud reefs which are scattered unconsolidated reef with large areas of exposed mud between clumps of oysters; and 3) shell hash, which is broken up shell that lacks cohesive properties and is often moved by waves creating shell ridges along shorelines or shell hash islands. Large solid linear reefs which run parallel and adjacent to manmade navigation channels (Price 1954) and improved natural tidal inlets in Texas, are often referred to as 'hull scraper' reefs. These reefs are formed by stacking dredge material mixed with shell. The subsequent erosion of dredge material, leaving the shell, results in the layering and lamination of relic shell which provides a solid substrate for spat to attach. These types of reef formation develop into thick deposits of aggregated shell elevated above the surrounding bay bottom.

The term 'oyster bed' is generally defined as an oyster reef on which oysters are actively being cultivated. Oyster beds are generally created or maintained by planting oysters, oyster shell, or other cultch material intended to promote the growth or establishment of oysters into a reef for harvest.

4.5.2 Environmental Factors

Various environmental factors including water temperature, salinity, water flow, dissolved oxygen, water quality, disease, parasitism, competition, and fishing can affect oyster survival and abundance. Larval survival, successful development into spat, growth into market size, and health and condition are greatly dependent on ambient environmental conditions.

4.5.2.1 Temperature Requirements

Oysters in the Gulf coast region tolerate a wide range of water temperatures. The ambient air temperature which influences water temperature can also vary greatly from the water temperature which the oysters inhabit. Water temperatures in the bays and estuaries of the Gulf vary with season and water depth, both of which influence the water temperature over a reef's surface. Variations in water temperature influence the biological processes of the oyster. In the Gulf region, oysters grow throughout the year with the greatest amount of growth occurring in the late winter and early spring months, and the least amount of growth occurring in the summer months (Quast et al. 1988). Although growth is greatest during the colder months, oysters are vulnerable to prolonged exposure to freezing temperatures. Temperatures over 32°C, in combination with high salinities, can only be tolerated for a short time before the oyster becomes stressed and weakened to the point of dying (Hofstetter 1990).

Oysters are warm water spawners, and the discharge of sperm and eggs begins when the water temperature rises above 24ºC (Hofstetter 1990). While water temperature, along with salinity regimes, determine when oysters spawn, these environmental factors also influence the mortality rate of developing larvae and the success of spat set (Quast et al. 1988). Temperature, along with other environmental factors, dictate successful spawning, larval survival, larval development, spat set, and growth rates into mature and market size oysters.

4.5.2.2 Salinity Requirements

Oysters are estuarine or brackish water inhabitants that thrive where fresh water inflows from rivers and streams mix with the salt water from the Gulf. While oysters can survive a wide range of salinities, tolerate fresh water for brief periods and grow in water saltier than the Gulf, the optimum salinity range for oysters is between 15-30 ppt (Hofstetter 1990). The ability of an oyster to tolerate higher salinities is inversely correlated to the ambient water temperature; increased water temperature reduces the ability of the oyster to tolerate high salinities. Similarly, an oyster can tolerate low salinity conditions for longer durations at lower ambient water temperatures (Quast et al. 1988).

Prolonged exposure to fresh water during flood events, known as 'freshets', can result in severe oyster mortality. The water temperature affects the length of time an oyster can survive exposure to fresh water. Oysters are capable of withstanding exposure to a freshet for several days in cold weather. Oysters exposed to a freshet for that same duration during warm weather would result in severe oyster mortality (Hofstetter 1990). Short duration or moderate flood events can be beneficial to oysters, by delivering nutrient rich flood water to the bay and stimulating the growth of plankton, the primary food source of oysters. Floods can also be beneficial because fresh water often kills, reduces or dilutes oyster diseases such as Dermo (*Perkinsus marinus*) (Ray 1987). Fresh water also reduces or kills oyster predators such as oyster drills of the genus *Stramonita*. Areas with higher salinities tend to be more susceptable to these two important factors of oyster mortalities in the Gulf.

Salinity along with water temperature determines when oysters spawn (Quast et al. 1988).

However, other environmental factors also influence spawning, larval survival, larval development, timing and quantity of the spat set, and growth rates into mature and market size oysters.

4.5.2.3 Water Flow Requirements

Being sessile organisms, oysters are entirely dependent on water currents to provide food and oxygen. Other crucial functions performed by water currents or flow are the dissipation of the oysters' waste, preventing burial by siltation, and dispersing oyster larvae (Quast et al. 1988). Prevailing currents contribute to the location and orientation of reefs. Naturally occurring oyster reefs are generally long and narrow with their long axis perpendicular to the predominant water currents or parallel to channels, contributing to the effectiveness of the currents (Price 1954).

While oysters can tolerate a wide range of current velocities, currents need to be swift and frequent enough to provide food and oxygen. However, high velocity currents, high tides, and excessive wave action often associated with flood, hurricane, and tropical storm events can be detrimental to oysters, by burying and smothering productive reefs and/or reducing respiration and filtration of nutrients (Berrigan 1988).

4.5.2.4 Dissolved Oxygen Requirements

Possessing a euryplastic (Alderice 1972) physiology allows oysters to use available oxygen over a wide range of temp-salinity combinations, thereby maintaining an energy gain from a constantly changing environment (Shumway 1996). The oxygen requirements for oysters varies and is dependent on the ambient water temperature and salinity; oxygen consumption increases with rising water temperatures and decreasing salinities (Shumway 1982). Oysters are also able to tolerate hypoxic conditions and can even survive brief exposures to anoxic conditions (Quast et al. 1988).

4.6 Habitat Deterioration

Like most species, oysters are dependent on habitat for their survival. Oysters are vulnerable to many types of habitat destruction, including overfishing, altered fresh water flow, changes to salinity regimes, physical removal, and burial by sediments. Habitat destruction can lead to shortages of accessible oyster cultch, impaired water quality due to less filtration of the bay (and therefore impaired habitat quality), increased predators, increased competition for resources, and increased exposure to diseases. The destruction of oyster reef habitat is twofold, impacting the oyster's habitat and also impacting the habitat of numerous other marine species. As a renewable resource, oyster reefs can replenish and sustain themselves when properly managed, given favorable environmental conditions.

4.6.1 Substrate Removal

Removal of shell material and oyster reef habitat can occur in several ways. Shell material can be physically removed (i.e. harvested or mined) from a bay system resulting in a permanent reduction in the amount of reef in that system. Burial prevents a reef from interfacing with the water column and inhibits larval settlement. The removal of live and dead shell material, depending on the extent and the method used, can result in siltation that smothers live oysters and buries cultch material inhibiting future spat set and recruitment (Quast et al. 1988). Dissolution is another way in which oyster habitat is lost. Organic and inorganic acids and chelators (especially reducing organic sediments in calm waters) will dissolve calcium carbonate in the shell. Bacterial and fungal secretions can also dissolve calcium carbonate (Carriker 1996). These actions can be accelerated by parsitism by boring clams and sponges (Section 5.2.1.2) which weaken the shell and expose greater surface area to these processes.

4.6.2 Effects of Hurricanes, Tropical Storms, and Floods

Increased amounts of silt carried by rivers and streams during flood events can completely bury oyster reefs ultimately killing the entire reef. Like floods, severe storms and hurricanes can also disturb the bay bottom, significantly increasing suspended solids and burying and killing oysters, and these events can also cover up shell material making these areas unavailable for future spat settlement (Berrigan 1988). Storms can also scour the reefs and actually remove shell from the bed.

During a flood event, oysters not buried by silt are at risk of being killed by prolonged exposure to freshets. The water temperature greatly affects the length of time an oyster can survive exposure to fresh water. Oysters are capable of withstanding exposure to a freshet for several days in cold weather. Oysters exposed to a freshet for that same duration during warm weather would result in severe oyster mortalities (Hofstetter 1990). Short duration or moderate flood events can be beneficial to oysters, by delivering nutrient-rich flood water to the bay and stimulating the growth of plankton, the oysters' primary food source. Floods can also be beneficial because fresh water often kills, reduces, or dilutes many of the oyster's predators and disease-bearing parasites.

4.6.3 Alteration of Inflows, Salinity and Circulation Patterns

Projects or events that alter the quantity, seasonal timing of freshwater inflows, and/or salinity and circulation patterns within an estuarine system greatly influence the oyster's productivity and survival. The movement and dispersal of oyster larvae are mostly dependent on circulation (or current) and the velocity of the tidal exchange within an estuary (Andrews 1983). Projects or events that alter the circulation patterns in a bay system during mass spawning could affect recruitment by carrying the oyster larvae into a portion of the bay with limited or no suitable cultch material, or transport the larvae into the open waters of the Gulf of Mexico. Conversely, lack of flow could limit larval supply and subsequent recruitment opportunities.

Alterations in freshwater inflow along the Southwest Florida coast resulting from watershed development and water management practices, have impacted salinity and water quality in the estuary and adversely affected oysters. The Comprehensive Everglades Restoration Program (CERP) includes components for managing the hydrology in affected estuaries, such as the Caloosahatchee, to improve the recruitment and survivorship of oysters, as well as the spatial and structural characteristics of oyster reefs and associated communities. Oyster reproduction and recruitment are used to set water quality targets and as indicators of restoration success of the CERP. Research indicates that managing seasonal flows and discharges as part of the CERP can have a positive effect on restoring and sustaining oyster reef habitat (Volety et al. 2009).

4.6.4 Competition for Space

An oyster reef is generally dominated by oysters. However, the density of the organisms living on a specific reef or area within a reef is also influenced by other benthic invertebrates, for example hooked mussels (*Ischadium (Brachidontes) recurvum*), bryozoans (*Membranipora* sp., *Bugula* sp., *Conopeum commensale*), barnacles (*Balanus* sp.), anemones (*Aiptasiomorpha texaensis*), serpulid worms (*Eupomatus dianthus*), slipper shells (*Crepidula fornicata*), hydroids (*Bougainvillia inaequalis*), tunicates (*Mogula* sp.), and species of macroalgae (Hedgepeth 1953, Pequegnat 1975, Andrews 1981). These fouling organisms compete with the oyster for food and also compete for space by attaching to the oyster's shell reducing the available space for oyster spat to settle (Hofstetter 1990).

Oyster spat often set in dense clusters on shell or hard substrates, causing intense competition for available food which can influence survival. Oyster spat not only compete with other spat but also compete with mature oysters and other benthic organisms for space (Galtsoff 1964, Mackenzie 1970), as well as nutrients (Schlesselman 1955).

Other types of commensals penetrate and damage the oyster's exterior shell such as boring sponges (*Cliona* spp.) and boring clams (*Diplothyra smithii*), or the oyster's interior shell such as mud worms (*Polydora websteri*). Heavy infestations of these organisms can cause the shell to become very fragile causing it to crumble under slight pressure, and the oyster is forced to exert more energy towards interior repairs than for feeding, growth, and reproduction.

4.7 Oyster Reef as Habitat for Other Species

Whether they consist of live oysters or dead shell material, oyster reefs constitute an important estuarine habitat. Apart from sustaining oyster populations, oyster reefs often support diverse biological communities. Oyster shell provides a substrate for sessile organisms, food and cover for grazing, scraping organisms; the oyster itself provides food and cover for a variety of estuarine species.

Depending on the species, oyster reef, oyster shell, and shell on mud habitats are used during various life stages of a particular species. Brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*) utilize oyster reefs during their postlarvae and juvenile life stages while pink shrimp (*Farfantepenaeus duorarum*) utilize a mixture of sand/shell/mud substrate during their postlarvae, juvenile, and subadult life stages (GMFMC 1998). Juvenile and adult stone crabs (*Menippe* spp.), xanthid mud crabs, and blue crabs (*Callinectes* spp.) can be found in abundance on oyster reefs and oyster reefs are the preferred habitat of subadult and adult red drum (*Sciaenops ocellatus*) (Miles 1950).

In many bay systems, oyster reefs are often the only natural and sometimes the only source of hard substrate in predominantly sandy or muddy bay bottoms. Sometimes overlooked as habitat to species other than the oyster, an oyster reef provides three-dimensional relief, structure, and cultch (i.e. habitat) for other invertebrates and fish and is associated with increased species abundance and diversity (Moyle and Cech 1996, Szedlmayer and Able 1996) compared to adjacent soft-bottom habitats (Coen et al. 1999).

Coen et al. (1999) divides oyster reef and associated finfish usages into three categories: 1) 'reef residents' use oyster reefs as their primary habitat; 2) 'facultative residents' utilize oyster reefs as well as other habitats with vertical relief (e.g. submerged aquatic vegetation); and, 3) 'transient species' may forage on or near oyster reefs. Of 79 finfish species, seven species were identified as reef residents and 72 as facultative resident transient species. Oyster reefs can be considered, with a high degree of certainty, essential for resident species such as gobies, blennies, toadfish, and clingfish (Coen et al. 1999) that utilize them as breeding, feeding and cover habitat, as well as providing habitat to numerous other facultative residents and transient species.

Oyster reefs also provide habitat for benthic invertebrates such as other mollusks like hooked mussels, bryozoans, barnacles, anemones, serpulid worms, slipper shells, hydroids, tunicates and species of macroalgae (Hedgepeth 1953, Pequegnat 1975, Andrews 1981).

4.7.1 Description of Essential Fish Habitat

The GSMFC has endorsed the definition of essential fish habitat (EFH) as found in the NMFS guidelines for all federally-managed species under the revised Magnuson-Stevens Act of 1996. The NMFS guidelines define EFH as:

> "Those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity. For the purpose of interpreting the definition of essential fish habitat: Waters - include aquatic areas and their associated physical, chemical, and biological properties that are widely used by fish, and may include aquatic areas historically used by fish where appropriate; substrate - includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary - means the habitat required to support a sustainable fishery and the managed species - contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity - covers a species' full life cycle."

For this FMP, we will utilize this definition but refer to such areas as 'essential habitats' to avoid confusion with the EFH mandates in the Magnuson-Stevens Act. These mandates include the identification and designation of EFH for all federally-managed species, development of conservation and enhancement measures including those which address fishing gear impacts, and require federal agency consultation regarding proposed adverse impacts to those habitats. However, the eastern oyster is not a federally-managed species and, therefore, does not have any habitat identified or recognized as EFH to the oyster itself. Oyster reefs do provide habitat to commercially and recreationally important bay and offshore fishery species and are considered EFH to brown, white, and pink shrimp as well as stone crab and red drum (GMFMC 1998).

4.8 Oyster Reefs as Shoreline Protection

The oyster's ability to produce a crystallizing cement of calcium carbonate (Harper 1997), allowing them to attach to other substrates in addition to oyster shell and a reef's ability to expand spatially in three-dimensions makes the oyster valuable for shoreline protection. In some bays, natural reefs are situated so that they serve to cut fetch across bays and reduce wave intensity on shorelines protecting the shoreline and shoreline habitats from erosional forces. Piazza et al. (2005) demonstrated that inter-tidal reefs adjacent to the marsh/water interface were effective in reducing shoreline retreat in low-energy environments, even through two landfalling tropical storm systems.

In bay systems where subsidence and other activities have severely reduced a natural reef's ability to reduce fetch and wave intensity, shorelines and shoreline habitats such as inter-tidal marsh have become vulnerable to erosion. Often referred to as living inter-tidal engineered structures, strategically placed oyster shell and other engineered structures have been and can be successfully used in shoreline protection activities. These structures become colonized with oysters and provide multiple ecosystem services in a variety of environments (Jones et al. 1994, Coen et al. 1999, Dame 1999, Micheli and Peterson 1999, Rodney and Paynter 2006). Shell material (clam and oyster), fly ash, limestone, gabions, reef rolls, reef domes, repurposed concrete, and riprap are all examples of substrates or structures that can be used as living inter-tidal engineered structures.

5.0 POPULATION SURVIVAL

5.1 Mortality

The long and short-term effects of mortality on Gulf of Mexico (Gulf) eastern oyster populations are poorly understood. The combined effects of harvesting, fluctuating environmental conditions, man-made perturbations, and natural mortality from disease and predation make it difficult to isolate the specific contributions of individual factors on total mortality. Certainly, man has been the most serious threat to oyster populations. Anthropogenic stressors, including habitat destruction (sedimentation), physical disruption (dredging), alteration of hydrologic regimes (freshwater diversion and channelization), pollution burdens, and overharvesting have resulted in long-term population losses. Oysters however, have exhibited a remarkable capacity to reestablish thriving populations when mortalities have resulted from natural phenomena, such as floods, drought, or hurricanes.

Adverse environmental factors may interfere with the welfare of oyster populations by inhibiting reproductive and recruitment capabilities, increasing vulnerability to disease and predation, and in extreme cases, by direct destruction of all phases in the life cycle. In reality, numerous negative factors may exert their effects in conjunction with all others, and their combined actions may produce a far greater effect than that caused by any single factor.

5.1.1 Larval Stages

Total mortality and mortality rates for each phase in the life cycle of eastern oysters are not completely known. Intuitively, mortality is expected to be highest during the planktonic larval stages due to vulnerability to predation and limited tolerances to changing environmental factors (Fulford et al. 2011). Numerous investigations have described the effects of environmental factors on larval oysters, particularly salinity and temperature tolerances (Davis 1958, Davis and Calabrese 1964, Hidu et al. 1974, Kennedy and Breisch 1981). At optimum salinities, larvae survive over a wider range of temperatures than at salinities near the lower tolerance limit. Oyster eggs and larvae are also sensitive to suspended silt (Kennedy and Breisch 1981).

5.1.2 Spat and Juvenile Stages

Finucane and Campbell (1968) reported that oyster mortalities were greatest during the first two months after settlement, while other researchers have estimated mortality rates from 15-100% among newly set oysters (Loosanoff and Engle 1940, Mackin 1961, Hofstetter 1977). Roegner and Mann (1995) reported high initial mortalities immediately post-settlement, with mortalities declining drastically after one week. Mortality rates may approach 100% during certain periods or under certain conditions, but overall survival or reestablishment of the population is generally ensured by the dynamic reproductive capabilities of oysters.

Spat mortality is also density-dependent, due to crowding and increased predation (Webster and Shaw 1968, Hofstetter 1977, Chatry et al. 1983, Newell et al. 2000). High mortality may act advantageously when young oysters are concentrated by reducing the density of survivors to levels where they may grow rapidly. Spat mortality is also dependent on tidal zonation and salinity regime (Roegner and Mann 1995). Settlement in higher salinity waters often increases exposure to oyster predators and diseases (Craig et al. 1989, Melancon et al. 1998). May (1971) reported that 80-90% of the oysters <50 mm on some reefs in Alabama were killed by oyster drills (S*tramonita haemostoma*). The effects of harvesting on spatfall and spat survival are not clear; however, heavy harvest activity in a localized area may increase mortality through physical disturbance and sedimentation.

5.1.3 Adults

Losses from natural mortality and mortality rates of sub-marketable and marketable oysters are poorly understood for Gulf stocks. Losses from natural mortality are difficult to assess, primarily because specific factors that contribute to loss cannot be isolated. While estimates of overall mortality are possible, the direct effects and interactions of environmental condition, habitat, harvesting, and other anthropogenic factors are less clear.

Few investigators have determined the impact of natural mortality on harvestable oyster stocks, except when losses have been of a catastrophic nature resulting from floods, hurricanes, or epizootics. Catastrophic events may result in near depletion of harvestable stocks, making biological and economical assessments relatively straightforward (Galtsoff 1930, May 1972, Little and Quick 1976, Hofstetter 1981, Berrigan 1988). Most often, however, natural mortality from predation, disease, or fluctuating environmental conditions occurs at a less rapid and near undetectable rate over an extended period of time. A long reproductive season, high recruitment and rapid growth in many productive areas of the Gulf also obscure the effects of mortality and add to the difficulty of determining mortality rates.

Estimates of annual mortality rates among subadult and adult oysters exceed 50-95% (Menzel et al. 1966, May 1971, Quick 1971, Little and Quick 1976, Swingle and Hughes 1976, Hofstetter 1977, Quast et al. 1988, Berrigan 1990). Quast et al. (1988) summarized results from experimental studies to determine mortality rates for oysters in several estuaries in Texas. In these studies, mortality rates for oysters in trays ranged from 1-44% per month for oysters between 15 and 100 mm. Berrigan (1990), comparing size frequency distributions on a restored reef over time, estimated average mortality rates of 3.3% per week among oysters >50 mm. Losses attributed to natural mortality accounted for 65% of the population (>50 mm) in 28 weeks.

Natural mortality represents a substantial economic loss to the oyster industry and remains the principle limiting factor for commercial harvesting in many regions. Natural mortality on some reefs, particularly intertidal reefs, is so high as to preclude commercial use. Although these reefs may be highly productive, few oysters live long enough to reach a commercially harvestable size. Quast et al. (1988) estimated that 86% of all oysters in Texas waters die before reaching marketable size.

It is unclear what effect fishing and culling activities have on overall mortality rates. Conflicting evidence suggests that harvesting pressure is the primary reason for population losses in some areas while other research indicates that natural mortality has a far greater impact on population depletion. For example, Brown et al. (2003) examined oysters contained for one month in protected trays. They estimated average mortalities of 2% for ‘seed’ oysters that had been dredged, transported, and placed on a lease. In contrast, oysters that were not protected showed periods of extremely high mortalities which they attributed primarily to black drum (*Pogonias cromis*) and oyster drills predation. Overfishing is probably most damaging to reefs that are located in waters where environmental conditions are marginal, recruitment is low, and sources of predation and stress are high.

5.2 Threats to Survival

Oysters suffer from numerous biological and anthropogenic sources of stress and mortality. Many competitors, parasites, predators, diseases, and pollutants have been identified, and the manner in which they infect or kill oysters has been described (Butler 1954, Overstreet 1978, Capuzzo 1996, Roesijadi 1996, White and Wilson 1996). However, except for isolated documented cases of very high mortality due to the parasite *Perkinsus marinus* (Hofstetter 1977) and the oyster drill (Schlesselman 1955, Chapman 1959, May 1971), estimates of the total impact of these sources of oyster mortality have not been adequately quantified. Furthermore, the relative impact of these sources of mortality, compared to each other and to fishing mortality, has not been determined. Information available concerning natural mortality is primarily in the form of identifying species, describing the manner in which they compete with, infect, or prey on oysters and other descriptive information. Anthropogenic threats are just as varied and impact oysters both directly and indirectly. These effects are often cumulative and many interact with natural mortality as well.

5.2.1 Natural Factors Affecting Survival

5.2.1.1 Competition and Commensalism

Oysters compete with other benthic organisms for space (Galtsoff 1969, Mackenzie 1970) and nutrients (Schlesselman 1955). Competitors include bryozoans (*Conopeum commensale*), barnacles (*Balanus* spp.), hooked mussels (*Ischadium recurvum*), slipper shells (*Crepidula fornicata*), anemones (*Aiptasiomorpha texaensis*), serpulid worms (*Eupomatus dianthus*), tunicates and algae (Ingle 1951, Hedgpeth 1953, Pequegnat 1975, Andrews 1981, White and Wilson 1996). The impact of competition for settlement space in the Gulf has not been completely determined and, in some instances, these species have a purely commensal relationship with oysters.

Boring sponges (*Cliona spp.*), boring clams (*Diplothyra smithii*), mud worms (*Polydora websteri*), hooked mussels, and algae compete with oysters for space and food and/or colonize the oyster shell matrix (Butler 1954, Galtsoff 1964, Menzel et al. 1966, Overstreet 1978). None of these organisms actually kill oysters, but extensive concentrations of boring sponges and clams may debilitate living populations and limit future generations by lowering reproductive effort and destroying cultch. In addition to competing for space and food, extensive populations of mud worms (*Polydora websteri*) may cause mortality by smothering juvenile oysters (Galtsoff 1964).

Various commensals that bore into the shell and penetrate the shell lining or irritate the mantle, and fouling organisms that simply attach to the shell, may negatively affect the product quality without severely injuring the oyster. Brittle shells, blisters, discoloration, and poor condition detract from the quality and presentation of oyster products.

Other filter-feeding organisms such as barnacles and mussels compete with oysters for available nutrients. However, information on the impact of this form of competition is incomplete.

5.2.1.2 Parasitism and Disease

A variety of parasites are known to infect oysters; the majority are considered only mildly pathogenic to their hosts (Gauthier et al. 1990). Although haplosporidans, flagellates, ciliates, trematodes, cestodes, and nematodes are commonly reported from oysters along the Gulf, few have been associated with massive oyster mortalities. The "protozoan" parasite *Perkinsus marinus,* however, has been identified as a significant pathogen and implicated in mass mortalities throughout its range. It is commonly called 'Dermo,' a derivation from *Dermocystidium marinum* (previously *Labyrinthomyxa marina*).

Parasitic infestation can reduce growth, inhibit general development, and lead to massive mortalities. Oyster mortality may be increased by physiological stress resulting from parasitic invasions which may debilitate oyster stocks. Numerous researchers have provided field and histological evidence identifying and elucidating factors affecting oyster parasitism in the Gulf

(Menzel and Hopkins 1955a, Hopkins 1957, Mackin 1962, Hofstetter 1964, Quick 1971, Overstreet 1978, Couch 1985).

The apicomplexan gregarines (*Nematopsis spp.*) occur in abundance, but no significant pathogenicity is attributed to them (Sprague and Orr 1952). Similarly, various ciliate parasites have been isolated with no significant pathogenicity. Unidentified nematode larvae, metacestode (*Tylocephalum* sp.), and the sporocysts and cercariae of bucephalid trematodes have been histologically identified in oysters. The trematode (*Bucephalus* spp.) has been reported to invade the gonads, displacing gonadal tissue, and producing severe infestations that effectively sterilized the host (Menzel and Hopkins 1955a, Hopkins 1957).

The pyramidellid gastropod, *Boonea impressa* (previously referred to as *Odostomia impressa*), is an ectoparasite that infests the eastern oyster (Robertson and Mau-Lastovicka 1979, Andrews 1981). The snail usually occurs in aggregates, or patches, with 20-30% of the snails moving daily and persisting for two weeks or longer. Individuals appear to move to avoid predation (Wilson et al. 1991). The actual effect of this gastropod on oyster populations is unknown. Juvenile oyster growth rate can be significantly reduced at a parasite level of 10 snails per oyster (White et al. 1984). They found parasite levels of 100 per oyster on the Texas coast and concluded that *B. impressa* may have a significant impact on that oyster population. However, Gale et al. (1991) noted that the effects of *B. impressa* on oysters may be highly dependent on several variables including available ‘energy’ in the form of available particulate organic matter.

Bacterial diseases caused by *Aeromonas* spp., and *Pseudomonas* spp. are known to affect oysters (Mackin 1962, Vanderzant et al. 1970, Vanderzant and Nickelson 1972, Vanderzant et al. 1973). The extent of infection by these bacteria and their effect on Gulf oysters has not been determined. *Aeromonas* spp. can infect and kill oyster larvae and juveniles (Guillard 1959, Tubiash et al. 1965). Infections with *Pseudomonas* spp. reportedly kill oysters at all stages (Galtsoff 1964).

5.2.1.2.1 Dermo

The most serious oyster parasite in Gulf waters is the pathogenic protozoan, *Perkinsus marinus* or Dermo. Dermo is known to infect oysters throughout the Gulf and northward along the Atlantic coast to Maine (Burreson and Ragone Calvo 1996, Soniat 1996, Ford and Tripp 1996). The distribution of Dermo, its pathogenicity, and its relationship to environmental factors, has received critical attention because of its association with extensive, warm water mortality of oysters (Mackin et al. 1950, Ray et al. 1953, Ray 1954, Dawson 1955, Ray and Chandler 1955, Quick and Mackin 1971, Beckert et al. 1972, Hofstetter 1977, Soniat and Gauthier 1989, Gauthier et al. 1990). Extensive research, as part of NOAA’s Status and Trends Program, has been conducted to determine the extent and severity of Dermo infections in Gulf oyster populations and to identify factors influencing its distribution (Craig et al. 1989, Wilson et al. 1990). These studies indicated that Dermo is widely distributed throughout the oyster-producing waters of the Gulf, and the prevalence of the parasite is high among oyster populations.

Intensive Dermo infections have been associated with massive mortalities. Increased mortality often occurs among larger oysters during the summer months when high water temperatures and salinities exacerbate disease conditions. Low water temperatures or salinities usually lessen the effects of the disease. Oyster mortality from Dermo may also occur as a result of synergistic actions from physiological and environmental stress, pollution, and predation.

For example, water temperature is an important factor controlling the occurrence and intensity of Dermo infections (Mackin 1962, Quick and Mackin 1971, Chu and Volety 1997). Reproduction of Dermo in oysters drastically decreases at temperatures below 20° C (Mackin

1962). Mean water temperatures in Gulf bays generally remain above 10° C in the winter and may be higher than 30° C during the summer. Therefore, the prevalence and intensity of Dermo may not be substantially reduced by low water temperatures during the winter, but infections may be promoted during the warmer and hottest months.

Salinity also modifies the distribution and effect of Dermo (Soniat 1985, Craig et al. 1989, Gauthier et al. 1990, Ragone and Burreson 1993). Ragone and Burreson (1993) reported increasing oyster mortality with increased salinity in experimental treatments and found a reduction in virulence with salinities below nine ppt. Rapid changes in salinity were addressed by La Peyre et al. (2003) showing freshets may reduce Dermo infection rates. This study and others also point out the myriad environmental factors involved in Dermo–oyster interactions. Although experimental observation has shown the effects of a single environmental variable, no single measure can describe a large majority of variation in infection and mortality in natural populations.

5.2.1.2.2 MSX

Haplosporidium nelsoni (MSX) is another disease-causing protozoan implicated in mass mortalities of oysters along the Atlantic coast. Similar to abundance and infection intensity of Dermo, those features in *H. nelsoni* appear to be positively correlated with salinity and temperataure (Ford et al. 1999, Paraso et al. 1999). Although various life stages of this protozoan have been reported from Maine to Atlantic Florida, epizootic events appear concentrated in the Mid-Atlantic states. For a complete review of MSX, see Ford and Tripp (1996) and Burreson and Ford (2004). To date there have been no reported epizootic events in the Gulf, although two recent publications have produced conflicting conclusions as to the presence of MSX in Gulf oysters. Ulrich et al. (2007) reported positive polymerase chain reaction (PCR) findings of *Haplosporidum nelsoni* in 31 of 40 oysters tested from Gulf and Caribbean waters, although the findings were not confirmed via histological evaluation of oyster tissue. Conversely, Ford et al. (2011) evaluated 210 oysters utilizing PCR and 180 of the 210 oysters were subsequently evaluated through tissue-section histology. Results from Ford et al. (2011) showed no evidence of *Haplosporidum nelsoni*, thereby confirming previous histological-based studies from the region, such as the annual NOAA Status and Trends Program evaluation.

5.2.1.2.3 Vibrio

Various species of Vibrio have been found throughout the oyster's natural range. Vibrios are also found free-living in estuarine and marine waters. The bacteria do not appear to be especially harmful to oyster populations, although high infection rates in cultured juveniles may lead to Hinge Ligament Disease (Elston 1984, Kraeuter and Castagna 1984, Dungan et al. 1989; as cited in Ford and Tripp 1996). The Vibrio-human interaction is important as it relates to the consumption of raw shellfish. This risk to human health has dramatically shaped modern oyster harvest, handling, and processing practices. The Vibrio-human disease relationship is covered in detail in Section 6.4.

5.2.1.3 Predation

Predation represents a dominant factor limiting oyster population growth with consequences for commercial harvests. Numerous investigations confirm the seriousness of oyster predation by protozoans, anemones, coelenterates, helminths, mollusks, crustaceans, and finfish along the Gulf. Devastating attacks upon oyster populations by oyster drills, stone crabs (*Menippe* spp.), and black drum have been well documented (Pearson 1929, Butler 1954, Gunter 1955, Menzel and Hopkins 1955b, Menzel and Nichy 1958, Menzel et al. 1966, Powell and Gunter 1968, Hofstetter 1977, Brown et al. 2003).

Many protozoans, coelenterates, barnacles, and mollusks prey on oyster larvae. Laboratory studies indicate that ciliated protozoans can ingest as many as six larvae at a time (Loosanoff 1959). The sea anemone (*Diadumene leucolena*) consumes oyster larvae at a rate of one per minute (MacKenzie 1977). Ctenophores (*Pleurobranchia* and *Mnemiopsis*), sea nettles (*Chrysaora quinquecirrha*), and moon jellyfish (*Aurelia aurita*) feed upon oyster larvae (Kennedy and Breisch 1981, Fulford et al. 2011). Steinberg and Kennedy (1979) reported that the acorn barnacle (*Balanus improvisus*) eliminated significant numbers of oyster larvae under experimental conditions. Many pelagic larvae including fishes, coelenterates, ctenophores, as well as, most benthic organisms with mucous and ciliary feeding mechanisms, capture bivalve larvae with perhaps the most efficient predators being the adult oyster themselves (Andrews 1983).

Numerous species of gastropods, crustaceans, and fish prey on spat, juveniles, and adult oysters, but the principal predators are most abundant in high salinity waters (Gunter 1955). In most areas where oyster populations flourish, critical fluctuations in daily and seasonal salinity patterns act to deter the establishment of predators with marine affinities. Increased stress that is associated with prolonged high salinity regimes often exacerbates the level and intensity of predation.

Florida rocksnails are euryhaline, but they are most abundant in higher salinities (Pollard 1973, Cooley 1978). Butler (1954) reported that the Florida rocksnail was the most serious natural predator along the Gulf and was distributed wherever oysters were found at salinity levels averaging above 15 ppt. May (1971) reported that the Florida rocksnail (=oyster drill, *S. haemastoma*) was the most serious oyster predator in Alabama waters and severely restricted oyster distribution in the state. Annual oyster mortality rates due to oyster drills were estimated to range from 50-85% in Louisiana (Schlesselman 1955) and from 50%-100% in Mississippi (Chapman 1959). Butler (1954) reported that losses to oyster drills were incalculable and concluded that their voracious feeding habits, high reproductive capacity, and widely distributed larval stages combined to make this snail the most destructive oyster predator in the Gulf environment.

Other investigations along the Gulf have identified several additional gastropods that may feed on oysters including whelks (*Busycon contrarium* and *B. perversum*), the crown conch (*Melongena corona*), the moon snail (*Polynices duplicatus*), and the ectoparasitic snail (*Boonea impressa*) (Ingle and Dawson 1953, Butler 1954, Menzel and Nichy 1958, Menzel et al. 1966, Quick 1971, White et al. 1984). The levels of predation due to these snails are poorly understood, but they are generally considered to be less devastating than the oyster drill (Butler 1954, Menzel et al. 1966).

Extensive oyster losses have been associated with oyster leeches, *Stylochus* spp. (Pearse and Wharton 1938, Ingle and Dawson 1953, Menzel et al. 1966, Overstreet 1978). Although these polyclad worms may cause serious damage, evidence indicates that they are secondary predators and generally cause harm in areas where oysters are already in a weakened condition (Pearse and Wharton 1938, Butler 1954, Quick 1971).

Stone crabs (*Menippe* spp.) have been identified as major oyster predators along the Gulf (Menzel and Hopkins 1955b, Menzel et al. 1966, Powell and Gunter 1968, Quick 1971). Stone crab densities as high as 8,000 crabs per hectare have been reported on reefs in Louisiana (Menzel and Hopkins 1955b). Their experiments indicated that each stone crab could kill as many as 219 oysters per year. Such populations could thus destroy over 700,000 oysters per acre, or about 1,000 bushels annually. The ability of adult stone crabs to feed upon mollusks has been shown to be dependent upon the generation of enormous crushing forces of up to 19,000 lb/in^2 (Brown et al. 1979) while claws are also used to cut or tear shell and tissue. Blundon (1988) reported that forces required to crack adult oysters are greater than forces generated anywhere along stone crab dactyls and suggested that the application of sublethal forces may progressively weaken the shell. Brown and Haight (1992) conducted laboratory experiments on prey selection by *M. adina*. Stone crabs selected smaller oysters and oyster drills because of mechanical limitations rather than active choice for smaller prey

Blue crabs (*Callinectes* spp.) are major predators of the oyster. Eggleston (1990) found that predation by large male *C. sapidus* can lead to local extinction of juvenile oysters (15-35 mm shell length) regardless of density, and Lunz (1947) identified them as the most serious predators of young oysters (5-30 mm) in South Carolina waters. Marshall (1954) studied the effects of predation on oysters in Florida and found survival of oysters was only 9% in a natural area as opposed to 85-86% in areas where oysters were protected from predation. Carriker (1967) noted that blue crabs pose an additional threat as estuarine oyster predators, because unlike starfish and oyster drills, they can move into low salinity waters. Menzel and Hopkins (1955b) found that blue crabs consumed an average of 19 oyster spat per day and concluded that while this species is an important predator of spat, it is a scavenger of adult oysters, eating only dead or sick individuals. Krantz and Chamberlin (1978) found blue crabs >100 mm in carapace width could consume single oysters up to 40 mm in length. For a further review of blue crab predation on oysters, see Guillory et al. (2001). *Panopeus herbstii* and *Eurypanopeus depressus* were reported to destroy young, thin-shelled oysters (McDermott 1960). *Neopanope texana* has been observed feeding on oyster spat 2.5-10 mm in length (MacKenzie 1970 and 1977).

Black drum are major predators of the oyster, especially seasonally. Cave and Cake (1980) found that black drum can crush and ingest oysters that fit within the pharyngeal apparatus. Large drum (over 900 mm TL) can consume oysters up to 112 mm in length while drum <900 mm consumed oysters <75 mm. Mean daily predation rate for individual fish was as high as 48 oysters. Large drum can consume more than two oysters per day for every kilogram of body weight. In feeding experiments, Cave (1978) noted that drum caught near oyster reef areas preferred oysters over other bivalve mollusks tested. He also observed that drum preferred single oysters over clusters; however, they could crush virtually any size or group of oysters that would fit inside the pharyngeal chamber. Brown *et al*. (2003) found that black drum can devastate newly seeded oyster reefs preying heavily on small oysters.

Other fish predators of oysters (at least oyster spat) include Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), cownose ray (*Rhinoptera bonasus*), sheepshead (*Archosargus probatocephalus*), and striped burrfish (*Chilomycterus schoepfi*) (Haven et al. 1978, Krantz and Chamberlin 1978, St. John and Cake 1980, White and Wilson 1996). The extent to which these fish impact oyster stocks has not been determined.

For a further description of oyster predators see Kilgen and Dugas (1989), White and Wilson (1996), and references therein.

5.2.1.4 Climatic Changes and Tropical Events

Both short and moderate-term climate events may impact oysters both directly and indirectly. Within the Gulf, hurricanes have been responsible for the destruction of entire reef systems. This may be caused by the physical scouring of the reef with storm surge and wave action, the burying of a reef with transported sediments, or the placement of large amounts of debris or vegetative overburden. Depending on the characteristics of the storm, local rainfall levels might drastically increase the freshwater inflow to the system (Switzer et al. 2006). However, as these storms are a part of the oyster's evolutionary history, they show the ability to recover from these events. This is often in the form of increased spat set (Livingston et al. 1999).

The reef's ability to recover also depends on disturbance frequency or magnitude. For example, a single strong tropical event may serve to physically damage a particular reef and cause high mortalities (Livingston et al. 1999). However, because of increased shell availability and increased recruitment, the reef may reach pre-disturbance oyster abundances within a period of 1-3 years. Conversely, relatively 'weaker' but more frequent tropical storms may serve to dramatically increase freshwater inflow and decrease the salinity over a reef, limiting reproduction, growth, or causing direct mortalities for longer time periods.

Longer-term events (1 to 10 year cycles) may modify conditions such that the biological habitat optima no longer intersect the physical optima. In the case of the El Niño Southern Oscillation (ENSO), an anomalous warming (El Niño) or cooling (La Niña) of the eastern Pacific results in changes in precipitation patterns, temperatures, and tropical activity over the northern Gulf. The El Niño period often results in cooler temperatures and increased precipitation in the southern United States with an overall decrease in tropical activity. Cooler water temperatures and changes in freshwater inflow might indirectly affect spawning and growth with possible direct mortality if conditions persist. La Niña is the opposite phenomenon in which temperatures are increased with decreased precipitation. This may lead to increases in Dermo infection intensities (Soniat et al. 2009). A reduction in freshwater to the estuary during these dry period cycles can lead to overall increases in predation from oyster drills and other marine predators as well. Finally, tropical cyclone activity is increased during this time, with possible effects as discussed above.

5.2.2 Anthropogenic Threats to Survival

Over 50% of the United States population lives within a coastal county and a majority of the country's most densely inhabited counties are located along the coasts (Crossett et al. 2004). This development is in direct proximity to estuarine environments and can have dramatic direct and indirect impacts. Dredge and fill activities result in the creation of dry land used for urban development in coastal areas nationwide. Indirect effects from urban development also impact the quality and quantity of estuarine habitat utilized by oysters. Hopkinson and Day (1980) suggest that processes occurring at the uplands-estuary interface can have direct ecological effects such as nutrient runoff and eutrophication. While some of the direct impacts to estuaries have been somewhat curbed in recent years by coastal zone management regulations, indirect and cumulative impacts continue to be a major concern.

Most environmental or habitat alteration problems affecting fishery resources and their habitats are socio-economic in nature. The impact is caused by a more lucrative venture other than a fishing or habitat preservation. Many situations that are sometimes classified as 'natural' occur due to inadequate managerial attention and end up posing an unforeseen threat to oyster and estuarine health. It is interesting that many early students of the eastern oyster had little to say about the habitat of oysters and its management, although they discussed environmental factors affecting the species (Galtsoff 1964, Coen et al. 1999).

The majority of degradation effects is usually localized and may not affect regional oyster metapopulations, except perhaps in some major urbanized estuaries. The cumulative impacts of several stressors at once are difficult to assess due to environmental variability, variable recruitment and dispersal, and temporal and spatial variability of some of the threats.

5.2.2.1 Pollution

Heavy metals, petroleum hydrocarbons, pesticides, chlorine derivatives, sewage, and other pollutants can negatively affect oyster populations. As the quantity and diversity of chemicals used in industry, agriculture, and waste water treatment increase, the quantity of chemical pollutants entering Gulf estuaries also increases (Gloyna and Malina 1964, Childress 1963, 1966, 1967, O'Connor 2002). Significant environmental impacts to coastal ecosystems occur via direct pollution from vessels. Pollution from recreational, commercial, and military vessels emanates from a variety of sources: including gray water, bilge water, black water (sewage), ballast water, anti-fouling paints, hazardous materials, garbage and other wastes, and the potential introduction of non-indigenous species (see Section 6.7 for detail).

Increases in sewage generated by coastal populations and excessive freshwater runoff contribute to bacterial contamination of reef areas. There are limited studies of oyster stress and mortality attributed to these types of pollution events. Information that is available is primarily in the form of identifying contaminants, describing the manner in which they affect oysters, and other descriptive information. One of the indirect effects of closure of reefs because of human disease risks is that it can result in a loss of 'maintenance' to beds within those closure areas. Long periods of closure can allow silt to accumulate while permanent closure can lead to destructive alternate uses of the beds, such as dredging shell for other purposes like construction or feed supplements (MacKenzie 1996, 1997, Dugas et al. 1997).

Heavy metals in the environment affect oysters during all stages of their life cycles. These substances can stress or kill oysters by reducing their ability to withstand diseases and parasites (Calabrese et al. 1973, MacInnes 1981, Okazaki and Panietz 1981). The presence of heavy metals in bay waters can lead to the mortality of embryos and larvae, reduce growth of larvae and spat, reduce spat setting, and cause shell thinning (Calabrese et al. 1973, Boyden et al. 1975, Cunningham 1976). Results of tests designed to determine contaminant concentrations at which 50% of oyster embryos die (LC50) indicate that, of the heavy metals tested, mercury(Hg), silver (Ag), copper (Cu), and zinc (Zn) are the most toxic. Nickel (Ni), lead (Pb), and cadmium (Cd) have been classified as relatively toxic while arsenic (As), chromium (Cr), manganese (Mn), and aluminum (Al) have been labeled as nontoxic to oyster embryos (Calabrese et al. 1973).

Determining the effect of petrochemical pollution on oysters is difficult because oil is composed of a complex mix of hydrocarbons that exhibit different levels of toxicity. Crude oil is generally less toxic than partially refined oils (Anderson and Anderson 1975). Oil exposure can substantially reduce feeding rates, decrease respiration, increase energy expenditure, and reduce byssal thread production resulting in weakened substrate attachment strength (Suchanek 1993). Chronic exposure to oil-contaminated sediment at low concentrations, 0.05-0.15 ppm, results in a reduction in food intake or utilization while exposure to higher concentrations of oil in the sediment can cause extensive mortalities (Mahoney and Noyes 1982). Impacts of oil during spawning events could be magnified because oil can reduce egg production and hatching rates, cause abnormal larval development or survival, and decrease survival and settlement of spat. Fertilization and developmental success is reduced in proportion to concentrations of water- soluble hydrocarbon fractions between 1 and 1,000 ppm (Rezoni 1975). Incidence of parasites is higher in oysters chronically exposed to oil pollution than in unexposed oysters (Barszcz et al. 1978).

Pesticides reduce oyster growth, cause pathological tissue damage, interfere with egg development, and cause mortalities (Davis and Hidu 1969, Rowe et al. 1971, Lowe et al. 1972, Schimmel et al. 1975). The extent to which pesticides affect oysters depends on the chemical, its concentration, and the oyster life stage. Pesticides can become heavily concentrated in oyster tissues (Davis and Hidu 1969, Rowe et al. 1971) and, depending on the chemical, oysters can concentrate pesticides at levels 41-85,000 times levels found in the surrounding environment. Oysters, however, can purge themselves of pesticides when the pollutants are removed from the environment (Davis and Hidu 1969, Rowe et al. 1971); thus, they have been implicated as a possible biological monitor of organochlorine pesticide contamination.

Chlorine and chlorinated compounds affect oyster survival, growth, feeding, reproduction and development. Chlorine may be used to purify municipal water supplies, disinfect sewage waste water and as a biocidal anti-fouling agent in industrial cooling water. Chlorine and chlorine derivatives (chlorine-produced oxidants) are extremely toxic to oyster larvae at concentrations as low as 0.005 ppm (Haven et al. 1978). Chlorine concentrations as low as 0.05 ppm cause reduced pumping rates, and concentrations >1 ppm cause oysters to close their valves (Galtsoff 1946). Exposure to chlorine concentrations between 0.12 and 0.16 ppm adversely affects adult oyster growth, food intake, and reproduction (Scott and Vernberg 1979). Chlorine concentrations > 0.16 ppm are toxic to adult oysters (Scott and Vernberg 1979).

5.2.2.1.1 Eutrophication

Eutrophication, stimulated by inadequately controlled nutrient inputs, supports excessive phytoplankton blooms, which contribute to the development of hypoxic/anoxic conditions. Excessive algae and plankton growth may have a negative effect in some estuaries, while light to moderate inputs of nutrients may enhance primary and oyster productivity where biological potential is limited (Kirby and Miller 2005). Eutrophication can contribute to increased incidences of toxic or harmful algal blooms (HABs), especially dinoflagellates.

5.2.2.1.1.1 Harmful Algal Blooms (HABs)

HABs occur naturally throughout the Gulf of Mexico, especially during the warm summer months. However, excessive nutrient run-off carried from locations upstream in the watershed can result in large, widespread occurrences of HABs and negatively impact oysters.

Dense blooms of these dinoflagellates may decrease particle clearance rates in oysters (Pate 2006) or lead to direct mortality (Stoecker et al. 2008, Mulholland et al. 2009). Increased frequency and quantity of plankton blooms can increase the abundance of planktivores, such as coelenterates and ctenophores (Purcell et al. 2007), which can prey upon oyster larvae and increase the mortality on these critical life stages (MacKenzie 1977, Fulford et al. 2011). The process of eutrophication can cause changes in phytoplankton community composition (Livingston 2007), e.g., increase the abundance of species that are too small or large to be effectively filtered and retained (non-toxic picoplankton blooms), and reduce the abundance of taxa, most useful as food to oysters (Loosanoff 1964). Alga blooms occur under particular chemical-physical conditions that could lead to environmental stress and, when coupled with any toxic effects of the HAB, could lead to oyster mortality. In Chesapeake Bay, Glibert et al. (2007) speculated that, depending on the timing of the HAB in relation to oyster spawning and recruitment, they have the potential to reduce survival of early life history stages of oysters. With continued nutrient loading into the Gulf from the major river systems, the potential for additional eutrophication and more frequent HABs could lead to changes in the Gulf's oyster populations.

While the term 'red tide' has been associated with HABs in the media, not all produce toxins that result in human illness. There are four types of toxins, however, which can affect human health and can accumulate in shellfish tissues in relatively high quantities: brevetoxin, hepatotoxin, domoic acid, and okadaic acid (Dortch et al. 1999). Brevitoxin, produced by *Karenia brevis* and hepatotoxin from cyanobacteria can cause serious respiratory problems in humans and neurotoxic shellfish poisoning (NSP) and are associated with fish, bird, and marine mammal deaths. The toxins, while harmful to most animals, do not necessarily result in the direct death of oysters but can remain in their tissue for weeks (Dortch et al. 1999).

5.2.2.1.1.2 Hypoxia and Anoxia

Hypoxia and anoxia events have become more common in the deeper parts of many estuaries and are a result of increased eutrophication (Funderburk et al. 1991, Dugas et al. 1997, Lenihan and Peterson 1998, Hagy et al. 2004). Even short periods of hypoxia/anoxia can be stressful or lethal to oysters, especially spat or seed, because they will not have the energy reserves to remain closed for long periods. Baker and Mann (1992) reported that hypoxic and anoxic conditions greatly reduced larval settlement. Furthermore, those individuals that did survive had greatly reduced growth compared to spat in normoxic conditions. Extended periods of anoxia may also lead to fatal bacterial infections (Fogelson 2007).

5.2.2.1.2 Siltation/Sedimentation

Silt from a variety of sources, including upstream land use (Ulanowicz and Tuttle 1992), can cover and 'smother' shell, beds, and other oyster-suitable substrate inhibiting oyster abundance (Galtsoff 1964, MacKenzie 1996, Thomsen and McGlathery 2006). This 'muck' can also cause a concurrent shift of the benthic community from filter-feeding to deposit-feeding species/mode, which in turn, can contribute to the siltation problem by creating silt-retaining beds, i.e., macro-infaunal tube fields, or recycling buried silt to the surface as erodable feces. Oyster eggs and larvae are most sensitive to suspended sediment (Davis and Hidu 1969). Settlement of oyster larvae onto a substrate can be reduced or inhibited with just a light covering of silt.

5.2.2.1.3 Dredge and Fill

Dredge and fill activities represent a direct physical impact to oysters either by removal or burying. This activity is most often associated with navigation channel construction, mineral extraction, levee construction, or coastal restoration activities (coastal development discussed below). In addition to removal or burial, the dredge and fill activities may resuspend sediments resulting in siltation of nearby reefs.

Fill activities, such as those employed for coastal protection, could have positive impacts on oyster populations. Shoreline stabilization projects where limestone rock or other non-native material is used as fill to protect shorelines from erosive forces caused by wave energies, may serve to provide appropriate settlement substrata for oyster larvae. Natural materials such as oyster shell have also been shown to provide shoreline protection in Alabama and Louisiana, while at the same time, provide valuable habitat to both oysters and reef-associated animals (Piazza et al. 2005). The shoreline protection strategy of building natural oyster reefs along marsh edges has gained popularity in Louisiana as state government, local governments, and environmental groups (i.e. The Nature Conservancy) have recently utilized such methods for coastal restoration efforts. In Alabama, the experimental use of these methods has shown promise, significantly slowing erosion up to 40% in some moderate to high energy areas as well as increasing the abundance of seagrasses and economically important fish and crab species (Scyphers et al. in press.)

5.2.2.2 Physical Changes to Reef Morphology

Oyster fishing has utilized harvesting practices that have led to some negative effects on reef morphology, growth, and long-term viability (Rothschild et al. 1994, Hargis and Haven 1999, MacKenzie 1996, Dugas et al. 1997, Lenihan and Peterson 1998).

5.2.2.2.1 Mechanical Harvesting

Early oyster harvesting and culling practices often reduced the vertical reef structure by spreading out and separating oysters. More recent culture methods have kept the beds low to facilitate more efficient harvesting. These activities have thus reduced some of the ecological benefits of the reef structure to the oyster and associated species (Rothschild et al. 1994, Hargis and Haven 1999). In addition, the lowering of reef height may place oysters within hypoxic layers common in many estuaries (Lenihan and Peterson 1998). Altering the physical structure of reefs can also make them more vulnerable to hurricane-induced sedimentation. For example, approximately half of the consolidated public oyster reefs in Galveston Bay were lost when sediments from Hurricane Ike settled onto these low-profile reefs. In contrast, private oyster leases, which typically exhibit a higher profile relative to the surrounding bay bottoms, were much less impacted by this storm event. Finally, the oyster harvesting dredges themselves may physically impact the oysters, especially spat and juveniles. This is especially important where extensive mechanical harvesting takes place after a recent spat set, as the spat shells are not strong enough to protect the oyster from harvest-related damage.

5.2.2.2.2 Loss of Shell, Cultch, and Shellstock

The loss of live oysters and shell from oyster reefs without replacing the lost substrate with shucked-shell or other suitable cultch material will ultimately result in reducing the hard surface and reef structure that benefits sustainable oyster populations (MacKenzie 1996, MacKenzie and Wakida-Kusunoki 1997). There continue to be issues with management agencies having difficulty in acquiring appropriate materials or quantities for shell planting and reef nourishment. There is a long history of using shucked shell in road beds, construction, and as calcium supplements in the livestock and poultry industries in the United States. Similarly, the harvesting from natural seed beds without cultch replacement can ultimately reduce the function and productivity of these beds over time (Rothschild et al. 1994). For some states, the acquisition of shell is extremely difficult given that a large majority of the shell stock is either exported or may become the property of an individual harvester, wholesaler, processor, or retailer. A lack of dedicated funding for shell planting projects continues to be a problem for some states.

In some cases, management may be directed towards the available shell resource (oyster reef habitat) rather than quantities of live, or harvestable oysters. This method of habitat management is based on the concept that total available shell is a major limiting resource affecting production (and sustainability). One of the management objectives is to determine the amount of shell (living and dead) that can be removed and still allow for the long-term commercial viability of a reef. This concept, referred to as a shell budget, is described within Section 11.3.2.

5.2.2.2.3 Reef Fragmentation

Fragmentation can happen on two scales, each of which has its own detrimental impacts. Impacts at the individual reef scale can occur through activities such as natural physiographic changes, depletion of shell and spat for transplants, and navigational maintenance. The result is that the reef will have a higher edge to area ratio. Any factor that affects the edges will thus have a relatively greater impact to the whole reef. Three such factors would include wave-induced sediment resuspension (Rothschild et al. 1994, Mann 2000), disease dynamics (Lenihan et al. 1999), and predation (Harwell 2004).

When fragmentation occurs on a larger scale, limitation to genetic homogeneity both locally and regionally, can occur. Despite the fact that oysters have high reproductive output, the pelagic larvae are susceptible to high mortality prior to settlement due to the stochastic nature of currents and conditions, and post-settlement as spat due to predation (Section 5.2.1.3). Genetic drift can be described as the random changes in the frequency of any given allele. In a small population, this drift is enhanced more by chance than by selective pressures, simply because the resultant progeny in each generation are drawn from a small pool of parents. Similarly, the concept of 'chaotic genetic patchiness' suggests that, because of low recruitment success by immigrant larvae, only a few adults successfully contribute to recruitment each year, resulting in a type of ‘sweepstakes’ reproduction (Hellberg et al. 2002). When all of the subpopulations of a larger metapopulation can trade offspring freely, the genetic drift is reduced because the fittest alleles will tend to stay most abundant (unless linked to detrimental alleles). The less connected two sub-populations are, the more likely genetic drift can take place. When reef fragmentation occurs on scales less than the scale of larval distribution, little effect should be observed. When fragmentation happens on a larger scale – loss of entire watersheds within an estuary, or loss of oysters from entire estuaries – loss of gene flow between oyster subpopulations can occur (Reeb and Avise 1990, Hellberg et al. 2002). A system of functionally connected reefs can capitalize upon variable environmental conditions during the spawning season (Eggleston 1999, Whitlatch and Osman 1999).

There are many models and descriptions of how planktonic larvae disperse and repopulate appropriate habitat (Blanton et al. 1999, Bradbury and Snelgrove 2001, North et al. 2008, Cowen and Sponaugle 2009, Kim et al. 2010). In principal, the larvae become more dilute as the distance from their source increases. This dispersal will be a function of both dilution (Hitchcock et al. 2008) and advective dispersion depending on the magnitude of currents in an area. The final density available to settle will also be related to the total mortality of the larval population. The number of successful migrants between populations that are required to maintain genetic homogeneity will be much less than the number of migrants required to fully re-populate an area that has been depleted after a major stress. The processes that allow interactions between two reefs in a localized system (diffusion alone or also intra-estuary currents) will be less complex than the processes that allow interaction between neighboring estuaries (diffusion plus intra-estuary plus coastal currents). Each time a link is lost or compromised, the inter-population interaction is reduced.

5.2.2.2.4 Other Fishery Activities

Mariculture or fisheries for other species, in or near the oyster reefs, can compete for habitat space and other critical resources (Burrell 1997), or contribute inhibitory waste products. Bottom-trawling may lead to scouring of the water bottom, direct mortality with gear impacts, and a resuspension of sediments (Wilber et al. 2005). As a result, several states have enacted regulations to prohibit the use of trawls over specific oyster areas.

5.2.2.3 Coastal Development

Increased use of coastal areas for residential, commercial, and recreational purposes (urbanization) alters the character of the land and its watersheds, and affects downstream or adjacent estuaries that have supported oyster populations. Urbanization competes with the waterfront access fishermen need to preserve and utilize oyster resources. This issue is almost ubiquitous in all coastal areas, or could be, and its potential multiple effects on oysters and their habitat can vary greatly among areas, even though specific cause-and-effect relations are poorly documented.

Changes in runoff inputs associated with urbanization and development can alter the hydrography and quality of aquatic habitats used by oysters from the hard-surfacing of roads and construction of elaborate storm drain systems that pour excessive or contaminated waters directly into estuaries (Burrell 1997, Dugas et al. 1997). Subtle changes in the mix of temperature and salinity due to storm water inputs may be disruptive to reproductive cycles and result in higher mortality rates. In addition, urbanization and coastal development is expected to result in expanded closures of shellfish harvesting areas due to degrading water quality, as well as increased sedimentation into adjacent bays and estuaries, which can lead to increased deposition on low-profile oyster habitat.

The loss or development of shoreline forests (MacKenzie 1997) can alter wind exposure in smaller estuarine tributaries that can affect oyster larvae dispersal processes, as well as alter watershed hydro-geodynamics.

5.2.2.3.1 Water Rights

Water rights are one of the biggest issues related to development on the coast as well as inland. As noted in Section 4.6.3, a number of states in the Gulf region are embattled in 'ownership' of water. Likewise, many of the states require freshwater to support their cities and populations that do not live near sufficient sources or build reservoirs to hold what little water they do receive causing issues downstream for other human communities and fisheries. For example, Texas will be facing even more significant losses of freshwater inflows into bays and estuaries as water demand for an increasing population grows. Water withdrawal rights in Texas are permitted in perpetuity. Return flows (water returned to the river after having been used by the permitee) have helped maintain consistent inflows into bays and estuaries; however, as demands for water continue to increase more of this permitted water is being resold to other users, both within and outside the watershed basin further reducing the quantity of water reaching bays and estuaries.

5.2.2.3.2 Thermal Discharge

Power plants produce large quantities of heated effluent so that thermal pollution is now a consideration in habitat alteration. Roessler and Zieman (1970) found that the area adjacent to a nuclear plant outflow in Biscayne Bay, Florida, in which all plants and animals were killed or greatly reduced in number, corresponded closely to the area delineated by the +4°C isotherm. Entrainment of oyster larvae into the cooling waters of power plants in some estuarine areas can reduce larval stock density from local areas and impact spat recruitment. Super heated cooling water may impair un-entrained oyster larvae near the outfall, but some warmer effluent from power plants in northern waters may alternately enhance larval recruitment.

5.2.2.3.3 Desalination

The world's largest desalinization plant became operational in 2007 in Tampa Bay. It draws 166,000 m^3 per day of power plant discharge saltwater to produce about 20,000m^3 per day of fresh water. Plans may allow it to increase to about 200,000 m^3 freshwater per day produced, presumably requiring filtration of up to 1.6 million m^3 of seawater. This water is currently drawn from power plants so filtration of larvae is not a concern, but could be if raw seawater was utilized in an area where larvae were limiting. A second possible risk would involve disruptions to optimal salinity conditions (resulting in hypersalinity) should plants be allowed to be constructed in areas where the discharge flowed into basins with limited circulation.

Another U.S. plant in El Paso Texas uses brackish groundwater, a non-threat for oysters. Other existing plants can be found in Aruba, Australia, Cyprus, Gibraltar, Israel, and the United Kingdom, and additional plants are planned for Haiti, Algeria, and India. Current plants are not anticipated to be major threats to oysters, but as increased competition for freshwater occurs, and freshwater flows to estuaries are reduced, the magnitude of threats related to desalination can be expected to increase.

5.2.2.4 Hydrologic Modification

The amount and timing of freshwater inflow are critical to the long-term survival of an oyster community (Section 4.5.2.2). Modifications to this inflow, as well as changes to overall hydrology, may result in direct mortality, or result in spatial/temporal shifts in estuarine conditions. One of the leading historical causes has been channelization of wetlands and waterbodies.

These channelizations have resulted in salinity shifts, increased erosion, increased turbidity, the physical removal of suitable substrate, and impacts from vessel usage (Wall et al. 2005). Channels constructed for shipping and mineral extraction have allowed a direct link between saline Gulf waters and the interior wetlands; however, perhaps the most important has been the modification of freshwater inflow to the estuary.

Modifications to inflow have resulted for many reasons. Impoundments, reservoirs, water control structures, and industrial use have all served to reduce inflow. This results in shifting salinity regimes within the estuary. Conversely, river reintroductions such as siphons, diversions, and delta creations all serve to increase inflows to certain areas. Many of these increases have been beneficial to overall oyster production in the long-term; however, short-term effects have led to direct mortality (freshets), increased turbidity, and a shift in suitable habitats. It is important that any freshwater increase to the system mimic natural conditions and provide a suitable salinity and temperature range that co-occurs over a suitable physical habitat (Volety et al. 2009). These habitats rely on freshwater inflow to deliver nutrients critical for productivity. Significant changes in the amount and timing of freshwater inflow may affect all life history stages of oysters that use estuaries.

5.2.2.4.1 Aquifer Withdrawals

Water withdrawals for municipal, industrial, and agricultural use may reduce water flow into inland rivers and, in extreme cases, may reverse the flow of groundwater. Reports in the Everglades have suggested that at times of high water usage in the residential areas of Dade County, brackish estuarine waters have actually been drawn into the aquifer. Significant changes in the amount and timing of freshwater inflow may affect all life history stages of oysters that use estuaries. These habitats rely on freshwater inflow to transport nutrients critical for productivity.

Additional upland activities resulting from wildfires and poor silvicultural practices may lead to increased upstream erosion rates, increased sediment load downstream, and decreased ground water recharge due to increased runoff and increased evaporation rates of sun-baked soil (J. Mareska pers. comm.) It has also been hypothesized that replacement of natural stands of mixed pine-hardwood with pine monoculture, in some parts of the southeastern United States, may have had an effect on shallow aquifers in some areas. Because pine species have active photosynthesis and corresponding transpiration throughout the year, in contrast to hardwoods that exhibit winter dormancy, there is potential for greater annual water withdrawal from the soil when landscapes are dominated by pine forest. This could affect recharge rates of shallow aquifers, particularly during years of drought; however, there have been no studies conducted to test this hypothesis (D. Jackson pers. comm.)

5.2.2.4.2 Water Management Projects

Some major freshwater control projects are underway in the Gulf states, and others are planned. A thorough knowledge of the biological and engineering feasibility of such projects is needed prior to planning, designing, and developing freshwater control projects since water control projects that disrupt the flow of fresh water for prolonged periods may result in serious adverse impacts to estuarine ecology. For example, the Bonnet Carre’ Spillway, located on the Mississippi River, serves to control river stages and flow rates. The spillway has been an important feature in controlling flood waters, and can effectively divert fresh water into Lake Pontchartrain and around the City of New Orleans. Freshwater diversion, when the spillway is opened, can have short-term and long-term effects on estuarine ecology and oyster production. Opening the spillway may simulate the natural flooding cycle of the river and result in favorable long-term effects on oyster production, but can also have significant detrimental short-term mortality impacts.

In 2010, multiple freshwater diversions along the Mississippi River (not the Bonnet Carre' Spillway, however) were opened for several months in Louisiana in an effort to prohibit surface oil resulting from the tragic Deepwater Horizon oil spill event from reaching the sensitive marshes of southeast Louisiana. Although studies are continuing and results may not be known for some time, many scientists believe that low salinities caused, in part, by the freshwater diversions negatively impacted oyster beds in the region. Heavy oyster mortalities were documented within the outfall basins of these diversions on both public and private oyster beds, although these basins did also experience documented oil intrusion.

5.2.2.4.3 Navigation Projects

Hydrologic alterations to bay ecosystems due to reductions in freshwater inflows coupled with deepening ship channels lead to increases in salinity which promotes the production of oyster-specific predators and diseases. In fact, a positive relationship between freshwater inflows and oyster abundance has been demonstrated for Galveston Bay, Texas (Buzan et al. 2009).

Port development and expansion can further alter freshwater inflow and change the hydrology substantially in areas near these projects. In Texas, port authorities are planning expansions to ship channels in several major oyster producing bays in anticipation of the expansion of the Panama Canal, expected to be completed in 2014. These channels provide a conduit for more saline waters to move up bay systems and coupled with reductions in freshwater inflows, may lead to increased incidences of oyster predators and diseases. This changing hydrology has been predicted to shift the optimal oyster producing areas further up the bay where substrate for spat settlement is limited, sediments are less capable of supporting the weight of cultch, and reefs that do become established will be subjected to wide fluctuations of salinity during flood and drought events (Powell et al. 2003).

5.2.2.5 Non-Native Flora and Fauna

The terms 'non-indigenous', 'non-native', and 'alien' are all used to describe species that have been introduced outside of their native range. Shipping, aquaculture, canal construction, and the aquarium and live seafood trades have all been the sources of documented introductions (Molnar et al. 2008). However, for the vast majority of non-native species, the specific introduction event is unknown.

The USGS, Nonindigenous Aquatic Species Program, reports that, at present, over 1,500 non-indigenous aquatic species have been introduced into United States waterbodies (USGS NAS 2008). Of that number, 74 have been identified as estuarine or marine species within the Gulf (Ray 2005). Although many of these species may be restricted to highly localized habitats, or never establish viable populations, some may be termed 'invasive. Invasives are defined as

> "…an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." (Executive Order 13112, 1999)

These species can alter or compete for habitat or resources necessary for oysters, act as direct predators on oysters, or modify the foraging ecology of other species impacting the overall ecology of a system (Kimbro et al. 2009). For example, the green mussel (*Perna viridis*) has established viable populations in southwest Florida (Baker et al. 2007). This mussel attaches to hard substrates and competes with the oyster for space and resources. A similar species, the brown mussel (*P. perna*), has been established in Texas and represents a similar threat (Ray 2005). Both of these species, especially *P. viridis*, have the ability to withstand highly variable environmental conditions, exhibit fast growth, and possess reproductive strategies that allow for rapid colonization

(Rajagopal et al. 2006).

This direct competition is also of concern when discussing introductions of eastern oyster congeners. With the collapse of the oyster fishery within the Chesapeake Bay, a lot of resources have been devoted to the study of possible ‘replacements’ to the native oyster. Specific species of concern are *Crassostrea gigas* and *C. ariakensis*. The risks involved with these planned introductions have received extensive review and evaluation (National Resources Council 2004b, USACE 2009) cannot be stressed enough. Not only can these organisms directly compete with natives, they may also modify the entire ecological structure of a reef as a result. In some cases, these introduced organisms may allow for the spread of other introduced species. Examples have been found for both *C. gigas* in the Chesapeake Bay and *C. ariakensis* in North Carolina. MSX was found to have been introduced into east coast waters during the 1950’s with known importations of *C. gigas* (Burreson et al. 2000). *Crassostrea ariakensis* acted as hosts for *Bonamia* spp., which itself was hypothesized to have arrived via ballast water (Bishop et al. 2006).

6.0 PUBLIC HEALTH CONCERNS INTRODUCTION AND HISTORY

The majority of this section is extracted with thanks from the National Shellfish Sanitation Program's *2007 Guide for the Control of Molluscan Shellfish* (NSSP 2007) and from the FDA's *Bad Bug Book* (available online at www.fda.gov).

6.1 Background

Molluscan bivalves, referred to here as 'shellfish,' are filter feeders which bio-accumulate contaminants and microorganisms, including human pathogens and toxigenic micro-algae when these organisms are present in the overlaying waters of the growing area. Because shellfish pump large quantities of water during the normal feeding process, the accumulation of bacteria in the shellfish may be as much as 100 times that found in the overlying waters and may be over 1000 times the concentration of chemicals, including heavy metals (NSSP 1965, Apeti et al. 2005). The determination that microorganisms or chemicals, which are harmful to humans when consumed, are present in growing waters can lead to immediate closure of the implicated growing area and/or recall of implicated product to prevent further risk to humans through consumption. Consumption of any raw or improperly cooked proteinacious food, such as raw meat or raw seafood, can result in serious illness and death in immunocompromised individuals such as pregnant women and people with liver disease and diabetes (NSSP 2007). Oysters are commonly eaten live, whole, and raw which puts immunocompromised individuals at a much higher risk than the normal, oyster-eating population.

Documentation of the information supporting growing area classification, proper tagging and record keeping, expeditious follow-up on reported illnesses, effective recall of implicated product and public warning announcements are all requisite to protecting public health. Shellfish growing areas implicated through epidemiological association must be closed immediately to prevent additional implicated product from reaching the consumer.

All Gulf of Mexico states have estuarine systems that may be affected by naturally occurring plankton and algal blooms. Some blooms, referred to as harmful algal blooms (HABs), such as the dinoflagellate, *Karenia brevis,* which produces neurotoxic shellfish poison, can result in public illnesses and cause public health officials to close shellfish harvesting areas during incidents. Both Florida and Texas have management plans to close shellfish harvesting areas during harmful algal blooms (see Section 5.2.2.1.1.1).

6.2 National Shellfish Sanitation Program (NSSP)

Oysters, clams, and mussels (shellfish) are unique foods which have been enjoyed by consumers for generations. The popularity of shellfish as a food can be traced through several centuries of American history. Public health controls for shellfish became a national concern in the U.S. in the late nineteenth and early twentieth centuries when public health authorities noted a large number of illnesses associated with consuming raw oysters, clams, and mussels. Shellfish-associated outbreaks were also medically recorded in other parts of the world, most notably in European countries.

In 1924, a widespread typhoid fever outbreak occurred in New York, Chicago, and Washington, D.C. which was finally traced to sewage-polluted oysters. Local and state public health officials and the shellfish industry became alarmed over this outbreak and requested that the Surgeon General of the U.S. Public Health Service develop necessary control measures to ensure a safe shellfish supply to the consuming public. As a result, the National Shellfish Sanitation

Program (NSSP) was developed in 1925 when the U.S. Public Health Service responded to that request for assistance from local and state public health officials in controlling disease associated with the consumption of raw shellfish (oysters, clams, and mussels).

Those public health control procedures within the NSSP established by the U.S. Public Health Service were dependent on the cooperative and voluntary efforts of State regulatory agencies. The efforts were augmented by the assistance and advice of the U.S. Public Health Service (now the U.S. Food and Drug Administration or FDA) and the voluntary participation of the shellfish industry. These three parties combined to form a tripartite cooperative program.

The National Shellfish Sanitation Program (NSSP) is the federal/state cooperative program recognized by the FDA and the Interstate Shellfish Sanitation Conference (ISSC) for the sanitary control of shellfish produced and sold for human consumption. The purpose of the NSSP is to promote and improve the sanitation of shellfish moving in interstate commerce through federal/ state cooperation and uniformity of State shellfish programs. Participants in the NSSP include agencies from shellfish producing and non-producing states, FDA, EPA, NOAA, and the shellfish industry. Under international agreements with FDA, foreign governments also participate in the NSSP. Other components of the NSSP include program guidelines, state growing area classification and dealer certification programs, and FDA evaluation of State program elements. The guidelines of the program have evolved into the NSSP Guide which is managed and updated by the ISSC.

To carry out this cooperative control program, each partner accepts responsibility for certain procedures. Each shellfish shipping state adopts adequate laws and regulations for sanitary control of the shellfish industry, completes sanitary surveys of harvest areas, and delineates and patrols restricted areas. In addition, the state inspects shellfish plants, and conducts such additional inspections, laboratory investigations, and control measures as necessary to insure that the shellfish reaching the consumer have been grown, harvested, and processed in a sanitary manner. The state annually issues numbered certificates to shellfish dealers who comply with the agreed-upon sanitary standards, and forwards copies of the interstate certificates to the FDA. For detailed breakdown of each state agency responsibility related to public health and general resource management, see Table 6.1. All of the Gulf states are required by the NSSP to have *Vibrio parahaemolyticus* and *V. vulnificus* Risk Management Plans (Section 16.3). Each state's plan is essentially the same with regards to limited summer harvest times, but there may be differences in some of the allowances [e.g., Post Harvest Processing (PHP) harvest, harvest for shucking only, earlier harvest times, etc.]

The FDA makes an annual or biannual evaluation of each state shellfish control program including the inspection of a representative number of shellfish processing plants, growing areas, and enforcement efforts as necessary. On the basis of the information obtained, the FDA determines the degree of conformity the state control program has with the NSSP. For the information of health authorities and others concerned, the FDA publishes a monthly list of valid interstate shellfish shipper certificates titled the Interstate Certified Shellfish Shippers List.

The shellfish industry cooperates by obtaining shellfish from safe sources, by providing plants which meet the agreed upon sanitary standards, by maintaining sanitary operating conditions, by placing the proper certificate number on each package of shellfish, and by keeping and making available to the control authorities records which show the origin and disposition of all shellfish. Although the basic public health principles of the NSSP have remained unchanged, program procedures have been updated and improved at periodic intervals.

The shellfish sanitation program responsibilities assigned to the Assistant Secretary for Health, Department of Health, Education and Welfare were delegated to the Commissioner of Food and Drugs in late 1968. The FDA continued to sponsor the proceedings from the National

Table 6.1 State agencies responsible for various tasks associated with resource management and public health management. Authorities and detailed tasks are provided in Section 7.2.

Task	Florida	Alabama	Mississippi	Louisiana	Texas
Licensing	FWC	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Seasons	FWC	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Harvest Limits	FWC	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Area Closures	DACS-BEA	AMRD and ADPH	MDMR Shellfish Bureau	LDHH	DSHS
Size Restriction	FWC	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Harvest Area Classification	DACS-BEA	ADPH	MDMR Shellfish Bureau	LDHH	DSHS
Processing Plant Certifications and Inspections	DACS-BEA	ADPH	MDMR Seafood Technology	LDHH	DSHS
Water Quality Monitoring	DACS-BEA	ADPH	MDMR Shellfish Bureau	LDHH	DSHS
Resource Management	DACS-BAD	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Leasing	DACS-BAD	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Cultch Planting	DACS-BAD	AMRD	MDMR Shellfish Bureau	LDWF	TPWD
Relaying	DACS-BAD	AMRD	MDMR Shellfish Bureau	LDHH	TPWD
Aquaculture	DACS-DOA		MDMR Shellfish Bureau		TPWD/ DSHS

Shellfish Sanitation Workshops which contained additional recommendations for revisions to the 1965 Manual of Operations.

6.3 Interstate Shellfish Sanitation Conference (ISSC)

On June 19, 1975, the FDA proposed National Shellfish Safety Program Regulations in the Federal Register. There was considerable discussion at the 1975 and 1977 Workshops concerning these proposed regulations. After evaluation of the comments received as a result of the proposed rules, the FDA determined that promulgating federal regulations would not likely achieve NSSP goals. Subsequently, FDA decided revision of the 1965 Manual of Operations was the best approach for strengthening the NSSP.

In 1982, a delegation of state officials from 22 states met in Annapolis, Maryland and formed the Interstate Shellfish Sanitation Conference (ISSC). The ISSC is composed of state shellfish regulatory officials, industry officials, FDA, and other federal agencies.

The ISSC recognized the importance of retaining many of the elements of the NSSP Manual that should not be incorporated into an ordinance. To accomplish this, the Model Ordinance Committee recommended development of the Interstate Shellfish Sanitation Program Guide which would include, in addition to a Model Ordinance (MO), guidance documents concerning important components of the NSSP, references, public health reasons for NSSP requirements, and procedures which support or are used in the NSSP. The ISSC Constitution, By-laws, and Procedures were revised to recognize an Interstate Shellfish Sanitation Program (ISSP) and its MO as replacing the NSSP on January 1, 1998 as the effective rules governing participation in the ISSC. However, further discussions by the ISSC Executive Board and FDA regarding recognition and identification of the Program have resulted in retention of the National Shellfish Sanitation Program title hereafter referred to as the NSSP.

In 1984, the FDA entered into a Memorandum of Understanding (MOU) with the ISSC recognizing the ISSC as the primary voluntary national organization of state shellfish regulatory officials that provide guidance and counsel on matters for the sanitary control of shellfish. The purpose of the ISSC is to provide a formal structure for state regulatory authorities to participate in establishing updated regulatory guidelines and procedures for uniform state application of the NSSP. The ISSC has adopted formal procedures for state representatives to review shellfish sanitation issues and develop regulatory guidelines. Following FDA concurrence, these guidelines are published in revisions of the NSSP's MO.

One of the foremost goals of the ISSC has been the adoption of the MO which would embody the principles and requirements of the Program. Adoption of the MO by each of the ISSC participating states implies commitment by each state to provide the necessary legal authority and resources to implement these regulatory requirements. Adoption also ensures uniformity across state boundaries and enhances public confidence in shellfish product.

The MO provides readily adoptable standards and administrative practices necessary for the sanitary control of molluscan shellfish and is also used by FDA as the basis for evaluating foreign shellfish sanitation programs. To accomplish this, FDA seeks to establish international MOUs with official agencies in those foreign countries that wish to export shellfish to the U.S. An MOU is established after the foreign government demonstrates to FDA that the government has laws or regulations equivalent to those published in the Manual, and that the foreign program was supported by trained personnel, laboratory facilities, and other resources as may be necessary to exercise control over the export shellfish industry. As with the states, once a country has an effective MOU, the shellfish control authority submits certificates of their certified shellfish dealers to the FDA. The FDA publishes the names of these certified shellfish shippers in the Interstate Certified Shellfish Shippers List as an approved source of shellfish.

The NSSP Guide for the Control of Molluscan Shellfish consists of the MO, supporting guidance documents, recommended forms, and other related materials associated with the NSSP. The MO includes guidelines to ensure that the shellfish produced in states in compliance with the guidelines are safe and sanitary.

6.4 Human Illnesses Associated with Oyster Consumption

There are several commonly occurring bacteria, enterovirulents, parasites, and viruses which can be contracted from the consumption of raw or under-processed foods. A complete list and descriptions of all food-borne illnesses, including those associated with oysters and shellfish in general, can be found in the FDA publication The Bad Bug Book*: Introduction - Foodborne Pathogenic Microorganisms and Natural Toxins Handbook* (available online at www.fda.gov). The microorganisms discussed below are agents of illness known to be associated with Gulf of Mexico harvested oysters.

6.4.1 *Salmonella* spp.

There is a widespread occurrence of Salmonella in animals, especially in poultry and swine. Environmental sources of the organism include water, soil, insects, factory surfaces, kitchen surfaces, animal feces, raw meats, raw poultry, and raw seafood, to name only a few. *Salmonella typhi* and the paratyphoid bacteria normally cause septicemia and produce typhoid or typhoid-like fever in humans. Other forms of salmonellosis generally produce milder symptoms.

6.4.2 *Vibrio cholerae* Serogroup

This bacterium is responsible for Asiatic or epidemic cholera. No major outbreaks of this disease have occurred in the United States since 1911. However, sporadic cases occurred between 1973 and 1991, suggesting the possible reintroduction of the organism into the U.S. marine and estuarine environment. The cases between 1973 and 1991 were associated with the consumption of raw shellfish or of shellfish either improperly cooked or re-contaminated after proper cooking. Environmental studies have demonstrated that strains of this organism may be found in the temperate estuarine and marine coastal areas surrounding the United States. Sporadic cases occur when shellfish harvested from fecally-polluted coastal waters are consumed raw. Cholera may also be transmitted by shellfish harvested from nonpolluted waters since *V. cholerae* is part of the autochthonous microbiota of these waters.

6.4.3 *Vibrio cholerae* Serogroup Non-01

This bacterium infects only humans and other primates. It is related to *V. cholerae* Serogroup, the organism that causes Asiatic or epidemic cholera, but causes a disease reported to be less severe than cholera. Both pathogenic and nonpathogenic strains of the organism are normal inhabitants of marine and estuarine environments of the United States. Shellfish harvested from U.S. coastal waters frequently contain *V. cholerae* serogroup non-01. Consumption of raw, improperly cooked or cooked, re-contaminated shellfish may lead to infection.

6.4.4 *Vibrio parahaemolyticus* (and other marine *Vibrio* spp.)

Vibrio parahaemolyticus (*V.p.*) is frequently isolated from the estuarine and marine environment of the U.S. Both pathogenic and non-pathogenic forms of the organism can be isolated from marine and estuarine environments and from fish and shellfish dwelling in these environments. Infections with this organism have been associated with the consumption of raw, improperly cooked, or cooked, re-contaminated fish and shellfish. A correlation exists between the probability of infection and warmer months of the year. Improper refrigeration of seafood contaminated with this organism will allow its proliferation, which increases the possibility of infection.

6.4.5 *Vibrio vulnificus*

Vibrio vulnificus (*V.v.*) is found naturally in estuarine environments and associated with various marine species such as plankton, shellfish (oysters, clams, and crabs), and finfish in all of the coastal waters of the United States. Environmental factors responsible for controlling members of *V.v.* in seafood and in the environment include temperature, pH, salinity, and increased dissolved organics. This organism has been isolated from oysters, clams, and crabs. Consumption of these products, raw or re-contaminated, may result in illness. No outbreaks of illness have been attributed to this organism. Sporadic cases occur infrequently, becoming more prevalent during the warmer months. Raw oyster consumption is the common association for primary septicemia and gastroenteritis, and liver disease is the underlying compromising condition. For the past several decades, there have been around 30 cases annually of *V.v.* associated with oysters harvested from Gulf waters, with mortalities around 50%.

6.4.6 Hepatitis A

Hepatitis A virus (HAV) is classified with the enterovirus group of the Picornaviridae family. HAV is excreted in feces of infected people and can produce clinical disease when susceptible individuals consume contaminated water or foods. Cold cuts and sandwiches, fruits and fruit juices, milk and milk products, vegetables, salads, shellfish, and iced drinks are commonly implicated in outbreaks. Water, shellfish, and salads are the most frequent sources. Contamination of foods by infected workers in food processing plants and restaurants is common.

6.4.7 Norovirus

The Norovirus family of viruses consists of several serologically distinct groups of viruses named after the places where the outbreaks occurred. Gastroenteritis is transmitted by the fecal-oral route via contaminated water and foods. Contaminated water is the most common source of outbreaks and may include water from municipal supplies, wells, recreational lakes, swimming pools, and water stored aboard cruise ships. Shellfish and salad ingredients are the foods most often implicated in Norovirus outbreaks. Ingestion of raw or insufficiently steamed clams and oysters poses a high risk for infection with Norovirus. Foods other than shellfish are contaminated by ill food handlers. Several large outbreaks of Norovirus associated with oysters have been linked to overboard fecal discharge and/or up-current sewage system failures.

6.4.8 Shellfish Toxins

Shellfish poisoning is caused by a group of toxins elaborated by planktonic algae (dinoflagellates, in most cases) upon which the shellfish feed. The toxins are accumulated and sometimes metabolized by the shellfish. The resulting human illnesses include paralytic shellfish poisonings (PSP), diarrheic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), and neurotoxic shellfish poisoning (NSP). NSP has been reported in association with Gulf of Mexico oysters.

While all the states have had closures due to NSP blooms, Florida and Texas are routinely affected and manage the closure of growing areas for NSP control as required by the NSSP. For copies of the Marine Biotoxin Contingency Plans, contact the individual state shellfish control authorities.

6.5 Action Levels, Tolerances, and Guidance levels for Poisonous or Deleterious Substances in Seafood

Because shellfish are filter feeders, they can readily accumulate substances from the water column. The types of poisonous or deleterious substances that have been recovered from shellfish include heavy metals, pesticides, petroleum products, polychlorinated biphenyls, and naturally occurring marine biotoxins (covered separately). The source of these contaminants may be industrial, agricultural, mining, spillage, sewage, dredging operations, and sludge dumps.

State shellfish control authorities are to follow those requirements of the NSSP model ordinance, section II, chapter II on risk assessment and risk management in managing shellfish waters implicated by harmful toxic or deleterious substances.

The FDA has established action levels, tolerances and guidance levels for poisonous or deleterious substances to control the levels of contaminants in human food including seafood (FDA Federal Register 1977, FDA 1985). Action levels are established and revised according to criteria specified in the Code of Federal Regulations (21 CFR 109 and 509), and are revoked when a regulation establishing a tolerance for the same substance and use becomes effective. Action levels and tolerance represent limits at or above which FDA will take legal action to remove adulterated products, including shellfish, from the market. Action levels and tolerances are established based on the unavoidability of the poisonous or deleterious substance and do not represent permissible levels of contamination where it is avoidable. Guidance levels are used to assess the public health impact of the specified contaminant.

Chapter II of the NSSP Guide provides a listing of action levels, tolerances and guidance levels established by the FDA for poisonous or deleterious substances in seafood including shellfish (see Section 16.4, Table 16.1).

6.6 Growing Area Classification

One of the goals of the NSSP is to control the safety of shellfish for human consumption by preventing its harvest from contaminated growing areas. The direct relationship between sewage pollution of shellfish growing areas and disease has been demonstrated many times over history. Shellfish-borne infectious diseases are generally transmitted via a fecal-oral route, usually beginning with fecal contamination of the growing waters. Feces/pathogens on land can run off into surface waters and overboard discharge in shellfish harvesting areas has been shown to be a direct cause of illnesses as well.

Shellfish from waters meeting approved area criteria are unlikely to be involved in the spread of disease that can be attributed to fecal contamination of the shellfish. The standards adopted in the United States in 1925, rely on a three-part standard for evaluating the safety of shellfish harvesting areas. Water criteria were then stated as:

(1) the area is sufficiently removed from major sources of pollution so that the shellfish would not be subjected to fecal contamination in quantities which might be dangerous to the public health,

(2) the area is free from pollution by even small quantities of fresh sewage, and

(3) bacteriological examination does not ordinarily show the presence of the coli-

aerogenes group of bacteria in 1cc dilution of the growing area water.

These standards have been generally proven effective in preventing major outbreaks of disease transmitted by the fecal-oral route, and the bacteriological standards have been updated several times.

In addition to pathogenic microorganisms, poisonous or deleterious substances may enter shellfish growing areas via industrial or domestic waste discharges, seepage from waste disposal sites, agricultural land, or geochemical reactions. The potential public health hazard posed by these substances must also be considered in assessing the safety of shellfish growing areas.

The probable presence or absence of pathogenic microorganisms in shellfish waters is important in deciding how shellfish obtained from an area may be used. All actual and potential growing waters should thus be classified according to the information developed in the sanitary survey. Classification should not be revised upward without careful consideration of trends and currently available data. A written sanitary survey report is required with analysis supporting the classification.

The classification in which a growing area is placed dictates how the shellstock from that area may be used (i.e. sold directly to the consumer to eat or required to be subjected to natural or artificial cleansing prior to sale to the consumer). Therefore, the state shellfish control authority (Authority) must make every effort to use the sanitary survey information to determine the correct classification in which to place the growing area to minimize public health risk to the consumer. Any change from a more restrictive growing area classification to a less restrictive classification requires a written sanitary survey report that carefully and thoughtfully evaluates the changes in the information and data supporting the current classification to justify the less restrictive classification.

The status of a growing area is different from its classification. A growing area is generally in the ‘open’ status for harvest subject to the limitations of its classification. When the conditions for the open status are not satisfied, the growing area may be placed in the ‘closed’ status of its classification. For example, in a public health emergency such as deterioration of growing area water quality following a hurricane, a growing area in the approved classification would be placed in the closed status until the water quality is determined to meet the water quality standards for its classification. After a closure, a reevaluation must be made prior to reopening. The growing area would be returned to its open status when the water quality returns to normal provided it continues to meet all other criteria for the approved classification. Some growing areas are so remote that there is no possibility of contamination. If an area qualifies for remote status, less restrictive monitoring requirements are imposed.

Generally speaking, there are five growing area classifications; approved, conditionally approved, restricted, conditionally restricted, and prohibited. *Approved* means that the growing waters meet the bacteriological criteria and other sanitary survey requirements outlined in the NSSP’s MO (see Section 16.4 for more extensive descriptions). *Restricted* is used to identify a growing area where harvested shellstock must be subjected to a suitable and effective treatment process through relaying or depuration. The restricted classification is an option available to the Authority if, through scientific testing, they can demonstrate the product can be cleansed sufficiently. To allow relaying or depuration, the growing area cannot be grossly polluted or only minimally adversely affected by disease agents.

Prohibited is used to identify a growing area where the harvest of shellstock for any purpose, except depletion or gathering of seed for aquaculture, is not permitted. The prohibited classification means that the area does not meet bacteriological criteria and other sanitary survey requirements.

The *conditional* classifications are designed to address growing areas that are subject to intermittent microbiological pollution. This optional classification offers the Authority an alternative to placing an area in the restricted or prohibited classification year round when during certain times of the year or under certain conditions, the shellstock from the growing area may be safely harvested. Public health protection and the control of shellfish safety in the use of conditional classifications are afforded through the use of a management plan.

6.7 Vessel Sewage Discharges and No Discharge Zones

Commercial and recreational boating play important roles in American society. Unfortunately, without proper management, these activities can contribute to water quality degradation. One type of degradation is caused by the discharge of untreated or partially treated human wastes from vessels, which can contribute to high bacteria counts and subsequent increased human health risks. Excessive amounts of nutrients from improperly treated sewage can harm coastal ecosystems by over-stimulating the growth of aquatic plants and algae, decreasing animal and plant diversity, and affecting use of the water for fishing and swimming. Pathogens, which are disease-causing microorganisms such as viruses, bacteria, and protozoans, can enter water bodies through the discharge of inadequately treated sewage from vessels (as well as from other sources such as runoff or inadequately treated effluents from sewage treatment facilities).

Significant environmental impacts to coastal ecosystems occur via direct pollution from vessels. Pollution from recreational, commercial, and military vessels emanates from a variety of sources: including gray water, bilge water, black water (sewage), ballast water, anti-fouling paints, hazardous materials, garbage and other wastes, and the potential introduction of non-indigenous species.

The EPA, USCG, and states work together, under Clean Water Act (Section 312), to protect human health and the aquatic environment from disease-causing microorganisms which may be present in sewage from boats. Section 312 provides states with a tool to protect their citizens and aquatic habitats by regulating vessel sewage discharge. A state can have all or portions of their waters designated as a ‘no-discharge zone’ (NDZ) for vessel sewage to achieve any of the following objectives:

(1) to protect aquatic habitats where pump-out facilities are available;

(2) to protect special aquatic habitats or species; and

(3) to safeguard human health by protecting drinking water intake zones.

Currently, six states have all (or nearly all) of their surface waters designated as NDZs; including: Michigan, Missouri, New Hampshire, New Mexico, Rhode Island, and Wisconsin. In addition, 15 other States have segments of their surface waters designated as NDZs; including Arizona, California, Connecticut, Florida, Georgia, Maryland, Massachusetts, Minnesota, New Jersey, Nevada, New York, North Carolina, South Carolina, Texas, and Utah. Approximately 50% of the NDZs are in fresh water and the other 50% are in salt or estuarine waters.

The EPA now requires a water permit program for pollutant discharges incidental to the normal operation of commercial vessels and recreational boats. Vessel owners or operators whose discharges were previously exempted from Clean Water Act requirements have been required to hold a permit to discharge since September 30, 2008.

6.8 Post Harvest Processing (PHP) for Vibrio Reduction

Industry-implemented post-harvest controls to reduce *V.v.* levels in oyster shellstock may include: time-temperature controls, post harvest processing (i.e. hydrostatic pressure, cool pasteurization, IQF/frozen storage, and irradiation), rapid chilling, and other emerging technologies. More information on PHPs is provided in Section 9.5.4.

6.9 Emergent Technologies for Detection of Pathogens and Toxins

Methods for detection of both pathogenic disease (viral and bacterial) as well as toxins are evolving rapidly. In the 2007 version of the NSSP, most methods for detection of pathogens were still modifications of culture or plate methodology dating to the 1970s or earlier. Toxin analysis was by either mouse bioassay or HPLC. In that version, there are mentions of newer technologies. One method relied on gene probes and a second on polymerase chain reaction (PCR) for amplification of genome-specific DNA. Details are limited and the reader is referred to other sources for a description of the methodology. For example, in the section Approved National Shellfish Sanitation Program Laboratory Tests: Microbiological and Biotoxin Analytical Methods the plan contains the following footnote “PCR methods as they are listed in Chapter 9 of the FDA Bacteriological Analytical Manual, 7th Edition, May 2004 revision, or a method that a State can demonstrate is equivalent”, indicating the methodology had interim approval. The FDA online version (www.fda.gov) has been available since at least 2009 and has an extensive list of methodologies and links to their references and includes overviews of methodologies for 18 specific pathogens and 3 microbial toxins, many of which may have applicability to shellfish in general or oysters specifically.

An increase in the use of biochemical methodology occurred in the late 1980s focusing on such diseases as *Vibrio vulnificus* (Morris et al. 1987, Brauns et al. 1991, McCarthy et al. 1999a, 1999b) and *Salmonella* spp. (Knight et al. 1990). The PCR method has progressed from an ability to detect presence:absence to one where quantitative estimates of abundance can occur. Real-Time quantitative PCR (RT-PCR or qPCR) can be used to estimate the quantity of DNA in a sample, from which the abundance of organisms of interest can be estimated. Nordstrom et al. (2007) describe a method for measuring not only *V. parahaemolyticus* but that could differentiate even specific, pathogenic strains from non-pathogenic strains. An alternate to the traditional plate method and newer PCR method is colony overlay procedure for peptidases (Richards et al. 2005). PCR has also been adapted to assessment of hepatitis A in clams (Goswami et al. 1993) and oysters (Rigotto et al. 2010), and for detection of *Cyclospora* and *Cryptosporidium.* Similar advances in detection of toxins have occurred via techniques such as electrophoresis and immunoassays. For a more complete description of these above mentioned assays and many others beyond the scope of this review, one should start with the FDA website (www.fda.gov).

7.0 FISHERY MANAGEMENT JURISDICTIONS, LAWS, AND POLICIES AFFECTING THE STOCK(S)

Oysters occupy various habitats depending upon the physiological requirements of each particular life history stage; however, the oyster fishery targets predominantly adults within the territorial sea and internal waters of the Gulf States. Numerous state and federal regulations have been promulgated to protect oysters and their habitat.

Various federal agencies, through their administration of laws, regulations and policies, may affect the oyster fishery, but actual management is accomplished by individual state regulations. The following is a partial list of some of the more important agencies and regulations that affect oysters and their habitat. State agencies should be consulted for specific and current state laws and regulations.

7.1 Federal

7.1.1 Management Institutions

Since virtually all known oyster populations occur in state waters, federal agencies do not directly manage oysters. However, a variety of federal agencies, through their administration of laws, regulations, and policies, may influence oyster quality and abundance.

7.1.1.1 Regional Fishery Management Councils

With the passage of the Magnuson Fishery Conservation and Management Act (MFCMA), the federal government assumed responsibility for fishery management within the Exclusive Economic Zone (EEZ), a zone contiguous to the territorial sea and whose inner boundary is the outer boundary of each coastal state. The outer boundary of the EEZ is a line 200 nautical miles from the (inner) baseline of the territorial sea. Management of fisheries in the EEZ is based on FMPs developed by regional fishery management councils. Each council prepares plans for each fishery requiring management within its geographical area of authority and amends such plans as necessary. Plans are implemented as federal regulation through the U.S. Department of Commerce (DOC).

The councils must operate under a set of standards and guidelines, and to the extent practicable, an individual stock of fish shall be managed as a unit throughout its range. Management shall, where practicable, promote efficiency, minimize costs, and avoid unnecessary duplication (MFCMA Section 301a).

The GMFMC has not developed a management plan for oysters. Furthermore, there is no significant fishery for oysters in the EEZ of the United States Gulf of Mexico.

7.1.1.2 National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Department of Commerce (DOC)

The Secretary of Commerce, acting through the NMFS, has the ultimate authority to approve or disapprove all FMPs prepared by regional fishery management councils. Where a council fails to develop a plan, or to correct an unacceptable plan, the Secretary may do so. The NMFS also collects data and statistics on fisheries and fishermen. It performs research and conducts management authorized by international treaties. The NMFS has the authority to enforce the MFCMA and Lacey Act and is the federal trustee for living and nonliving natural resources in coastal and marine areas.

The NMFS exercises no management jurisdiction other than enforcement with regard to oysters in the Gulf of Mexico. It conducts some research and data collection programs and comments on all projects that affect marine fishery habitat.

The DOC, in conjunction with coastal states, administers the National Estuarine Research Reserve and National Marine Sanctuaries Programs as authorized under Section 315 of the Coastal Management Act of 1972. Those protected areas serve to provide suitable habitat for a multitude of estuarine and marine species and serve as sites for research and education activities relating to coastal management issues.

7.1.1.3 Office of Ocean and Coastal Resource Management (OCRM, NOAA)

The OCRM asserts management authority over marine fisheries through the National Marine Sanctuaries Program. Under this program, marine sanctuaries are established with specific management plans that may include restrictions on harvest and use of various marine and estuarine species. Harvest of oysters could be directly affected by such plans.

The OCRM may influence fishery management for oysters indirectly through administration of the Coastal Zone Management Program and by setting standards and approving funding for state coastal zone management programs. These programs often affect estuarine habitat on which osyters depend.

7.1.1.4 National Park Service (NPS), Department of the Interior (DOI)

The NPS under the DOI may regulate fishing activities within park boundaries. Such regulations could affect the harvest of oysters if implemented within a given park area. The NPS has regulations preventing commercial fishing within one mile of the barrier islands in the Gulf Islands National Seashore off Mississippi, Padre Island National Seashore in Texas, and in regulating various fishing activities in Everglades National Park in Florida.

7.1.1.5 United States Fish and Wildlife Service (USFWS), DOI

The USFWS has no direct management authority over oysters. The USFWS may affect the management of oysters through the Fish and Wildlife Coordination Act, under which the USFWS and the NMFS review and comment on proposals to alter habitat. Dredging, filling, and marine construction are examples of projects that could affect oysters and their habitat.

In certain refuge areas, the USFWS may directly regulate fishery harvest. This harvest is usually restricted to recreational limits developed by the respective state. Special use permits may be required if commercial harvest is to be allowed in refuges.

7.1.1.6 United States Environmental Protection Agency (USEPA)

The USEPA, through its administration of the Clean Water Act and the National Pollutant Discharge Elimination System (NPDES), provides protection for oysters and their habitat. Applications for permits to discharge pollutants into estuarine waters may be disapproved or conditioned to protect these marine resources.

The USEPA, individual states and the USCG work together, through the Clean Water Act Section 312, to provide each state with the opportunity to protect its citizens and its aquatic habitats through No Discharge Zone (NDZ) designations and national standards for marine sanitation devices on boat toilets or heads. Section 312 of the Clean Water Act helps protect human health and the aquatic environment from disease-causing microorganisms that may be present in sewage from vessels and boats. There are three distinct kinds of NDZ designations that may be available to an interested state: (1) to protect aquatic habitats where pumpout facilities are available, (2) to protect special habitats or species, and (3) to protect human drinking water intake zones. In all three cases, the interested state petitions the Administrator of USEPA to make the designation official. Upon such a finding, it is left to the state and the USCG, if applicable, to enforce the limits of the NDZ. This means that the discharge of untreated and treated sewage is strictly forbidden and subject to fine if violated. Also, the USCG can use its authority to board vessels to verify that adequate facilities are present in such areas. Currently, areas associated with oyster harvesting can only be designated as NDZs when sufficient pumpout facilities are present in the area to service vessel traffic.

The National Estuary Program is administered jointly by the USEPA and a local sponsor. This program evaluates estuarine resources, local protection and development of policies, and seeks to develop future management plans. Input is provided to these plans by a multitude of user groups including industry, environmentalists, recreational and commercial interests, and policy makers. National Estuary Programs in the Gulf include Sarasota, Tampa, Mobile, Barataria/Terrebonne, Galveston, and Corpus Christi bays.

7.1.1.7 United States Army Corps of Engineers (USACOE)

Oyster populations may be influenced by the USACOE's responsibilities pursuant to the Clean Water Act and Section 10 of the Rivers and Harbors Act. Under these laws, the USACOE issues or denies permits to individuals and other organizations for proposals to dredge, fill, and construct in wetland areas and navigable waters. The USACOE is also responsible for planning, construction, and maintenance of navigation channels and other projects in aquatic areas, and these projects could affect oysters and their habitat.

7.1.1.8 United States Coast Guard

The United States Coast Guard is responsible for enforcing fishery management regulations adopted by the DOC pursuant to management plans developed by the GMFMC. The Coast Guard also enforces laws regarding marine pollution and marine safety, and they assist commercial and recreational fishing vessels in times of need.

Although no regulations have been promulgated for oysters in the EEZ, enforcement of laws affecting marine pollution and fishing vessels could influence oyster populations.

7.1.1.9 United States Food and Drug Administration (FDA)

The FDA directly regulates the harvest and processing of seafood and oysters through its administration of the Food, Drug, and Cosmetic Act and other regulations that prohibit the sale and transfer of contaminated, putrid, or otherwise potentially dangerous foods. The FDA has relegated its enforcement authority for molluscan bivalves to the member states of the ISSC. The FDA does reserve the right and authority to enforce the Food, Drug, and Cosmetic Act and other regulations if the states fail to do so. In addition, the FDA maintains the Interstate Certified Shellfish Shippers List (ICSSL) (www.fda.gov). A principal objective of the ICSSL is to provide a mechanism for state health officials and consumers to receive information as to whether lots of shellfish shipped in interstate commerce meet acceptable sanitation criteria. Dealer certification depends on maintaining acceptable operational and sanitary conditions. This determination is based on nationally uniform inspections by standardized inspectors.

7.1.1.10 United States Customs and Border Protection

Imported seafood and oysters are not legally entered into the United States until the shipment has arrived at a port of entry with the appropriate shipping documents and has been released by the United States Customs and Border Protection.

7.1.1.11 Interstate Shellfish Sanitation Conference (ISSC)

The ISSC is composed of state shellfish regulatory officials, industry officials, FDA, and other federal agencies. One of the foremost goals of the ISSC has been the adoption of the Model Ordinance which embodies the principles and requirements of the Program. Adoption of the Model Ordinance by each of the ISSC participating states implies commitment by each state to provide the necessary legal authority and resources to implement these regulatory requirements. Adoption also ensures uniformity across state boundaries and enhances public confidence in shellfish product.

The purpose of the ISSC is to provide a formal structure for state regulatory authorities to participate in establishing updated regulatory guidelines and procedures for uniform state application of the National Shellfish Sanitation Program (NSSP). The ISSC has adopted formal procedures for state representatives to review shellfish sanitation issues and develop regulatory guidelines. Following FDA concurrence, these guidelines are published in revisions of the NSSP Model Ordinance.

7.1.1.12 National Shellfish Sanitation Program (NSSP)

The NSSP is the federal/state cooperative program recognized by the FDA and the Interstate Shellfish Sanitation Conference (ISSC) for the sanitary control of shellfish produced and sold for human consumption. The purpose of the NSSP is to promote and improve the sanitation of shellfish moving in interstate commerce through federal/state cooperation and uniformity of State shellfish programs. Participants in the NSSP include agencies from shellfish producing and non-producing states, FDA, EPA, NOAA, and the shellfish industry. Under international agreements with FDA, foreign governments also participate in the NSSP. Other components of the NSSP include program guidelines, state growing area classification and dealer certification programs, and FDA evaluation of State program elements. The guidelines of the program have evolved into the NSSP Handbook which is managed and updated by the ISSC.

7.1.2 Treaties and Other International Agreements

Individual Memoranda of Understanding (MOUs) exist with member countries of the NSSP and include Canada, Mexico, Chile, New Zealand, Republic of Korea, and other past member countries. These MOUs are negotiated individually with those countries and the FDA and they are evaluated by FDA shellfish specialists prior to the signing of the MOU and thereafter, routinely (annually or bi-annually) evaluated for compliance. These MOUs specifically address any shellfish that meet the NSSP requirements.

7.1.3 Federal Laws, Regulations, and Policies

The following federal laws, regulations, and policies may directly and indirectly influence the quality, abundance, and ultimately the management of oysters.

7.1.3.1 Magnuson Fishery Conservation and Management Act of 1976 (MFCMA); Magnuson-Stevens Conservation and Management Act of 1996 (Mag-Stevens) and Sustainable Fisheries Act; Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006.

The MFCMA mandates the preparation of FMPs for important fishery resources within the EEZ. It sets national standards to be met by such plans. Each plan attempts to define, establish, and maintain the optimum yield for a given fishery. The 1996 reauthorization of the MFCMA set three new additional national standards to the original seven for fishery conservation and management, included a rewording of standard number five, and added a requirement for the description of EFH and definitions of overfishing.

The 2006 reauthorization builds on the country's progress to implement the 2004 Ocean Action Plan which established a date to end over-fishing in America by 2011, use market-based incentives to replenish America's fish stocks, strengthen enforcement of America's fishing laws, and improve information and decisions about the state of ocean ecosystems.

7.1.3.2 Interjurisdictional Fisheries (IJF) Act of 1986 (P.L. 99-659, Title III)

The IJF established a program to promote and encourage state activities in the support of management plans and to promote and encourage management of IJF resources throughout their range. The enactment of this legislation repealed the Commercial Fisheries Research and Development Act (P.L. 88-309).

7.1.3.3 Federal Aid in Sport Fish Restoration Act (SFRA); the Wallop-Breaux Amendment of 1984 (P.L. 98-369)

The SFRA provides funds to states, the USFWS, and the GSMFC to conduct research, planning, and other programs geared at enhancing and restoring marine sportfish populations.

7.1.3.4 Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), Titles I and III and The Shore Protection Act of 1988 (SPA)

The MPRSA provides protection of fish habitat through the establishment and maintenance of marine sanctuaries. The MPRSA and the SPA acts regulate ocean transportation and dumping of dredged materials, sewage sludge, and other materials. Criteria for issuing such permits include consideration of effects of dumping on the marine environment, ecological systems, and fisheries resources.

7.1.3.5 Federal Food, Drug, and Cosmetic Act of 1938 (FDCA)

The FDCA prohibits the sale, transfer, or importation of "adulterated" or "misbranded" products. Adulterated products may be defective, unsafe, filthy, or produced under unsanitary conditions. Misbranded products may have false, misleading, or inadequate information on their labels. In many instances, the FDCA also requires FDA approval for distribution of certain products.

7.1.3.6 Clean Water Act of 1981 (CWA)

The CWA requires that an USEPA approved NPDES permit be obtained before any pollutant is discharged from a point source into waters of the United States including waters of the contiguous zone and the adjoining ocean. Discharges of toxic materials into rivers and estuaries that empty into the Gulf of Mexico can cause mortality to marine fishery resources and may alter habitats.

Under Section 404 of the CWA, the USACOE is responsible for administration of a permit and enforcement program regulating alterations of wetlands as defined by the act. Dredging, filling, bulk-heading, and other construction projects are examples of activities that require a permit and have potential to affect marine populations. The NMFS is the federal trustee for living and nonliving natural resources in coastal and marine areas under United States jurisdiction pursuant to the CWA.

7.1.3.7 Clean Vessel Act of 1992 (CVA), as amended

The CVA of 1992 (Public Law 102-587) amended the Sport Fish Restoration Act (SFR), commonly referred to as the Dingell-Johnson (DJ) Act. The original SFR Act was passed on August 9, 1950. The 1992 amendment to the SFR Act established a five year federal grant program and provided $40 million out of the Aquatic Resources Trust Fund for the CVA Program.

The CVA Grant Program provides grant funds to the states, the District of Columbia and insular areas for the construction, renovation, operation, and maintenance of pumpout stations and waste reception facilities for recreational boaters and also for educational programs that inform boaters of the importance of proper disposal of their sewage. The governmental agency designated by each respective governor is eligible to participate in the CVA Program. The governmental agency may partner with local governments, private marinas, and others to fund eligible projects.

7.1.3.8 Federal Water Pollution Control Act of 1972 (FWPCA) and MARPOL Annexes I and II

Discharge of oil and oily mixtures is governed by the FWPCA and 40 Code of Federal Regulations (CFR), Part 110, in the navigable waters of the United States. Discharge of oil and oily substances by foreign ships or domestic ships operating or capable of operating beyond the United States territorial sea is governed by MARPOL Annex I.

MARPOL Annex II governs the discharge at sea of noxious liquid substances primarily derived from tank cleaning and deballasting. Most categorized substances are prohibited from being discharged within 22 km of land and at depths of less than 25 m.

7.1.3.9 Coastal Zone Management Act of 1972 (CZMA), as amended

Under the CZMA, states receive federal assistance grants to maintain federally-approved planning programs for enhancing, protecting, and utilizing coastal resources. These are state programs, but the act requires that federal activities must be consistent with the respective states' CZM programs. Depending upon the individual state's program, the act provides the opportunity for considerable protection and enhancement of fishery resources by regulation of activities and by planning for future development in the least environmentally damaging manner.

7.1.3.10 Endangered Species Act (ESA) of 1973, as amended (P.L. 93-205)

The ESA provides for the listing of plant and animal species that are threatened or endangered. Once listed as threatened or endangered, a species may not be taken, possessed, harassed or otherwise molested. It also provides for a review process to ensure that projects authorized, funded or carried out by federal agencies do not jeopardize the existence of these species or result in destruction or modification of habitats that are determined by the Secretary of the DOI to be critical.

Oysters in the U.S. Gulf of Mexico are neither endangered nor threatened, although an ESA review of oysters throughout its range was recently undertaken by NMFS. Furthermore, present fishing activities for oysters are not known to adversely affect any threatened or endangered species.

7.1.3.11 National Environmental Policy Act of 1970 (NEPA)

The NEPA requires that all federal agencies recognize and give appropriate consideration to environmental amenities and values in the course of their decision-making. In an effort to create and maintain conditions under which man and nature can exist in productive harmony, the NEPA requires that federal agencies prepare an environmental impact statement (EIS) prior to undertaking major federal actions that significantly affect the quality of the human environment. Within these statements, alternatives to the proposed action that may better safeguard environmental values are to be carefully assessed.

7.1.3.12 Fish and Wildlife Coordination Act of 1958

Under the Fish and Wildlife Coordination Act, the USFWS and NMFS review and comment on fish and wildlife aspects of proposals for work and activities sanctioned, permitted, assisted, or conducted by federal agencies that take place in or affect navigable waters, wetlands, or other critical fish and wildlife habitat. The review focuses on potential damage to fish, wildlife, and their habitat; therefore, it serves to provide some protection to fishery resources from activities that may alter critical habitat in nearshore waters. The act is important because federal agencies must give due consideration to the recommendations of the USFWS and NMFS.

7.1.3.13 Fish Restoration and Management Projects Act of 1950 (P.L. 81-681)

Under this act, the DOI is authorized to provide funds to state fish and game agencies for fish restoration and management projects. Funds for protection of threatened fish communities that are located within state waters could be made available under the act.

7.1.3.14 Lacey Act of 1981, as amended

The Lacey Act prohibits import, export, and interstate transport of illegally taken fish and wildlife. As such, the act provides for federal prosecution for violations of state fish and wildlife laws. The potential for federal convictions under this act with its more stringent penalties has probably reduced interstate transport of illegally possessed fish and fish products.

7.1.3.15 Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or "Superfund")

The CERCLA names the NMFS as the federal trustee for living and nonliving natural resources in coastal and marine areas under United States jurisdiction. It could provide funds for "clean-up" of fishery habitat in the event of an oil spill or other polluting event.

7.1.3.16 MARPOL Annex V and United States Marine Plastic Research and Control Act of 1987 (MPRCA)

MARPOL Annex V is a product of the International Convention for the Prevention of Pollution from Ships, 1973/1978. Regulations under this act prohibit ocean discharge of plastics from ships; restrict discharge of other types of floating ship's garbage (packaging and dunnage) for up to 46 km from any land; restrict discharge of victual and other recomposable waste up to 22 km from land; and require ports and terminals to provide garbage reception facilities. The MPRCA of 1987 and 33 CFR, Part 151, Subpart A, implement MARPOL V in the United States.

7.1.3.17 Fish and Wildlife Act of 1956

This act provides assistance to states in the form of law enforcement training and cooperative law enforcement agreements. It also allows for disposal of abandoned or forfeited property with some equipment being returned to states. The act prohibits airborne hunting and fishing activities.

7.1.3.18 National Aquaculture Act (NAA) of 1980, Reauthorization 1985

The NAA in 1980 established national policy to encourage the development of aquaculture in the United States. The National Aquaculture Improvement Act (NAIA) of 1985 designated the U.S. Department of Agriculture (USDA) as the lead federal agency for coordination of federal activities and for dissemination of aquaculture information. Under this act, advisory, educational, and technical assistance is provided to encourage the implementation of aquaculture technology in rehabilitation and enhancement of publicly-owned fish and shellfish stocks, and in the development of private commercial aquaculture enterprises. The Joint Subcommittee on Aquaculture (JSA), established by the NAA, issued the National Aquaculture Development Plan of 1983, recognizing the status of aquaculture (including oyster culture), current technologies, impediments to development, existing programs, recommended programs and actions, and anticipated impacts.

7.2 State Management Organizations

Table 6.1 outlines the various state management institutions and authorities.

7.2.1 Florida

In the state of Florida, there are two organizations responsible for the management of oysters. The Florida Fish and Wildlife Conservation Commission handles commercial fishing licenses and establishes seasons and harvest limits. The Florida Department of Agriculture and Consumer Services handles area closures, harvest area classification, product processing, plant certifications and inspections, monitors water quality in harvest areas, and is responsible for managing public oyster reefs and aquaculture on sovereignty submerged lands.

7.2.1.1 Florida Fish and Wildlife Conservation Commission

Florida Fish and Wildlife Conservation Commission
Division of Marine Fisheries Management
620 South Meridian Street
Tallahassee, Florida 32399
Telephone: (850) 487-0554
www.myfwc.com

The agency charged with the administration, supervision, development, management, and conservation of fish and wildlife resources is the Florida Fish and Wildlife Conservation Commission (FWC). This Commission is not subordinate to any other agency or authority of the executive branch. The administrative head of the FWC is the executive director. Within the FWC, the Division of Marine Fisheries Management is empowered to manage marine and anadromous fisheries in the interest of all people of Florida. The Division of Law Enforcement is responsible for enforcement of all marine resource-related laws, rules, and regulations of the state.

The FWC, a seven-member board appointed by the governor and confirmed by the senate, was created by constitutional amendment in November 1998, effective July 1, 1999. This Commission was delegated rule-making authority over marine life in the following areas of concern: gear specification, prohibited gear, bag limits, size limits, quotas and trip limits, species that may not be sold, protected species, closed areas, seasons, and quality control codes. Florida has habitat protection and permitting programs and a federally-approved CZM program.

7.2.1.1.1 Legislative Authorization

Prior to 1983, the Florida Legislature was the primary body that enacted laws regarding management of oysters in state waters. Chapter 370 of the Florida Statutes, annotated, contained the specific laws directly related to harvesting, processing, etc. both statewide and in specific areas or counties. In 1983, the Florida Legislature established the Florida Marine Fisheries Commission and provided the Commission with various duties, powers, and authorities to promulgate regulations affecting marine fisheries. Title 46, Chapters 46-27 contained regulations regarding oyster. On July 1, 1999 the Florida Marine Fisheries Commission (including the Florida Marine Patrol) and the Florida Game and Freshwater Fisheries Commission were merged into one Commission. Marine fisheries rules of the Florida Fish and Wildlife Conservation Commission are now codified under Chapter 379, Florida Statutes (F.S.) and Chapter 68B, Florida Administrative Code (F.A.C.). Rules regulating oyster harvesting are codified under Chapter 68B-27, F.A.C.

7.2.1.1.2 Reciprocal Agreements and Limited Entry Provisions

7.2.1.1.2.1 Reciprocal Agreements

Florida statutory authority provides for reciprocal agreements related to fishery access and licenses. Florida has no statutory authority to enter into reciprocal management agreements.

7.2.1.1.2.2 Limited Entry

Florida has no statutory provisions for limited entry in the oyster fishery, with the exception of the requirement to obtain an Apalachicola Bay Oyster Harvesting License to harvest oysters from Apalachicola Bay.

7.2.1.1.3 Commercial Landings Data Reporting Requirements

Florida requires wholesale dealers to maintain records of each purchase of saltwater products by filling out a Marine Fisheries Trip Ticket (Chapter 68E-5.002 of the Administrative Code specifies the requirements). Information to be supplied for each trip includes Saltwater Products License number; vessel identification; wholesale dealer number; date; time fished; area fished; county landed; depth fished; gear fished; number of sets; whether a head boat, guide, or charter boat; number of traps; whether aquaculture or lease number; species code; species size; amount of catch; unit price; and total dollar value which is optional. The wholesale dealer is required to submit trip tickets weekly if the tickets contain quota-managed species such as Spanish mackerel; otherwise, trip tickets must be submitted every month.

7.2.1.1.4 Penalties for Violations

Penalties for violations of Florida fish and wildlife laws and regulations are established in Florida Statutes, Section 379.401.

7.2.1.1.5 Annual License Fees

Resident wholesale seafood dealer	
· county	$400.00
· state	550.00
Nonresident wholesale seafood dealer	
· county	600.00
· state	1,111.00
Alien wholesale seafood dealer	
· county	1,100.00
· state	1,600.00

Resident retail seafood dealer	75.00
Nonresident retail seafood dealer	250.00
Alien retail seafood dealer	300.00
Saltwater products license	
· resident-individual	50.00
· resident-vessel	100.00
· nonresident-individual	200.00
· nonresident-vessel	400.00
· alien-individual	300.00
· alien-vessel	600.00
· resident – crew	150.00
· non-resident – crew	600.00
· alien – crew	900.00
Recreational saltwater fishing license	
· Resident	
annual –from vessel or shore	17.00
shore fishing only	9.00
· Nonresident	
three day	17.00
seven day	30.00
annual	47.00
Annual Vessel Registration Fee	vessel specific
Apalachicola Bay Oyster Harvesting License (includes the SPL)	
· Resident	100.00
· Nonresident	500.00

7.2.1.1.6 Laws and Regulations

Florida's laws and regulations regarding the harvest of oysters are statewide. The following discussions are general summaries of laws and regulations, and the FWC should be contacted for more specific information. *The restrictions discussed in this section are current to the date of this publication and are subject to change at any time thereafter.*

Subsection 379.361(2), F.S., provides for the issuance of Saltwater Products Licenses and subsection 379.361(5) provides for the issuance of Apalachicola Bay Oyster Harvesting Licenses. Specific provisions apply to the Apalachicola Bay Oyster Harvesting License, including: no person shall harvest oysters in Apalachicola Bay without a valid license; the Department of Agriculture and Consumer Services shall collect the annual fee; and each person who applies for the license shall attend an educational seminar before receiving the license for the first time.

Subsection 379.362 provides for the sale of wholesale and retail licenses for saltwater products dealers. It is unlawful for any person, firm or corporation to deal in saltwater products without procuring the required dealer licenses.

7.2.1.1.6.1 Size Limits

Minimum size limit is three (3) inches while on the water, except: (1) a 15% tolerance for undersized attached oysters; and (2) a 5% tolerance for undersized oysters. (Rule 68B-27.015)

7.2.1.1.6.2 Gear Restrictions

Oysters may only be harvested by hand or tongs. The use of any dredge, drag, scrape, or other mechanical device is prohibited, except by leaseholders of specific shellfish leases (Rule 68B-27.018 and .020)

7.2.1.1.6.3 Closed Areas and Seasons (Rule 68B-27.019)

Seasons: Closed July 1 through September 30 statewide except:

- Wakulla, Dixie, Levy counties closed June 1 through August 31
- Harvest allowed June 1 through August 31 only in areas specified in 5L-1.003(1) for the Apalachicola Bay system
- Harvest allowed September 1 through May 31 only in areas specified in 5L-1.003(1) for the Apalachicola Bay system

Areas: Harvestable areas are determined by the Department of Agriculture and Consumer Services, Division of Aquaculture through their *SHELLFISH HARVESTING AREA CLASSIFICATION BOUNDARIES AND MANAGEMENT PLANS*.

7.2.1.1.6.4 Quotas and Bag/Possession Limits (Rule 68B-27.014)

Recreational: No person shall harvest in or from state waters more than two bags of oysters per day, nor possess while in or on state waters more than two bags per person or vessel per day.

Commercial: No person shall harvest in or from state waters more than twenty bags of oysters per person or vessel, whichever is less, per day. Except in Apalachicola Bay beginning October 1 through June 30 of the following year, each person harvesting oysters shall be subject to a bag limit of twenty bags and the vessel limit shall be twenty bags times the number of persons aboard harvesting oysters (68B-27.014, F.A.C.).

7.2.1.1.6.5 Other Restrictions

Special restrictions for harvesting oysters from Apalachicola Bay include provisions limiting the number of days per week when oysters can be harvested for commercial purposes (68B-27.017, F.A.C.).

7.2.1.1.7 Historical Changes to Oyster Regulations in Florida

July 7, 1988

Authorizes use of dredges on leased lands in Apalachicola Bay under certain conditions

Prohibits mechanical devices or trawls to harvest oysters from public lands

Allows recreational harvest of oysters in Apalachicola Bay on weekends

Designates production zones for purposes of identifying shellstock containers

Requires washing and shading of oysters

Deletes obsolete restrictions on number of days allowed for commercial harvest of oysters in Apalachicola Bay and allows DNR Executive Director to open the Bay to commercial harvest on Friday, Saturday, and Sunday in certain circumstances

Allows authorized persons other than Marine Patrol officers to check oysters at monitoring stations

Requires that tags remain on oyster bags until contents are processed.

July 1, 1989

Implements the requirement for oyster harvesters in Apalachicola Bay to obtain the Apalachicola Bay Oyster Harvesting License [s.17, ch 89-175, LOF].

April 18, 1990

Reinstates the closure of North Bay in Bay County to all harvest of oysters from June 1 through August 31 each year and allows oysters cultivated from eggs by licensed or lawfully allowed mariculture operations to be possessed and sold at sizes below the minimum size limit for purposes of grow-out to legal size under certain conditions.

March 10, 1991

Establishes a statewide commercial limit of 15 bags daily per person or vessel, whichever is less, except the limit in Levy and Dixie counties is set at 20 bags daily per person or vessel, whichever is less

Sets a statewide recreational daily limit of two bags per person or vessel, whichever is less

Establishes a statewide three inch minimum size limit for oysters with a 15% tolerance for undersized, attached oysters, and a 5% tolerance for undersized, unattached oysters

Requires persons harvesting oysters from areas where monitoring stations are operating to pass through these stations and comply with all Department of Natural Resources requirements for such stations

Prohibits the commercial harvest of oysters in Apalachicola on Friday, Saturday, and Sunday from July 1 through September 30 and on Saturday and Sunday from October 1 through June 30

Prohibits the use of trawls, dredges, drags, scrapes, or other mechanical devices (except ordinary hand tongs) for harvesting oysters, and allows oysters to be harvested by hand, while diving, swimming, leaning from vessels, or wading, and by tongs

Prohibits the harvest of oysters statewide between sunset and sunrise, except where monitoring stations are in operation, in which case harvest is prohibited between 4:00 p.m. and sunrise

Establishes a statewide harvest season for oysters as October 1 through June 30 each year, except that the season in Dixie and Levy counties shall be September 1 through May 31 each year, and Apalachicola Bay shall have a summer harvest season between July 1 and September 30 each year

Exempts certain licensed or lawfully allowed mariculture operations from size limits, bag limits, and seasons by meeting certain criteria

Exempts leaseholders of submerged lands from these rules if pursuant to provisions in valid leases.

November 29, 1993

Establishes a daily commercial harvest limit of 20 bags of oysters statewide

Allows the commercial harvest of oysters, during the October through June "winter season" in Apalachicola Bay, seven days a week from November 16 through June 30

Allows Apalachicola Bay to be closed for health purposes or if the Department of Environmental Protection determines that the harvest of 300 bags of oysters per acre in the Bay is not sustainable.

October 3, 1994

Changes the oyster harvesting season in Wakulla County to occur from September 1 through May 31 each year.

September 13 - December 12, 1994 - APALACHICOLA BAY - Emergency Rule, CH 46ER94-1, F.A.C.

Prohibits the harvest of oysters from Apalachicola Bay from September 13, 1994 through November 13, 1994. Allows commercial fishermen to harvest a daily vessel limit of 10 bushels of oysters on weekdays only from November 14, 1994 through December 12, 1994, and allows recreational fishermen to harvest a daily vessel limit of one bushel of oysters during this period.

June 1, 1999 - APALACHICOLA BAY

Allows the harvest of oysters in Apalachicola Bay on Sundays through Thursdays from July 1 through September 30 each year

Eliminates the commercial vessel bag limit for oysters in Apalachicola Bay from October 1 through June 30 each year.

October 7, 2001

Provides that enforcement of the oyster minimum size limit be conducted on the water only.

September 1, 2005

Changes the Apalachicola Bay winter oyster harvest season from Oct. 1 - June 30 to Sept. 1 - May 31 and the summer season from July 1 - Sept. 30 to June 1 - Aug. 31.

May 18, 2006

Allows oysters to be harvested in Apalachicola Bay for commercial purposes any day of the week during the period beginning on November 16 each year through May 31 of the following year.

7.2.1.2 Florida Department of Agriculture and Consumer Services

Florida Department of Agriculture and Consumer Services
407 South Calhoun Street
Tallahassee, Florida 32399-0800
Division of Aquaculture
1203 Governors Square Blvd, Fifth Floor
Tallahassee, Florida 32301

Division of Law Enforcement
2005 Apalachee Parkway
Tallahassee Florida 32399-6500

7.2.1.2.1 Legislative Authorization

Chapter 570.07, Florida Statutes, provides the broad scope responsibilities for the Department of Agriculture and Consumer Services relating to the regulation of agriculture, including aquaculture and molluscan shellfish. Section 570.61, F.S., provides the powers and duties of the Division of Aquaculture, including: administering the aquaculture certification program; enforcing shellfish sanitation standards, administering shellfish and aquaculture lease programs ensuring that shellfish processing facilities comply with applicable food safety requirements; and mitigating, creating, and enhancing natural shellfish harvesting areas.

The Department of Agriculture and Consumer Services is the lead agency in encouraging the development of aquaculture, and Chapter 597.003, F.S., provides the powers and duties of the Department relating to aquaculture and aquaculture products. Section 597.010, F.S., provides regulations for shellfish, and subsection 597.010(14), F.S., provides that the Department shall improve, enlarge, and protect the natural oyster and clam reefs and beds of the state. Section 597.020, F.S., authorizes the Department to license, certify, inspect, and regulate shellfish processors, including sanitation, handling, processing, packaging, and storing oysters.

Chapter 379.361(5), F.S., provides that the Department of Agriculture and Consumer Services is responsible for issuing Apalachicola Bay Oyster Harvesting License, and includes the qualifications, fees, and requirements of the license.

The Board of Trustees of the Internal Improvement Trust Fund is responsible for the acquisition, administration, management, control, supervision, conservation, protection, and disposition of all state-owned lands and submerged lands held in the public trust. Subsection 253.002 (1), F.S., provides that the Department of Agriculture and Consumer Services shall perform, on behalf of the Board, the staff duties and functions related to use and management of sovereignty submerged lands for aquacultural purposes. Section 253.68, F.S., provides the authority to lease or use sovereignty submerged lands and the water column for aquaculture activities. Such leases or authorizations may permit the use of state-owned submerged lands for the commercial cultivation of oysters.

7.2.1.2.2 Harvest Area Classification (BAES)

Coastal waters are classified by the Florida Department of Agriculture and Consumer Services, Division of Aquaculture, Bureau of Aquaculture Environmental Services, Shellfish Environmental Assessment Section (SEAS) based on sanitary, hydrographic, meteorologic and bacteriological surveys. Sanitary surveys identify waters where contaminants may be present in amounts that present a health hazard; hence, should not be open to harvest. The bacteriological survey identifies waters meeting National Shellfish Sanitation Program (NSSP) fecal coliform standards. A comprehensive shellfish harvesting area survey is written for each shellfish harvesting area to document the methods and findings of these surveys, as well as proposed changes in classification and management. NSSP guidelines require that these reports be maintained annually, reevaluated every three years, and resurveyed every 12 years. Areas that do not comply with sanitary requirements are to be immediately reclassified or closed. The comprehensive shellfish harvesting area survey is the basis for a draft amendment to the Comprehensive Shellfish Control Code, Chapter 5L-1, Florida Administrative Code for reclassification of an area. The following summarizes routine administrative procedures applied to amending a rule generated by the Division and submitted for approval. A notice containing the date, time, location, and purpose of a public workshop is advertised and mailed to interested parties. A workshop is conducted on the proposed reclassification to distribute information and receive comment from the shellfish industry and local and state officials. Recommendations consistent with the NSSP are incorporated into a final draft survey and amendment. The final draft amendment and the date, time, location, and purpose of a public hearing are advertised and mailed to interested parties. A public hearing is conducted, if requested within 21 days of the advertisement. Recommendations received during the 21-day advertisement period that are consistent with the NSSP are incorporated into the survey and amendment. An economic impact statement prepared by the Department is incorporated into a final draft amendment. The amendment is submitted for Department certification. Unless challenged within 21 days after filing, the proposed reclassification becomes effective a minimum of 20 days after the amendment is filed with the Secretary of State.

Waters are classified for harvest of shellfish as Approved, Conditionally Approved, Restricted, Conditionally Restricted, Prohibited and Unclassified (= Unapproved) as defined by the ISSC in the Model Ordinance (see Appendix 16.5.3 for complete definitions).

7.2.1.2.3 Processing Plant Certifications and Inspections (BAES)

Processing plants are licensed and inspected by the Florida Department of Agriculture and Consumer Services, Division of Aquaculture, Bureau of Aquaculture Environmental Services, Processing Plant Inspection Section based on provisions of the National Shellfish Sanitation Program (NSSP). Regulations are found in the Comprehensive Shellfish Control Code, Chapter 5L-1, Florida Administrative Code. The following summarizes routine administrative procedures applied to amending a rule generated by the Division and submitted for approval. A notice containing the date, time, location, and purpose of a public workshop is advertised and mailed to interested parties. A workshop is conducted on the proposed regulation to distribute information and receive comment from the shellfish industry and local and state officials. Recommendations consistent with the NSSP are incorporated into a final draft amendment. The final draft amendment and the date, time, location, and purpose of a public hearing are advertised and mailed to interested parties. A public hearing is conducted, if requested within 21 days of the advertisement. Recommendations received during the 21-day advertisement period that are consistent with the NSSP are incorporated into the survey and amendment. An economic impact statement prepared by the Department is incorporated into a final draft amendment. The amendment is submitted for Department certification. Unless challenged within 21 days after filing, the proposed reclassification becomes effective a minimum of 20 days after the amendment is filed with the Secretary of State.

7.2.1.2.4 Water Quality Monitoring (BAES)

The Shellfish Environmental Assessment Section (SEAS) in the Bureau of Aquaculture Environmental Services is responsible for classifying and managing Florida shellfish harvesting areas. The goal of shellfish harvesting area classification and management is to provide maximum utilization of shellfish resources and to reduce the risk of shellfish-borne illness. SEAS headquarters is located in Tallahassee; its FDA certified shellfish laboratory is located in Apalachicola. The section is responsible for the 1,200 bacteriological sampling stations in 37 shellfish harvesting areas, encompassing 1,445,833 acres.

7.2.1.2.5 Resource Management (Bureau of Aquaculture Development - BAD)

7.2.1.2.5.1 Managing Public Oyster Reefs

The Florida Department of Agriculture and Consumer Services and predecessor agencies have been involved in rehabilitating oyster reef habitat for more than 60 years. Throughout this time, oyster resource management has primarily focused on projects to support and sustain oyster fisheries, while the ecological value of restored reefs has been accepted as an added public benefit. The Division of Aquaculture provides a multi-dimensional approach to oyster resource development that has been built on decades of experience in oyster reef restoration. Currently, the Division deposits about 250,000 bushels of processed oyster shell and fossil oyster shell annually to rehabilitate public oyster reefs as part of an ongoing oyster resource development program. The Division designs and constructs oyster habitat that is compatible with Florida's diverse estuarine systems which supports self-sustaining oyster reef communities and performs essential ecological services.

Successful oyster reef restoration requires a multidimensional approach to ensure that all of the critical components are considered, including: the biological, environmental, hydrological, and physical parameters. The Division provides a single active unit with the infrastructure in place to effectively complete an oyster reef construction project. This working unit offers capability, experience, and efficiency that translate to increased cost-effectiveness, providing more reef habitat for the available funds.

The Division's oyster culture program is assisted by laws which mandate that the Department improve, enlarge, and protect public oyster reefs and which declare that 50% of all shells from oysters and clams shucked commercially in the state shall be the property of the Department when the shell is needed for cultch planting operations{597.010(23), F.S.}.

Productive oyster reefs provide numerous ecological benefits, including increased fishery and wildlife habitat, increased species diversity, and complex trophic dynamics. Additionally, functioning oyster populations provide numerous ecosystem services, including: filtering capacity to maintain water quality; structural stability to reduce coastal erosion and to protect nearshore resource values; and nutrient recycling. Functioning oyster reefs are recognized as an essential component in stabilizing and sustaining ecological relationships in estuarine ecosystems.

7.2.1.2.5.2 Relaying and Transplanting Programs

Relaying and transplanting provide management options to restore shellfish resources to offset losses of productive reef habitat resulting from sedimentation, adverse environmental conditions, catastrophic events such as hurricanes and floods, and over harvesting. Relaying is the term used to describe the operation of relocating adult shellfish from waters that are classified as Restricted or Conditionally Restricted to waters that are approved for shellfish harvesting. Relaying takes advantage of productive oyster reefs that are located in waters where harvesting for direct-to-market sales are prohibited to avert public health problems associated with actual or potential pollution. Tremendous quantities of oysters are located in restricted areas where they are lost to the fishery, unless they can be relocated to approved harvesting areas. In Florida, the most practical method of moving oysters to approved harvesting areas is by hand tonging or picking up by hand

and transporting the oysters by shallow draft vessels. Relaying involves the replanting of oysters on public reefs where harvesting can be prevented until the shellfish are allowed adequate time to cleanse themselves. Relaying is most often accomplished during closed harvesting seasons.

Resource development projects that require relaying take advantage of oysters' ability to cleanse themselves of contaminants (depurate) and offer a practical means to use a previously debilitated resource. Because oysters filter a large volume of water while they are feeding and respiring, they are capable of concentrating waterborne contaminants that may be of serious public health concern. However, this process can be reversed, and oysters will rid themselves of contaminants when they are placed in waters with good water quality. Therefore, when oysters are removed from waters classified as Restricted or Conditionally Restricted and relocated into waters that are approved for shellfish harvesting, they eventually depurate and become safe for consumption. Since relaying requires removing oysters from potentially polluted waters, stringent oversight and supervision are required to ensure that program guidelines are followed and public health is protected. Chapter 5L-1, F.A.C. provides for the regulation and control of relaying.

Likewise, transplanting projects take advantage of abundant supplies of juvenile oysters from reefs that are located in waters that are not favorable for oyster growth and survival. Numerous intertidal reefs in many coastal areas support high concentrations of juvenile oysters, but overcrowding reduces growth and survival. When oysters are removed from these sources and relocated to public reefs where water quality is favorable for growth and survival, wholesome oysters can be harvested for market in a short time.

Similar to relaying, transplanting involves moving seed, juvenile, and adult oysters from various locations to public reefs where environmental conditions are more favorable for growth and survival to marketable size. Unlike relaying, transplanting takes advantage of oysters that are in waters that are classified as Approved or Conditionally Approved. Relocating oysters in transplanting projects does not present the same public health concerns as relocating oysters in relaying projects. Many of Florida's productive estuaries and coastal waters contain numerous oyster reefs where juvenile and subadult oysters are abundant. However, oyster populations on many reefs, particularly intertidal reefs, are subjected to overcrowding and rigorous environmental conditions that adversely affect their growth and survival. When oysters are transplanted onto reefs where environmental conditions are more favorable, they may grow rapidly to marketable size. Transplanting takes advantage of this available resource that would otherwise not be harvested.

Staff works cooperatively with local oystermen to identify the sites where oysters will be relocated. Reefs are selected based on historical productivity, degree of depletion, hydrography, substrate characteristics, and environmental water quality. Cooperative resource development projects depend on the participation of local oystermen's associations. These associations act as contractors and are responsible for recruiting project participants, paying the participants, and for keeping records. The associations are paid a flat price per bushel of oysters delivered, and in turn pay the oystermen a flat price per bushel delivered and retain an overhead fee for administering the contract. This fee is negotiated at a non-profit level so that oystermen are allowed a fair price for their labor and the associations receive a fair price for their services.

Participation by local oystermen and their families is critical to the success of these projects. Because the majority of oystermen who are familiar with the local waters belong to local associations, these associations are the only entities that can guarantee labor for conducting the projects. These projects allow members of the oyster harvesting industry to earn money while participating in resources development programs and again when the oysters are harvested for market. These projects also provide work when harvesting waters are closed for extended periods and allow the industry to participate, first-hand, in oyster resource management.

7.2.1.2.5.3 Aquaculture and Shellfish Leasing Program

Florida has been very progressive in its support of aquacultural development. The Florida legislature and the Governor and Cabinet, sitting as the Board of Trustees of the Internal Improvement Trust Fund ("the Board of Trustees" or the "Board"), have recognized that it is in the state's interest to promote aquacultural production by leasing sovereign submerged lands. The Board of Trustees may authorize the use of sovereignty submerged lands to produce aquacultural products pursuant to the policies provided in Chapter 253, F.S. and Chapter 18-21, Florida Administrative Code (F.A.C). Chapter 253, F.S., provides the authority and conditions for leasing sovereign submerged lands and the water column for the purpose of aquaculture. Subject to the limitations contained in sections 253.67-253.75, F.S., the Board of Trustees may lease submerged lands to which it has title for the conduct of aquaculture activities and grant exclusive use of the bottom and the water column to the extent required by those activities.

In 2000, the Board of Trustees delegated authority to the Commissioner of Agriculture, or his designee, to act on behalf of the Board in authorizing the use of sovereign submerged lands for aquacultural purposes. The Florida Department of Agriculture and Consumer Services is the State's lead aquaculture agency and is responsible for coordinating and assisting in the development of aquaculture statewide. The Department's commitment to developing aquaculture is based on the belief that aquaculture is an integral segment of Florida's agricultural and economic future by providing high quality aquacultural products to worldwide markets while advancing Florida's resource management goals.

In 1999 the Florida Legislature created the Division of Aquaculture within the Department of Agriculture and Consumer Services. The Division conducts numerous activities to promote the development of aquaculture, including administering and managing the shellfish and aquaculture leasing programs. The Division of Aquaculture is also responsible for making sovereign submerged state lands and the overlying water column available for producing aquaculture products. Currently, the Bureau administers 79 shellfish leases containing 1,285 acres and more than 600 aquaculture leases containing about 1,450 acres. Persons wishing to lease submerged lands or the water column to conduct aquacultural activities must submit a written application as prescribed in Chapter 253, F.S., and Chapter 18-21, F.A.C. The Division will provide applicants with an application form, guidelines for completing the application, and a list of steps involved in the application review and approval processes.

7.2.2 Alabama

7.2.2.1 Alabama Department of Conservation and Natural Resources

Alabama Department of Conservation and Natural Resources (ADCNR)
Alabama Marine Resources Division (AMRD)
P.O. Box 189
Dauphin Island, Alabama 36528
Telephone: (251) 861-2882

Management authority of fishery resources in Alabama is held by the Commissioner of the Department of Conservation and Natural Resources. The Commissioner may promulgate rules or regulations designed for the protection, propagation, and conservation of all seafood. He may prescribe the manner of taking, times when fishing may occur, and designate areas where fish may or may not be caught; however, all regulations are to be directed toward the best interest of the seafood industry.

Most regulations are promulgated through the Administrative Procedures Act approved by the Alabama Legislature in 1983; however, bag limits and seasons are not subject to this act. The Administrative Procedures Act outlines a series of events that must precede the enactment of any regulations other than those of an emergency nature. Among this series of events are (a) the advertisement of the intent of the regulation, (b) a public hearing for the regulation, (c) a 35-day waiting period following the public hearing to address comments from the hearing, and (d) a final review of the regulation by a joint house and senate review committee.

Alabama also has the Alabama Conservation Advisory Board (ACAB) that is endowed with the responsibility to provide advice on policies of the ADCNR. The board consists of the governor, the ADCNR commissioner and ten board members.

The AMRD has responsibility for enforcing state laws and regulations, for conducting marine biological research, and for serving as the administrative arm of the commissioner with respect to marine resources. The division recommends regulations to the commissioner.

Alabama has a habitat protection and permitting program and a federally approved CZM program.

7.2.2.1.1 Legislative Authorization

Chapters 2 and 12 of Title 9, Code of Alabama, contain statutes that concern marine fisheries.

7.2.2.1.2 Reciprocal Agreement and Limited Entry Provisions

7.2.2.1.2.1 Reciprocal Agreement Provisions

Alabama statutory authority provides for reciprocal agreements with regard to access and licenses. Alabama has no statutory authority to enter into reciprocal management agreements.

7.2.2.1.2.2 Limited Entry

Alabama has no statutory provisions for limited entry.

7.2.2.1.3 Commercial Landings Data Reporting Requirements

Alabama law required seafood dealers to file trip ticket reports by the tenth of the following month with the Alabama Department of Conservation and Natural Resources. The seafood dealers are required to provide a copy of the trip ticket to the oyster catcher. Both the dealer and catcher are required to sign the trip tickets.

7.2.2.1.4 Penalties for Violations

Violations of the provisions of any statute or regulation are considered a Class C misdemeanor and punishable by fines of $0 to $500 and up to 3 months in jail.

7.2.2.1.5 Annual License Fees

The following is a list of license fees for the harvest of oysters in Alabama waters current to the date of publication; however, they are subject to change at any time. Check with the ADCNR for current license availability and costs.

Resident Commercial Oyster Catcher	$26.00
Nonresident Commercial Oyster Catcher	Varies by State
Resident Oyster Dredge	26.00
Nonresident Oyster Dredge	Varies by State
Resident wholesale seafood dealer	201.00
Nonresident wholesale seafood dealer	Varies by State
Resident wholesale seafood dealer vehicle	101.00
Nonresident wholesale seafood dealer vehicle	101.00

7.2.2.1.6 Laws and Regulations

7.2.2.1.6.1 Minimum Size

Oysters taken for either commercial or personal consumption must be at least three inches in length. A 5% tolerance is allowed for undersized oysters and cultch material for the cargo on hand and no more than 10% of undersize oysters and cultch material in any one sack (AL reg 220-3-.02).

7.2.2.1.6.2 Seasons

The Department of Conservation and Natural Resources and the Department of Public Health are authorized to open and close areas during all parts of the year. Taking oysters from a closed area is a misdemeanor. All public water bottoms not closed by the Health Department or the Director of the AMRD are open to the taking of oysters from 7:00 a.m. to 2:00 p.m. Monday through Friday of each week from January 1 through April 30. All public water bottoms in Alabama are closed to harvest from May 1 through September 30 of each year. Harvesting may resume Monday through Friday from 7:00 a.m. to 2:00 p.m. and Saturdays from 7:00 a.m. to 12:00 noon from October 1 through December 31 (AL reg 220-3-.15).

7.2.2.1.6.3 Fishing Methods and Gear Restrictions

Persons are allowed to take up to 100 oysters for personal consumption without a catcher's license. Oysters may be taken from public reefs and waterbottoms by hand or oyster tongs. Oyster dredges may be used by owners or lessees of private oyster reefs only after purchasing an oyster dredge license and receiving written authorization from the Department of Conservation and Natural Resources. Oyster dredges may be used on public bottoms that have been opened by regulation after obtaining a dredge license, commercial oyster catchers license and a dredge permit. (The time and area to be worked will be specified in the permit). Oysters from public reefs and oysters from private leases can not be on a boat at the same time. Oysters must be culled on the reef from which they are taken.

7.2.2.1.6.4 Leases

Persons, firms, or corporations that desire to lease oyster bottoms shall make application in writing to the commissioner of Conservation and Natural Resources accompanied by such fees as may be prescribed. It is the duty of each such 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 a plat of the area filed with the Division of Marine Resources together with a list of any persons using said lease area.

7.2.2.1.6.5 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 $0.35 each at the Marine Resources Division offices. There is a sixteen (16) sack limit per boat per day of oysters taken from public bottoms.

7.2.2.2 Alabama Department of Public Health

Alabama Department of Public Health (ADPH)
Seafood Branch
4168 Commander's Drive
Mobile, AL 36615

7.2.2.2.1 LegislativeAuthorization

The Alabama State Board of Health is authorized to adopt and promulgate Shellfish Sanitation rules under and by virtue of the authority of §§9-12-126, 22-2-2(6), and 22-20-5, Code of Alabama 1975, and Alabama Administrative Code 420-3-18.

7.2.2.2.2 Harvest Area Classification

Oyster harvesting areas in Alabama waters are classified in accordance with the bacterial water quality standard as established in Rule 420-3-18-.07. *Current approved growing areas should be determined by contacting the ADPH.*

7.2.2.2.3 Processing Plant Certifications and Inspections

The ADPH permits and inspects processing plants for compliance with Alabama Administrative Code 420-3-18-.04, Permits, and AAC 420-3-18-.05, Inspections. An inspection of an oyster processing plant shall be performed at least once each quarter. Additional inspections of an oyster processing plant shall be performed as often as necessary for the enforcement of these rules. Certifications can be suspended or revoked by a state health officer for failure to comply according to rules 420-3-18-.06 and 420-3-18-.07.

7.2.2.2.4 Water Quality Monitoring

The procedures employed in the bacteriological examination of oysters and oyster growing waters are contained in the "Recommended Procedures for the Examination of Sea Water and Shellfish," American Public Health Association, Inc., 1740 Broadway, New York, New York 10019. Rule 420-3-18-.09(5) has been rescinded, Rule 420-3-18-.10 refers to opening and closing criteria for oyster harvesting.

7.2.2.2.5 Shellstock Identification

The ADPH requires proper labeling and recording of shellstock under Rule 420-3-18-.05 and must include the growing area, date of harvest, name and permit number of harvester, or the name and permit number of shipper.

7.2.2.2.6 Sanitation of the Harvesting Processing and Distribution of Shellfish

The document entitled *National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish, 2007 Revision*, promulgated by the U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, is incorporated by reference and made a part of Rule 420-3-18-.09 as if set out in full and all provisions thereof are adopted as a rule of the State Board of Health.

7.2.3 Mississippi

7.2.3.1 Mississippi Department of Marine Resources (MDMR) and Mississippi Commission on Marine Resources (MCMR)

Mississippi Department of Marine Resources
Shellfish Bureau
1141 Bayview Avenue
Biloxi, Mississippi 39530
(228) 374-5000
www.dmr.state.ms.us

Mississippi Commission on Marine Resources
1141 Bayview Avenue, Suite 101
Biloxi, Mississippi 39530
(228) 374-5000
www.dmr.state.ms.us

The MDMR administers coastal fisheries and habitat protection programs. Authority to promulgate regulations and policies is vested in the MCMR, the controlling body of the MDMR. The MCMR consists of five members appointed by the Governor. The MCMR has full power to "manage, control, supervise and direct any matters pertaining to all saltwater aquatic life not otherwise delegated to another agency" (Mississippi Code Annotated 49-15-11).

Mississippi has a habitat protection and permitting program and a federally-approved Coastal Zone Management Program (CZMP). The MCMR is charged with administration of the Mississippi Coastal Program (MCP), which requires authorization for all activities that impact coastal wetlands. Furthermore, the state has an established CZMP approved by NOAA. The CZMP reviews activities that would potentially and cumulatively impact coastal wetlands located above tidal areas. The Executive Director of the MDMR is charged with administration of the CZMP.

7.2.3.1.1 Legislative Authorization

Title 49, Chapter 15 of the Mississippi Code of 1972, annotated, contains the legislative regulations related to harvest of marine species in Mississippi. Chapter 15 also describes regulatory duties of the MCMR and the MDMR regarding the management of marine fisheries. Title 49, Chapter 27 involves the utilization of wetlands through the Wetlands Protection Act and is also administered by the MDMR. Section §49-15-2 was implemented by the Mississippi Legislature on July 1, 1997 and sets standards for fishery management as related to the Magnuson-Stevens Act (1996). Section §49-15-15(1)(c)(as amended) also requires the MCMR to regulate all seafood sanitation and processing programs.

7.2.3.1.2 Reciprocal Agreements and Limited Entry Provisions

7.2.3.1.2.1 Reciprocal Agreements

Section §49-15-15(h) provides statutory authority to the MDMR to enter into or continue any existing interstate and intrastate agreements, in order to protect, propagate, and conserve seafood in the state of Mississippi.

Section §49-15-30(1) gives the MCMR the statutory authority to regulate nonresident licenses in order to promote reciprocal agreements with other states.

7.2.3.1.2.2 Limited Entry

Section §49-15-16 gives the MCMR authority to develop a limited entry fisheries management program for all resource groups.

Section §49-15-29(3) states that, when applying for a license of any kind, the MCMR will determine whether the vessel or its owner is in compliance with all applicable federal and/or state regulations. If it is determined that a vessel or its owner is not in compliance with applicable federal and/or state regulations, no license will be issued for a period of one year.

7.2.3.1.3 Commercial Landings Data Reporting Requirements

Title 22, Part 9 of the MCMR establishes data reporting requirements for marine fisheries' operations, including confidentiality of data and penalties for falsifying or refusing to make the information available to the MDMR.

7.2.3.1.4 Annual License Fees

Mississippi Resident	
Recreational Oyster	$10.00
MS Residents only limit 3 sacks per week	
Commercial Oyster Tonging	60.00
Commercial Oyster Dredging	110.00
Captains License	10.00
Individual licenses required for additional captains on each vessel	
Seafood Dealer	100.00
Seafood Transport	100.00
Interstate Commerce	20.00
Alabama Resident	
Seafood Dealer	250.00
Oyster Tonging	110.00
Captains License	10.00
Florida Resident	
Oyster Tonging	110.00
Oyster Dredging	210.00
Captains License	10.00
Seafood Dealer	1,000.00
Louisiana Resident	
Oyster Tonging	1,110.00
without Mississippi Shrimp License	
Oyster Dredging	1,070.00
without Mississippi Shrimp License	
Oyster Tonging	640.00
with Mississippi Shrimp License	
Oyster Dredging	600.00
with Mississippi Shrimp License	
Captains License	10.00
Louisiana Resident Seafood Dealer	1,150.00
Louisiana Seafood Dealer Vehicle	30.00
Texas Resident	
Oyster Tonging	110.00

Oyster Dredging	210.00
Captains License	10.00
Seafood Dealer	200.00
All Other States	
Oyster Tonging	110.00
Oyster Dredging	210.00
Seafood Dealer	200.00

7.2.3.1.5 Laws, Regulations, and Penalties for Violations

Section §49-15-63 provides penalties for violations of Mississippi laws and regulations regarding oysters in Mississippi.

7.2.3.1.5.1 Night Harvesting of Oysters

Section §49-15-41 states that it shall be unlawful for any person to fish, catch, or take oysters from any of the oyster reefs in the State of Mississippi by the use of any tongs, dredge, rake, or other mechanical device, during the hours between sunset and sunrise of each day. Violation of this section shall be punishable by a fine not to exceed $10,000.00 and/or up to one year in the county jail.

7.2.3.1.5.2 Sale or Possession of Illegal Oysters

Section §49-15-44 provides that the MCMR shall prohibit the sale or possession of illegal oysters. It is unlawful for any person, firm, or corporation to possess or to engage in the sale of oysters not certified in this state, or to shuck or repack for sale any illegal oysters, unless that person, firm, or corporation possesses a bill of sale, valid permit or affidavit of another state, properly dated, evidencing the legality of the sale or possession of the oysters in that state. Any person in possession of illegal oysters shall be subject to civil or criminal prosecution and shall be fined not less than $100.00 or punished as provided in Section 49-15-63.

7.2.3.1.5.3 Dredging limits; reefs reserved for tonging; penalties

Section §49-15-39 has provisions for protection of tonging reefs from dredging. It is unlawful for any person to catch or take oysters by means of dredging in any of the waters designated as tonging reefs by the MCMR. The MCMR shall designate certain areas as tonging reefs. A violation of this section is punishable by a fine of $500.00. For a second offense, when the offense is committed within a period of three years from the first offense, the violation is punishable by a fine of $1,000.00. For a third or subsequent offense, when the offense is committed within a period of three years from the first offense, the violation is punishable by a fine of $2,000.00. In addition, upon conviction of a third or subsequent offense within three years of the first offense, it shall be the duty of the court to revoke the license of the convicted party and of the vessel used in the offense, and no license shall be issued to that person or for the vessel to engage in the catching or taking of any seafood from the waters of this state for a period of one year following the conviction.

7.2.3.1.5.4 Municipality Authority to Enforce Oyster Laws

Section §49-15-45 provides that any municipality bounded by the Gulf of Mexico or Mississippi Sound, which has wholly or partly within its corporate limits, or in the waters adjacent thereto, a public oyster reef reserved for catching oysters exclusively by use of hand tongs, is hereby authorized to aid and cooperate with the MCMR in enforcing all laws regulating the catching, taking, and transporting of oysters, including all of the provisions of this chapter, and all regulations and ordinances of such commission relating to such oyster reefs.

In carrying out the provisions of this section such municipality may purchase, equip, and maintain a suitable patrol boat and employ and pay the salaries of a crew to operate same and officers to enforce such laws and ordinances and neither prosecutions nor convictions by such municipality shall bar further prosecution and conviction by the MCMR or its officers for the same offense. All fines collected by such municipality in enforcing the provisions of this chapter shall be paid into the general fund of the municipality and all costs and expenses incurred in connection with this chapter shall be paid out of the general fund of the municipality. The authority vested in such municipality under this section shall be limited to enforcement of statutes passed by the Legislature and ordinances and regulations adopted by the MCMR.

7.2.3.1.5.5 Size Limits

Except for oysters legally harvested on private lease sites, it shall be unlawful for any person, firm, or corporation to take from the reefs of this state any oysters that measure less than three inches from the hinge of the oyster to its bill. It shall be unlawful to fail to immediately cull and return all dead shells, small oysters, and oysters in excess of the daily sack limits. It shall be unlawful for any person, firm, or corporation to purchase, sell, or have in his possession or under his control any unculled and undersized oysters taken from the public reefs. There is a

10% tolerance of undersized oysters, by number, that shall be allowed in relation to any culling.

7.2.3.1.5.6 Closed Areas and Seasons

The MCMR shall set the opening date of oyster season in an Opening Order at a regularly scheduled meeting which includes the date for season opening, the shellfish growing areas to open, the check-in and check-out stations and alternate stations, sack limits, and any necessary regulations relating to shellfish harvesting, processing and distribution. A notice of the opening date shall be published in a newspaper or newspapers having general circulation in the three coastal counties. Opening and closing of shellfish growing area waters and oyster reefs shall be by issuance of a legal notice signed by the MCMR or as hereby authorized the MDMR, its Executive Director, Director of Marine Fisheries, Program Coordinator or other MDMR designee thereof. The Executive Director of the MDMR is authorized to close any area to harvest when necessary to conserve the resource.

When sampling data indicate this time frame sequence is not adequate to protect public health in a reef area, said area may be closed immediately and any oysters or other shellfish taken from said area may be required to be returned to the water. If closure is necessitated by any other polluting event, which threatens imminent peril to public health, closure will be immediate and any oysters or other shellfish taken which have been subjected to such pollution as determined by the MDMR shall be returned to the water.

During any closure of a conditionally approved area the MDMR will sample closed areas in accordance with the respective Management Plan and state statute.

7.2.3.1.5.7 Quota and Bag/Possession Limits

The MCMR has authority to set and modify sack limits in conjunction with an Opening Order and at any time during the season. The Executive Director of the MDMR is authorized to close any area to harvest when necessary to conserve the resource and modify sack limits as appropriate.

7.2.3.1.6 Public Health and Product Safety

Section §49-15-15(1)(c)(as amended) requires the MCMR to regulate all seafood sanitation and processing programs.

Unlike other states, the Mississippi State Department of Health plays no role in monitoring and controlling shellfish growing areas. All responsibilities for seafood sanitation and processing outlined below are addressed by the MDMR.

7.2.3.1.6.1 Designation of Harvest Areas and Classification

The MDMR shall manage and maintain a Management Plan for Shellfish Growing Waters and harvesters' operations according to the relevant specifications stated in the Model Ordinance of the National Shellfish Sanitation Program (NSSP). The plan includes opening and closing criteria for all shellfish growing area waters and their classification in accordance with relevant NSSP or ISSP growing waters (see Section 16.4 for growing area definitions).

7.2.3.1.6.2 Processing Plant Certifications and Inspections

The MCMR is required by Section §49-15-15(1)(c)(as amended) to regulate all seafood sanitation and processing programs.

7.2.3.1.6.3 Water Quality Monitoring

Under Section §49-15-36, the MCMR shall promulgate regulations regarding the closing of oyster reefs to protect the public health in accordance with the NSSP. The waters of reefs closed under this chapter shall be tested between five and ten days after closure. When that testing indicates the oysters on the closed reef are suitable for consumption, the reef shall be opened for the taking of oysters as soon as notice of that opening may be made to interested parties. The authority to open or close oyster reefs under this chapter shall be solely within the discretion of the MCMR, acting through the MDMR.

7.2.3.1.7 Resource Management

7.2.3.1.7.1 Projects to Create or Establish New Oyster Beds and Culling Requirements

Section §49-15-38 establishes requirements for the collection and planting of shells and the penalties and fees for failure to deliver shells.

The MCMR is authorized to acquire and replant shells, seed oysters, and other materials, when funding is available, for the purpose of growing oysters. A shell retention fee is collected to be used to buy and plant shells to refurbish the oyster reefs. Any person, firm, or corporation failing or refusing to pay the shell retention fee required under Section 49-15-46 to the MDMR when called for by the MDMR, is guilty of a misdemeanor and, upon conviction, shall be fined not more than $100.00 for each barrel of shells for which they fail or refuse to tender the shell retention fee. In addition to the fine, the violator shall pay the reasonable value of the oyster shells and shall be ineligible to be licensed for any activity set forth in this chapter for a period of two years from the date of conviction.

The planting of oyster shells as provided under this chapter shall be under the direction and supervision of the Executive Director of the department. The governing authorities of each county and municipality bordering upon the Mississippi Sound may assist the MCMR in the planting of oyster shells.

Section §49-15-40 states that the MCMR may support projects in the nature of digging or constructing canals or ditches to bring additional water to existing oyster reefs or beds in need of that water, or for the purpose of creating or establishing new oyster reefs or beds. All reefs created or established under this section shall be public reefs. The MCMR may expend any monies as it deems necessary and expedient to participate in the digging of those canals. The MCMR may also enter into interstate or intrastate efforts to support these projects and may seek and utilize aid from all federal, state, and local sources in this endeavor. To aid in the construction of any canals or ditches, the MCMR may exercise the right of eminent domain in the manner provided by law.

7.2.3.1.7.2 Molluscan Depuration Facilities

Section §49-15-40 states that the MCMR may construct, operate, and maintain an onshore, molluscan depuration facility using any federal or special funds, other than general funds, for the purpose of testing and proving depuration technology of oysters and other molluscan shellfish. In connection with the construction, operation, and maintenance of the facility, the MCMR may contract with any persons it deems necessary for the operation, testing, maintenance, and evaluation of the facility, subject to the approval of the State Personnel Board. The MCMR may locate the facility on any available public properties, subject to the approval of the governing body of that jurisdiction and all other applicable state laws. Once depuration technology has been tested and proven for oysters, the MCMR may conduct any other tests and experiments with oysters or other shellfish as may be necessary to enhance production or quality of shellfish.

7.2.3.1.7.3 Lease of Water Bottoms

Section §49-15-27 allows the MDMR to lease water bottoms for the growing and harvesting of oysters. Title 22, Part 1 of the MCMR sets forth the specific requirements.

7.2.3.1.7.3.1 Lease Application Requirement

The MDMR shall accept applications for on-bottom leases within the coastal waters of Mississippi restricted to operations using natural shell or other approved cultch material without employing racks or other support structures. Any individual or entity interested in leasing bottoms shall complete a bottom lease application form and submit it to the MDMR Director of Marine Fisheries. Leasing is only available to Mississippi residents, businesses, and entities.

Bottom lease applications must be for five acres or more, but shall not exceed 100 acres and are contiguous. Configured as a square or rectangle with the lease area boundaries meeting at right angles, the lease area cannot be greater than twice the distance of the width of the lease area, and no proposed lease areas will be approved that are within one-quarter nautical mile of an existing lease area or lease area that is pending final approval.

Political subdivisions of the State of Mississippi may lease up to 1,000 acres of bottoms for oyster reef development. Such political subdivisions are authorized to permit residents of the State of Mississippi to harvest shellfish from such reefs and charge and receive a fee for each sack of shellfish harvested if no conflicts exist with sites requested in applications filed prior to the application, a fair and reasonable rental payment has been set, and such a lease will ensure the maximum cultivation and propagation of shellfish.

Additional requirements exist under Title 49, Chapter 19 regarding on-bottom shellfish leasing regulations and the MDMR should be consulted for the most current requirements.

7.2.3.1.7.3.2 Conditions of Leases

All leases granted by the MCMR shall be for a period of one year with the right of the lessee to renew the lease for an additional year, and from year to year, at the same ground rental so long as lessee actively cultivates and gathers shellfish and complies with all provisions specified herein, and all applicable state laws, ordinances, Titles and Parts and public notice requirements, provided that no lease shall be renewed for more than 25 years unless it is rebid. All leases shall expire on April 30 of each year.

Appropriate poles, stakes or buoys, constructed of such material as will not be injurious to watercraft, shall mark all leases at the expense of the leaseholder. Each leaseholder shall mark at least the four corners of each lease with an appropriate marker, list the lease number and marker position on each, and shall maintain all markers in compliance with the U.S. Coast Guard.

All leases made by the MCMR shall be subject to the paramount right of the State of Mississippi and any of its political subdivisions authorized by law, to promote and develop ports, harbors, channels, industrial or recreational projects, freshwater diversion projects, and all such leases shall contain a provision that, in the event such authorized public body shall require the area so leased or any part thereof for such public purposes, that the lease shall be terminated on reasonable notice fixed by the MCMR in such lease.

Additional requirements exist under Title 49, Chapter 15 regarding on-bottom shellfish leasing regulations and the MDMR should be consulted for the most current requirements.

7.2.3.1.7.3.3 Regulations for Relaying Activities

Under Section §49-15-37, all persons or entities other than the MDMR wishing to relay shellfish in the State of Mississippi shall complete and submit a written application for a relaying permit to the MDMR, attn: Biological Program Coordinator. All applicants must hold a valid Mississippi oyster lease, have been a resident for at least five years, and have a valid Mississippi shellfish license. All shellfish harvested from leases after relaying must comply with Mississippi's regulations and all requirements under Title 49, Chapter 15.

Additional requirements exist under Title 49, Chapter 15 regarding oyster relaying regulations and the MDMR should be consulted for the most current requirements.

7.2.4 Louisiana

7.2.4.1 Louisiana Department of Wildlife and Fisheries

Louisiana Department of Wildlife and Fisheries (LDWF)
P.O. Box 98000
Baton Rouge, Louisiana 70898
Telephone: 225-765-2370

The LDWF is one of the major administrative units of the Louisiana government. A seven-member board, the Louisiana Wildlife and Fisheries Commission (LWFC) is appointed by the Governor. Six of the members serve overlapping terms of six years, and one serves a term concurrent with the Governor. The LWFC is a policy-making board with no administrative functions. The legislature has sole authority to establish management programs and policies; however, the legislature has delegated certain authority and responsibility to the LDWF. The Secretary of the LDWF is the executive head and chief administrative officer of the department and is responsible for the administration, control and operation of the functions, programs and affairs of the department. The secretary is appointed by the Governor with consent of the Senate.

Within the administrative system, an Assistant Secretary is in charge of the Office of Fisheries with assistance from a Deputy Assistant Secretary and Fisheries Division Administrator. Within the Office are several Sections headed by Biologist Directors performing the functions of the state relating to the administration and operation of programs, including research relating to oysters, waterbottoms, and seafood including, but not limited to, the regulation of oyster, shrimp, and marine fishing industries." The Enforcement Division, in the Office of the Secretary, is responsible for enforcing all marine fishery statutes and regulations.

Louisiana has habitat protection and permitting programs and a federally approved CZM program administered by the Louisiana Department of Natural Resources. LDWF is a commenting agency on coastal use permits and consistency determinations under the CZM program.

7.2.4.2 Legislative Authorization

Title 56 Louisiana Revised Statutes contains rules and regulations that govern marine fisheries in the state. Specific statutes for oysters are included in Sections 421 through 452.

7.2.4.3 Reciprocal Agreement and Limited Entry Provisions

7.2.4.3.1 Reciprocal Agreement Provisions

7.2.4.3.1.1 Licenses

The LWFC is authorized to enter into reciprocal fishing license agreements with the proper authorities of any other state.

7.2.4.3.1.2 Management

The LWFC is authorized to enter into reciprocal management agreements with the states of Arkansas, Mississippi, and Texas on matters pertaining to aquatic life in bodies of water that form a common boundary.

7.2.4.3.2 Limited Entry

A limited entry system exists for the Public Seed Grounds with a vessel permit now required to fish those grounds. The vessel used must meet certain criteria as to date of manufacture or historical participation in the oyster fishery as found in Louisiana Revised Statutes 56: 433.1 and Louisiana Administrative Code 76 Part VII Chapter 5.

7.2.4.4 Commercial Landings Data Reporting Requirements

Processors, or any other first purchasers, must report the previous month's purchases by the tenth of each month. The quantity, vessels, owners, and other dealers from whom oysters are purchased must be included in the reports. Wholesalers, processors, and first purchasers are also required to report sales of oysters and to whom oysters are sold [R.S. 56:303.7, 56:306].

7.2.4.5 Penalties for Violations

Oyster violations vary from Class 1 to Class 6. Penalties depend upon the class of violation and previous offenses. Fines may range from $25 to $100 and from $1,000 to $5,000; imprisonment from 180 days to two years, forfeiture of anything seized in connection with the violation as well as, future monitoring via a Vessel Monitoring System. Civil penalties may be applied in certain situations.

7.2.4.6 Annual License Fees

Commercial fisherman license	
Resident	$ 55.00
Nonresident	460.00
Vessel license	
Resident	15.00
Nonresident	60.00
Wholesale/retail dealer	
Resident	250.00
Nonresident	1,105.00
Transport license	
Resident	30.00
Nonresident	30.00
Oyster tong (per tong)	
Resident	30.00
Nonresident	240.00
Oyster dredge (per dredge)	
Resident	25.00
Nonresident	200.00
Oyster harvester’s license	
Resident	100.00
Nonresident	400.00
Oyster Seed Ground Permit	
Resident	15.00
Nonresident	60.00
Oyster Cargo Vessel Permit	
Resident	250.00
Nonresident	1,105.00

7.2.4.7 Laws and Regulations

7.2.4.7.1 Minimum Size

All oysters taken from public grounds must be three inches or larger in length from hinge to ‘mouth’. An allowance of 15% of dead shell and/or undersize oysters is accepted. A lessee, when fishing public grounds, may be permitted to take undersize oysters for bedding purposes only and may commercially harvest any size oysters from his private lease. [R.S. 56:433]

7.2.4.7.2 Seasons

Seasons are designated by LWFC action; public grounds may be opened for the harvest of seed oysters only the first Wednesday following Labor Day. Then, beginning on the second Monday in October each year, grounds may open to the harvest of market size oysters in addition to seed. All harvest will cease by April 30 of each year, although the Commission may extend the season if biological data indicate that sufficient quantities of oysters exist on the public grounds to accommodate such additional taking.[R.S. 56:433]

7.2.4.7.3 Fishing Methods and Gear Restrictions

Oysters may be taken from oyster grounds by dredges, scrapers, and tongs. All dredges and scrapers shall be no longer than six feet in width, measured along the tooth bar. The dredge teeth shall be no longer than five inches in length. No implements or appliances shall be used in any manner which will impair or destroy any water bottoms [R.S. 56: 435).

An exception exists in Calcasieu Lake where only a single mechanical-assist dredge may be used that has a tooth bar no more than 36 inches long. In addition, single scrapers with mechanical assist, must have a flat bar length of no more than 36 inches [R.S. 56:435.11]

7.2.4.7.4 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 water bottom in order to locate accurately and fix the limits of the water bottoms embraced in each lease. Areas shall also be prominently marked with signs that state the lease number and initials of the lessee [R.S. 56:425-432].

Occasional moratoriums on issuing of new leases may occur.

7.2.4.7.5 Restrictions

No person shall trawl or seine over any privately leased bedding ground or oyster propagating place that is staked off, marked or posted as required by law or regulation. It is a violation to harvest oysters from unleased state water bottoms (i.e. water bottoms that are neither under lease nor part of the public oyster grounds).

The taking of oysters from the natural reefs of Louisiana and from privately owned bedding grounds between the hours of one-half hour after sunset and one-half hour before sunrise is prohibited [RS 56:436].

7.2.4.7.5.1 Quotas and Bag Limits

The Commission may utilize bag or possession limits for management purposes within the public grounds. Currently, the only legislatively fixed bag-limit is 25 sacks within the Calcasieu Lake and Sabine Lake systems [RS 56:435.11]. There is no bag or possession limit for privately leased areas.

7.2.4.2 Louisiana Department of Health and Hospitals

Louisiana Department of Health and Hospitals (LDHH)
Office of Public Health
P.O. Box 3214
Baton Rouge, LA 70802

The LDHH is responsible for enforcing laws, rules, and regulations related to public health within the State of Louisiana. Concerning oysters, this represents regulations for public health from initial harvest to consumption. The Office of Public Health is responsible for these regulations via its Sanitarian Services including the Commercial Seafood Program and the Molluscan Shellfish Program.

7.2.4.2.1 Legislative Authorization

Louisiana Revised Statutes Title 40 provides legislative authorization with rules promulgated within Louisiana Administrative Code Title 51.

7.2.4.2.2 Growing Area Classification

Waters are classified using guidelines contained in the National Shellfish Sanitation Program Model Ordinance. Within Louisiana, these categories are: Approved, Conditionally Approved, Restricted, and Prohibited. These classifications are given after a sanitary survey is conducted, with the survey identifying and evaluating all actual and potential sources of pollution which may affect the growing area. The surveys also identify any meteorological, hydrologic, or other environmental influences on bacterial or other pollutant loads. This survey and associated water quality data are maintained on an annual basis. The growing area classifications are reevaluated at least every three years to assure the accurate classification of each growing area.

In addition, growing areas may be further subdivided into harvest areas for management and regulation to ensure public health. Currently, within Louisiana, this is done with the delineation of 28 harvest areas along the coast.

7.2.4.2.3 Water Quality Monitoring

The LDHH maintains continual water quality monitoring within the Louisiana Coastal Zone. Bacteriological data are used in the classification and management of the growing areas.

7.2.4.2.4 Handling of Oysters for Market

The LDHH maintains rules for the handling of oysters destined for public consumption to ensure public health. These rules are co-enforced by the LDHH and the LDWF.

7.2.4.2.4.1 Harvest Vessel Conditions

The LDHH has implemented standards of handling and conditions that must exist on a vessel harvesting oysters for public consumption. These rules include specific requirements to regulate the construction of harvest vessels, sewerage storage, and sewerage discharge. In addition, rules are in place concerning the timing and refrigeration of harvested shellstock. Harvest rules are enforced by the LDWF.

7.2.4.2.4.2 Harvest Tags

Tags must be placed on any container holding shell-stock for public consumption. The initial tagging is placed by the harvester before removal from the vessel or before entering a different harvest area as identified by LDHH. At a minimum, the tag must contain:

1. The dealer’s name, address, and LDHH certification number
2. The harvester’s LDWF identification number
3. The date of harvesting
4. The harvest area, as defined by LDHH
5. Type and quantity of shellfish
6. Additional health and regulatory statements

Tags are sold through the LDWF headquarters and selected field offices.

7.2.4.2.4.3 Processing Plant Certifications and Inspections

LDHH maintains and enforces rules to ensure that processing facilities meet both State and Federal guidelines for the safe handling and processing of oysters destined for consumption. There are currently rules in place governing building design, permitting, equipment type and usage, refrigeration, and handling. Rules are promulgated according to Louisiana Revised Statutes Title 40 *et seq*.

7.2.5 Texas

In the state of Texas, two independent agencies share responsibility for the management of oysters in state waters. The Texas Parks and Wildlife Department manages the coastal resource and enforces the legislative and regulatory aspects of the fishery while the Texas Department of State Health Services (DSHS) is responsible for product safety and the classification and closure of resource areas in the interest of human health.

7.2.5.1 Texas Parks and Wildlife Department

Texas Parks and Wildlife Department (TPWD)
Coastal Fisheries Branch Division
4200 Smith School Road
Austin, Texas 78744
Telephone: (512) 389-4863

The Texas Parks and Wildlife Department is the administrative unit of the state charged with management of the coastal fishery resources and enforcement of legislative and regulatory procedures under the policy direction of the Texas Parks and Wildlife Commission. The Commission consists of nine members appointed by the Governor for six-year terms. The Commission selects an Executive Director who serves as the chief administrative officer of the Department. The Executive Director selects a Deputy Executive Director for Natural Resources who, in turn, selects the Director of the Coastal Fisheries, Inland Fisheries and Wildlife, and the Law Enforcement Divisions. In the Divisions, each branch is headed by a Deputy Director.

7.2.5.1.1 Legislative Authorization

Chapter 61, Texas Parks and Wildlife Code (Uniform Wildlife Regulatory Act) provides the Texas Parks and Wildlife Commission with responsibility for management of the state's wildlife resources. This chapter provides a flexible law to enable the Commission to deal effectively with changing conditions to prevent depletion and waste of wildlife resources. In 1985, Chapter 76, Parks and Wildlife Code was expanded to grant the Commission authority to regulate by proclamation the taking, possession, purchase, and sale of oysters.

As directed by the Texas Legislature, the Commission was restricted from making any proclamation under Chapter 76, Parks and Wildlife Code until it had approved and adopted an oyster management plan and economic impact analysis prepared by the Department. On November 3, 1988, the Commission took the required action and has managed oysters based on provisions of the Texas Oyster Fishery Management Plan (Quast et al. 1988) since that time.

7.2.5.1.2 Reciprocal Agreement and Limited Entry Provisions

7.2.5.1.2.1 Reciprocal Agreement Provisions

7.2.5.1.2.1.1 Licenses

Texas statutory authority allows reciprocal license agreements such as the one that provides for the acceptance of recreational fishing licenses from either state, Texas or Louisiana, in waters that are a common boundary of the two states.

7.2.5.1.2.1.2 Management

Texas has no statutory authority to enter into reciprocal management agreements.

7.2.5.1.3 Limited Entry

In 2005, the Texas Legislature adopted a 'license moratorium' for Commercial Oyster Boat Licenses. Direct statutory provisions for limited entry now exist for the Department, and the Commission has the authority to increase license fees. These provisions can serve as an indirect method of access limitation as well. The program provides for transfer for current licenses to other fishermen. In addition, the General Land Office, an agency of the state controlling state lands to include submerged lands, has requested that TPWD place a moratorium on leasing of any additional bay bottom for private oyster reefs.

7.2.5.1.4 Commercial Landings Data Reporting Requirements

All seafood dealers who purchase directly from fishermen are required to report these transactions by filing a monthly marine products report (trip ticket report) through the Department's commercial landings data collection program. These reports must include species, vessel information, poundage, ex-vessel price, name and license number of harvester, and location of fishing activity. Dealers pay a sales fee of $1.00 for each barrel of oysters handled to the State Comptroller office. All commercial fishermen who sell their catch to persons other than licensed dealers (restaurants or directly to the general public) must report those sales on a trip ticket to the commercial landings data collection program.

7.2.5.1.5 Penalties for Violations

Penalties for violation of Commission regulations or legislative statutes governing the oyster fishery are found in Section 76.118, Texas Parks and Wildlife Code. These penalties range from a Class C, Texas Parks and Wildlife Code misdemeanor with a fine from $25 to $500 to a Texas Parks and Wildlife Code felony with a fine from not less than $2,000 nor more than to $10,000 and confinement from two years to ten years in the institutional division of the Texas Department of Criminal Justice for any term of not more than ten years or less than two years.

7.2.5.1.6 Annual License Fees

Wholesale fish dealer (each place of business except trucks)	$825.00
Wholesale fish truck dealer (for each truck used as a place of business)	590.00

Required for any person engaged in the business of buying for the purpose of selling, canning, preserving, processing or handling for shipments or sale, fish, oysters, shrimp or other commercial, edible aquatic products to retail fish dealers, hotels, restaurants, cafes, or consumers. May purchase for resale, or receive for sale, barter, or exchange fresh or frozen aquatic products only from persons who hold a valid commercial fisherman's license, commercial oyster fisherman's license, commercial oyster boat license, or a wholesale fish dealer's license.

Retail fish dealer (each place of business except trucks)	92.40
Retail fish truck dealer (each truck used as a place of business)	171.60

Required for any person who buys any fresh or frozen, edible aquatic products for the purpose of sale to consumers. May purchase for resale fresh or frozen aquatic products only from persons or entities in this state who hold a valid commercial fisherman's license, or a wholesale fish dealer's license.

Commercial oyster boat license

Resident	441.00
Nonresident	1,764.00

Required for each boat used to transport or for taking oysters for pay or for the purpose of sale, barter, or exchange or any other commercial purpose from the public waters of this state by utilizing a dredge, tongs, or other mechanical means. May be purchased any time if person is eligible and expires August 31 of the following year.

Commercial oyster fisherman's license

Resident	126.00
Nonresident	315.00

Required of any person who takes oysters from the public waters of this state for pay or for the purpose of sale, barter, or exchange or any other commercial purpose. (Not required of the captain and crew of licensed commercial oyster boats.) May be purchased any time if the person is eligible.

Commercial oyster boat captain's license

Resident	32.00
Nonresident	126.00

Required of any person who operates a commercial oyster boat while taking oysters from the public waters of this state.

Sports oyster boat license (required when using a sports oyster dredge or tongs to take oysters)

Resident (for boats registered in Texas or having a U.S. Coast Guard documented homeport in Texas)	13.00
Nonresident	51.00
Resident combination hunting and saltwater fishing license	68.00

Sport Fishing License

Resident Saltwater Fishing Package	35.00
Nonresident Saltwater Fishing Package	63.00
Resident One Day – All Water License	11.00
Non-Resident One Day – All Water License	16.00

(Consecutive additional Days for the "One Day- All Water Licenses" are available for an additional fee at the time of purchase)

A person taking oysters is required to have a valid Saltwater Fishing License. A person taking oysters with tongs or a dredge must also hold a sports oyster boat license. Oysters may be taken by hand, with tongs, or by oyster dredge. Sports oyster dredge may not be more than 14 inches in width.

Oyster boat and oyster fishermen licenses may be purchased anytime if eligible and expire on August 31 of each year.

7.2.5.1.7 Laws and Regulations

Texas' laws and regulations regarding the harvest of oysters are statewide, but can specify certain regulations for different areas based on changing environmental conditions. The TPWD should be contacted for specific information. *The regulations discussed in this section are current to the date of publication and are subject to change at any time thereafter.*

7.2.5.1.7.1 Minimum Size/Possession Limit

Minimum size for oysters is three inches. Oysters three-fourths to three inches are to be culled and returned to the reef from which they were taken. However, each cargo may not contain more than 15% of oysters under the three inch minimum. A Sport Fisherman is limited to possess no more than two sacks of legal oysters per person. No commercial oyster boat may take more than 90 sacks of oysters per boat per day, and may not possess more than six sacks (equivalent of two barrels) of unculled oysters. A sack is defined as 110 lbs of oysters (including the sack).

7.2.5.1.7.2 Seasons

The open season is from November 1 through April 30. Private oyster lease holders may take oysters from private leases year round when holding proper permits issued by TPWD. During open season, oysters may be taken from sunrise to sunset. There is no open season in areas closed by the Texas Department of State Health Services (DSHS). Licenses may be purchased any time of the year but commercial licensees must be eligible.

7.2.5.1.7.3 Fishing Methods, Area and Gear Restrictions

For commercial purposes, only one oyster dredge not more than 48 inches in width across the mouth and not more than two-barrel capacity may be used at any given time on board any boat in public waters. Commercial vessels may not have more than two legal dredges on board and no more than one dredge connected in any way to a lifting device during the open public season. The additional dredge must be secured below deck to the wheelhouse or to the deck preventing its immediate use.

7.2.5.1.7.4 Leases

No individual may own, lease or control more than 300 acres of land covered by water under certificates of location. Each certificate of location cannot be for more than 100 acres of land covered by water. Additionally, an individual may act as an agent for persons who, in the aggregate, own, lease, or control more than 300 acres of land. Oyster leases are granted for 15 years.

Persons interested in acquiring an oyster lease may file a written application with the TPWD. On receipt of an application, the department shall examine the proposed location as soon as practicable and, if the location is subject to certification, then the applicant shall have the location surveyed by a competent surveyor. In addition, after the final survey, the applicant shall mark the lease boundaries as provided in section 58.30 of the proclamations of the Texas Parks and Wildlife Commission. If adjoining leases are proposed, the approximate boundaries of each lease must be clearly marked. Proposed leases are ineligible if five or more barrels of oysters are determined to be present on the site prior to leasing. The area must not be a natural reef or have been such at any time during an eight-year period preceding the site inspection.

Leases are used as depuration sites for oysters transplanted from restricted waters, as classified by the Texas Department of State Health Services. Leaseholders are allowed to transplant oysters from these restricted waters under a TPWD issued permit. The TPWD determines the total number of boats that will be allocated to a lease for transplant activities. Oysters may be harvested from private leases only under a permit issued by TPWD.

7.2.5.1.7.5 Restrictions

Oysters may be taken only from waters approved by the Texas Commissioner of Health. Oysters may not be taken from marked, private leases except by permission of the lessees.

7.2.5.1.7.6 Historical Changes to Oyster Regulations in Texas

Adopted in 1985 The Texas Legislature granted management authority of the Oyster Fishery in Texas to The Texas Parks and Wildlife Department contingent on developing an oyster fishing management plan.

Adopted in 1988 The Texas Oyster Fishery Management Plan resulted in Commission authority over regulation of traditional management measures, including means, methods, times, places, quantity, and size of harvest.

Effective August 29, 1996 The Texas Parks and Wildlife Commission adopted amendments that recodified and streamlined the current regulations concerning oyster harvest as a new chapter 58 and brought the regulations under sunset review.

Effective February 25, 2002 The Texas Parks and Wildlife Commission adopted amendments to chapter 58 of the proclamations regarding oyster leases and oyster transplant permits. These amendments established terms and conditions for private oyster leases to protect the interest of the state and create public benefits to better manage the leases.

Effective October 13, 2003 The Texas Parks and Wildlife Commission adopted amendments to chapter 58 of the proclamations regarding the possession of more than one dredge on board an oyster boat. The regulation of one dredge on board did not provide the flexibility to the commercial operation to replace a damaged or lost dredge. The current regulation provided for a second dredge to be on board but required it to be stored below or secured to the deck so as not to be readily accessible for use. This provided law enforcement the greater opportunity to enforce the one-dredge rule while allowing commercial operations flexibility to continue operations.

Effective June 10, 2004 The Texas Parks and Wildlife Commission adopted amendments to chapter 58 of the proclamations that provided for gear restrictions for the taking of oysters for commercial and personal use, reduced time requirements for oyster transplant notification to the Department, oyster lease boat allocation for transplanting oysters, the requirement that transplant vessels have a valid permit on board and reporting requirements for private leases.

Effective October 27, 2005 The Texas Parks and Wildlife Commission adopted amendments to chapter 58 that created a uniform nomenclature for measuring the take of oysters in the industry. It defined the term “sack” so as to create a volume definition for oysters (110 lbs of oysters including the sack), that would be standard in the industry. The amendment was intended to make it easier for fishermen to comply to limits and easier for enforcement of the rules.

Effective July 2, 2006 The Texas Parks and Wildlife Commission adopted amendments to chapter 58 that established the current daily bag limit for the commercial harvest of oysters at 90 sacks per day, per boat and the current daily bag limit for non-commercial harvest at two sacks per person. The rationale for the amendment is to stabilize the market throughout the year by limiting the daily limit based on previous year harvest records.

Effective September 1, 2009 The 81st Texas Legislature enacted a law that increases the penalty for harvesting oysters in a closed area to a class "A" misdemeanor punishable by up to a $4000 fine and up to a year in jail for all crew members and the captain of a vessel. Subsequent offenses may be enhanced to a state jail felony.

7.2.5.2 Texas Department of State Health Services

Texas Department of State Health Services **(DSHS)**
Seafood and Aquatic Life Group
P.O. Box 149347
Austin, Texas 78714-9347

The DSHS promotes optimal health for individuals and communities while providing effective health, mental health, and substance abuse services to Texans. DSHS serves the health needs of Texans in a number of ways through the prevention and preparedness activities and the regulation of consumer goods and services as they relate to public health.

Environmental and Consumer Safety Section
Seafood and Aquatic Life Group MC 1987
Texas Department of State Health Services
P. O. Box 149347
Austin, Texas 78714-9347

The mission of the Seafood and Aquatic Life Group is to protect the consumer from disease or other health hazards transmissible by oysters, clams, mussels and scallops, and crab meat produced in or imported into Texas. The Seafood and Aquatic Life Group also protects recreational fishers from disease or contaminants found in fish and other aquatic species caught in Texas lakes, rivers, bays, or nearshore state waters. The mission is carried out by classifying shellfish growing areas, certification of molluscan shellfish shippers and crab meat processors, and testing of tissue samples from fish and seafood harvesting areas.

7.2.5.2.1 Growing Area Classification

The authority conferred on the commissioner by the Health and Safety Code, §436.101 is hereby delegated pursuant to Health and Safety Code §436.003(a) to the Section Director of the Environmental and Consumer Safety Section, or his/her designee, under the provisions of this section. The Section Director shall:

(1) designate coastal water (as defined in the rules of the Texas Parks and Wildlife Department, 31 TAC, Chapter 51) for the purposes of taking molluscan shellfish as:

(A) an approved area;
(B) a conditionally approved area;
(C) a restricted area;
(D) a conditionally restricted area; or
(E) a prohibited area.

(2) designate classified growing areas as open areas or closed areas.

Additional classification duties are specified under Title 25, Texas Administrative Code (TAC) sections 241.50, 241.51, and 241.52 of the Texas Molluscan Shellfish rules. Section 241.50 provides definitions concerning growing area classification. Section 241.51 adopts the National Shellfish Sanitation Program Model Ordinance, and Section 241.52 gives the authority to the Commissioner of Health for opening and closing of shellfish harvesting areas along with classification of shellfish harvest areas.

7.2.5.2.1.1 Shell Stock Transplanting and Gathering for Depuration (Texas Administrative Code 241.53)

Designates persons involved in transport of molluscan shellfish by ensuring proper permits from TPWD are required. The Department tracks source of shellstock, quantity of shellstock, destination of shellstock, and date of transplant permit expiration. For more details check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.2 Molluscan Shellfish Aquaculture (Texas Administrative Code 241.54)

Designates what hatcheries product came from, if land based activities or open water, must have all associated licenses and permits from appropriate state and federal agencies. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.3 Land Based Aquaculture (Texas Administrative Code 241.55)

Describes operational plan of proposed or actual facility and ensures quality of product. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.4 Polyculture Systems (Texas Administrative Code 241.56)

Operational plan requirements are discussed and described for this type of aquaculture facility. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.5 Molluscan Shellfish Harvesting and Handling (Texas Administrative Code 241.57)

Describes requirements for shellfish harvesters, vessels, handling of shellstock, and required tagging of molluscan shellfish. For more details please check the following website:
http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.6 Certification Requirements (Texas Administrative Code 241.58)

Details dealer certification to receive certification of compliance for each designated type of dealer which includes: Shucker/Packer (SP), Shellstock Shipper (SS), and Repacker (RP). For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.7 Inspections (Texas Administrative Code 241.59)

After issuance of certification, the Department, on a monthly basis, conducts inspectional duties. Hazards Analysis and Critical Control Points (HACCP) are reviewed during each inspection both in the firm’s records and by physical observation. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.8 Enforcement (Texas Administrative Code 241.60)

Gives the Department the right to certify, suspend, or revoke certificates of compliance. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.9 Molluscan Shell Stock Temperature Control (Texas Administrative Code 241.61)

Defines temperature control, and sets a temperature limit on shellstock that will be held by certified dealer. For more details please check the following website:

http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.10 Trucks and Other Vehicles Used to Transport Molluscan Shell Stock to the Original Dealer (Texas Administrative Code 241.62)

Concerns the safe transport of shellstock to properly maintain and prevent contamination and decomposition of molluscan shellstock. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.11 General HACCP Requirements (Texas Administrative Code 241.63)

Lays out how to conduct a hazard analysis of a certified dealers facility, and provides a plan to explain the critical limits and control points of that facility. Corrective action plans are also described and verification of actions taken. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.12 General Sanitation Requirements (Texas Administrative Code 241.64)

Describes how the certified dealer shall go about monitoring the conditions and practices of his/her facility. These monitoring activities concern such things as safety of water for processing, cleanliness, prevention of cross contamination, hand washing, control of pests, and a host of other acceptable practices. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.13 Dealer Molluscan Shell Stock Identification (Texas Administrative Code 241.65)

Describes tagging requirements for dealer's tags. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.14 Shucked Molluscan Shellfish Labeling (Texas Administrative Code 241.66)

Describes the requirements for labeling shucked molluscan shellfish on approved containers to hold or for transport. Such things as "SELL BY DATE", "DATE SHUCKED", and "BEST IF USED BY" are detailed in this section. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.15 Labeling of Molluscan Shellfish Subjected to Post-Harvest Processing (Texas Administrative Code 241.67)

Describes the requirements for labeling of Post Harvest Processed molluscan shellfish on approved containers. This also has some standard language to use for labeling of product and record keeping. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm.

7.2.5.2.1.16 *Vibrio vulnificus* Management Plan for Oysters (Texas Administrative Code 241.68)

Required by the NSSP in states where *Vibrio vulnificus* cases have occurred. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.17 Shipping Documents and Records (Texas Administrative Code 241.69)

Describes the requirements for shipping of molluscan shellfish in instate and interstate commerce. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.18 Tagging of Depurated Molluscan Shellfish (Texas Administrative Code 241.70)

Describes the tagging requirements of depurated products that have to be labeled "DEPURATED" in letters large enough to be on the approved label or container. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.2.5.2.1.19 Depuration Records (Texas Administrative Code 241.71)

Describes the record keeping requirements for depurated molluscan shellfish products. For more details please check the following website: http://www.dshs.state.tx.us/seafood/rules.shtm

7.3 Regional/Interstate

7.3.1 Gulf States Marine Fisheries Compact (P.L. 81-66)

The Gulf States Marine Fisheries Commission (GSMFC) was established by an act of Congress (P.L. 81-66) in 1949 as a compact of the five Gulf States. Its charge is:

> "to promote better utilization of the fisheries, marine, shell and anadromous, of the seaboard of the Gulf of Mexico, by the development of a joint program for the promotion and protection of such fisheries and the prevention of the physical waste of the fisheries from any cause."

The GSMFC is composed of three members from each of the five Gulf States. The head of the marine resource agency of each state is an ex-officio member, the second is a member of the legislature, and the governor appoints the third, a citizen who shall have knowledge of and interest in marine fisheries. The chairman, vice chairman, and second vice chairman of the GSMFC are rotated annually among the states.

The GSMFC is empowered to make recommendations to the governors and legislatures of the five Gulf States on action regarding programs helpful to the management of the fisheries. The states do not relinquish any of their rights or responsibilities in regulating their own fisheries by being members of the GSMFC.

Recommendations to the states are based on scientific studies made by experts employed by state and federal resource agencies and advice from law enforcement officials and the commercial and recreational fishing industries. The GSMFC is also authorized to consult with and advise the proper administrative agencies of the member states regarding fishery conservation problems. In addition, the GSMFC advises the U.S. Congress and may testify on legislation and marine policies that affect the Gulf States. One of the most important functions of the GSMFC is to serve as a forum for the discussion of various problems, issues, and programs concerning marine management.

7.3.2 Interjurisdictional Fisheries Act of 1986 (P.L. 99-659, Title III)

The Interjurisdictional Fisheries (IJF) Act of 1986 established a program to promote and encourage state activities in the support of management plans and to promote and encourage management of IJF resources throughout their range. The enactment of this legislation repealed the Commercial Fisheries Research and Development Act (P.L. 88-309).

7.3.2.1 Development of Management Plans (Title III, Section 308(c))

Through P.L. 99-659, Congress authorized the Department of Commerce to appropriate funding in support of state research and management projects that were consistent with the intent of the IJF Act. Additional funds were authorized to support the development of interstate FMPs by the Gulf, Atlantic, and Pacific States Marine Fisheries commissions.

8.0 DESCRIPTION OF FISHING ACTIVITIES AFFECTING STOCKS IN THE MANAGEMENT UNIT (MU)

8.1 History of Utilization

Prehistoric utilization of oysters dates to at least 2,000 B.C. (Wicker 1979). Native Americans would discard oyster shell and other food rubbish into piles. The resulting shell middens consisted predominantly of oyster shell, indicating that oysters made up a substantial portion of their diet (Kalm 1750, Russell et al. 1936, McIntire 1958, Byrd 1974). Oysters were collected primarily by women and children, in pre-Columbian times, wading in shallow waters and extracted by hand (Ingersoll 1881) or by crude tools devised to aid gathering. One such device consisted of rakes made of two strong poles, curved at the ends and interlaced with string vines (Dyer 1917). Speculation infers that oysters were smoked, dried, or consumed raw by aboriginal Indians (Calver 1920). However, oyster trading was probably not extensive due to trade and transportation difficulties (Wicker 1979).

The use of oyster shell was widespread throughout its range. The Mayans living near the southern coast of the Gulf of Mexico used ground shells of oysters and other mollusks to make lime which was mixed with sand and used to construct their homes (MacKenzie and Wakida-Kusunoki 1997). In addition, they used oyster shells as one of the binding materials to hold together large blocks in constructing many of their large temples and other structures. In the early years of this century, oyster shells were used to fill hollows in the ground when homes were constructed. The shells were also burned to make lime for painting houses and trees.

The earliest records of oyster consumption in colonial America can be dated back to the mid-1700s. Du Pratz (1758) recorded that early French settlers harvested oysters; however, consumption was likely one of a last resort when other food supplies had dwindled. Kalm (1750) chronicled vast amounts of oysters being sold throughout New England colonies. Kalm wrote that in October along the Pennsylvania coast, people came in large numbers to the mouth of the Delaware River to collect oysters and men could be seen selling oysters from carts in many of the inland towns. Kalm (1750) reported frequent exportation of pickled oysters, or oysters fried and stored in butter out of the colonies to the West Indies and ‘other parts’. Kalm noted the pickled oysters fetched as much as six times what the merchant paid for the raw product.

By the 19th century, the market for oysters expanded, and they became somewhat of a delicacy. Many tons of oysters were shipped to the east coast and Midwest as more people were able to afford them (MacKenzie 1996). They also became quite popular in local areas along the Gulf coast. They became a staple on restaurant menus, were prepared in various dishes, and were included on menus of cross-country railroads.

Consumer demand fueled the efforts to maximize early oyster harvests. Oyster canning technology and railroad development during the mid-1800s opened markets for eastern oysters as far west as St. Louis and the increased harvests reduced oyster prices lower than those for beef, poultry, and fish (MacKenzie 1996). Oysters became a regular part of the American diet during oyster season. New Yorkers averaged two meals of oysters per week and consumed 500,000 bushels of oyster per season in the early-1900s. The people of New Orleans consumed 750,000 bushels of oysters per year during the same time period (MacKenzie 1996). Cellars, saloons, parlors, bars, and lunchrooms specializing in serving oysters were common (Ingersoll 1881) throughout the 19th and 20th centuries and included some of the earliest establishments such as the Union Oyster House in Boston (opened 1826), Mayes Oyster House in San Francisco (1867), and the Acme Oyster House in New Orleans (1910). However, a decline in demand for oysters occurred in the mid-1980s, even though seafood consumption became an increasingly important part of the consumer’s diet as part of a trend toward more healthful eating habits (Lipton and Kirkley 1994). Lipton and Kirkley (1994) found that demand for oysters dramatically declined from 1984-1994 as a result of health/nutrition, product safety, water pollution, and adulterated product concerns. Despite these concerns, Wirth and Minton (2004) estimated that the total U.S. consumption of oysters was over 58 million lbs and per capita consumption was around 0.20 lbs of oyster meat in 2001.

In addition to the value of the meats, oysters are desired for their shells in industry as a source of calcium. Oyster shells have been ground to various consistencies and used in the manufacture of many products such as chicken feed (Galtsoff 1964), paints, and pharmaceuticals (MacKenzie 1996). In humans, calcium carbonate is a dietary supplement for healthy bones, muscles, nervous system, and heart. Calcium carbonate is also used as an antacid to relieve heartburn, acid indigestion, and stomach upset.

As far back as mid to late 1800s, the U.S. Patents Office has approved patents utilizing oyster shell in various forms of construction material from cement (McKay 1872) to asphalt additives (Holmes 1945). The oyster shell's shape and compaction qualities make it a highly desirable material for construction like roadbeds, particularly in low-lying or swampy areas. Since this type of construction activity occurs largely in the same general area where oysters are harvested and processed, the construction industry competes with the oyster industry for shell. The use of oyster shell in road beds and construction was widespread and the mining of prehistoric shell resulted in a rapid depletion of potential cultch material.

The construction industry is usually able to pay a higher price for shell and is better physically equipped to transport shell from process locations to use locations. These shells are thus irreclaimable to the oyster industry to use as cultch. This loss of shell has forced states to utilize alternative materials such as crushed limestone and concrete for reef building and restoration. A detailed discussion of cultch materials is included in Section 16.5.

8.2 Commercial Oyster Fishery

Oyster populations in the Gulf are driven by various factors which include physical, chemical, and biological controls such as the occurrence of hypoxia, predators, and disease (Section 5.0). In addition, prevailing environmental conditions can reduce commercial production due to reef closures resulting from public health concerns (Section 6.0). The commercial landings in the Gulf are relatively steady over the long-term but punctuated by wide annual variation. These fluctuations in catch and landings highlight the degree to which the oysters and fishery managers are sensitive to environmental change.

8.2.1 Development of the Fishery

It is uncertain when the commercial fishery for oysters in the Gulf was first developed. It is likely that commercial fishing was first developed by aboriginal Americans who established trade for smoked oysters in many areas of North America. As the early Europeans began to rely more on native foodstuffs and develop local economies, the industry evolved into its modern form.

Management efforts with regulatory agencies are recorded back to the late 19th century. Alabama had one of the earliest recorded laws related to oyster management in the Gulf. An unpublished compilation of the history of Alabama oyster laws reported the first legislative action in 1852. The law was likely rewritten into the 1867 Code of Alabama but both described the banning of all mechanical oyster harvesting in Alabama waters other than by rake or tongs (ADCNR unpublished report). In 1891, the Alabama legislature created the State Oyster Inspector with the responsibility for the enforcement of laws regarding oysters. Beginning in 1915, the legislature created the Department of Game and Fish to consolidate all of the various resource management agencies in the state. The Board of Oyster Commissioners (1909-1911), and then the Alabama Oyster Commission (1911-1915), were responsible for the enforcement of laws regarding oysters until 1915 when the legislature created the Public Reef Warden. In 1919, the legislature created the office of Chief Oyster Inspector. In 1935, the legislature changed the department's name to the Department of Conservation of Game, Fish, and Seafood and moved the functions of the Chief Oyster Inspector to the Alabama Oyster Commission. Since 1935, this position as well as the State agencies enforcing oyster laws and managing oyster resources has been renamed and reorganized numerous times, until in 1971, the Alabama Department of Conservation and Natural Resources became the primary agency for enforcing and managing oyster resources. ADCNR currently regulates this fishery through the Marine Resources Division.

The first attempt to regulate Florida's fisheries began back in 1831, ten years after Florida became a state. At this time, British citizens were banned from fishing in Florida waters due to a law which had been passed on from Spanish rule. This law was repealed when the British Governor of the Bahamas requested permission for Bahamian fishermen to fish in Florida waters. Several laws were passed in Florida related to fishing in general after 1831with penalties placed on violators. These rules were not strictly enforced, however, until 1861 when the legislature enacted a bill that provided stiffer penalties and placed enforcement with existing local government officials. The state levied a number of taxes on the processing and exportation of fishery resources. In 1889, the Florida Fish Commission was created to improve the effectiveness of fisheries regulation, supervise the fishery industries, and enforce the regulatory laws of the state. At that time, the tax collectors and assessors of the several coastal counties were designated Fish Commissioners, who would enforce regulations and prosecute violators.

Oyster fisheries management in Florida dates back to the beginning of the 19th century (Swift 1897, Danglade 1917, Whitfield and Beaumariage 1977). In 1902, the position of Oyster Commissioner was established and, in 1903, the first Fish Warden was appointed. In 1913, the Florida Shellfish Commission was organized, shellfish harvesting laws were enacted, and a statewide leasing program was established (Whitfield and Beaumariage 1977, Pacetti 1980). The Florida Board of Conservation was established in 1933 and assumed control of the statewide shellfish management and leasing programs. Since that time, various agencies, including the Florida Department of Natural Resources, the Department of Environmental Protection, the Marine Fisheries Commission, the Fish and Wildlife Conservation Commission, and the Department of Agriculture and Consumer Services have been responsible for various components of oyster resource and fisheries management. Fisheries-directed management practices have included establishing harvesting seasons, size limits, bag limits, and gear restrictions.

Mississippi established control of the oyster reefs under the three coastal counties where they existed in 1896. In 1902, the county jurisdiction was withdrawn and the Board of Oyster Commissioners was appointed by the governor. The Commission met monthly during the oyster canning season to provide supervision to the industry. Through the creation of the Commission, any oysterman owning a vessel over one ton was required to purchase a license. Finally, a tax was levied upon packed oysters and a state Oyster Fund was created for cultivating and maintaining the Mississippi oyster beds.

In 1870, the state of Louisiana began to address concerns that oyster reefs in coastal Louisiana were being rapidly depleted and destroyed. The Legislature passed Act #18, establishing the first season closure for oysters. The act set the closure from April 1 to September 15 and provided penalties for taking oysters. The following year, the legislature revised the closed season, putting the month of April back into the regular season. In 1879, laws were put in place to designate public and private oyster beds and requirements to return culled oysters to the beds (public or private), with penalties for violation (misdemeanor with fines for each offense of not less than $10 nor more than $50). The legislation also specified that it was illegal to plant or bed oysters from May 1 to September 1 and established that a violation of this law would constitute a misdemeanor and established fines for each offense of not less than $10 or more than $100. This statute also established the size of private oyster beds (not to exceed 8.25 acres), rules for marking these beds and establishing penalties for illegal harvesting. In 1900, the legislature appointed a legislative investigative commission to study the oyster industry and the existing management activities. As a result of their findings, the state created the Oyster Commission of Louisiana in 1902 and gave the Commission statewide control over the industry (Adkins 1988).

Texas oyster management traces its beginnings to 1895, when the Office of the Fish and Oyster Commissioner was created by House Bill 55, 24th Legislature, Regular Session, and a Commissioner was appointed by the Governor. The Commissioner's duties included the protection of fish, turtles, and terrapin of the bays and coastal waters of the state, the protection of natural oyster beds and reefs, and the protection of the location of private beds. The Commissioner had the authority to appoint Deputy Commissioners to assist in carrying out the duties of the office.

8.2.2 Fishing Methods, Gear, Boats and Vessels

Fishing methods, gear, and vessels used in the oyster fishery have changed very little over the past century; however, the introduction of motor power to the industry produced many changes, opening new markets, increasing harvests, and allowing production under most weather conditions.

The two primary methods of oyster harvest are derived from the gear used, tonging, and dredging. Tonging employs the use of hand tongs, sometimes called 'rakes', from the side of a small vessel to take oysters from the reef. Typically, rakes or heads are attached at the ends of long handles or stales (Figure 8.1A). Tongs are 14-16 feet long; consequently, tonging is restricted to shallow bays, bayous, and sounds, due to the length of the gear. In very shallow tidal areas, oysters may also be harvested using short-handled tongs called nippers. Nippers typically have eight foot stales with 8-12 inch rake heads and are useful in areas with scattered or single oysters as opposed to oyster clumps. Modern oyster dredging involves the use of one or more dredges (Figure 8.1B)

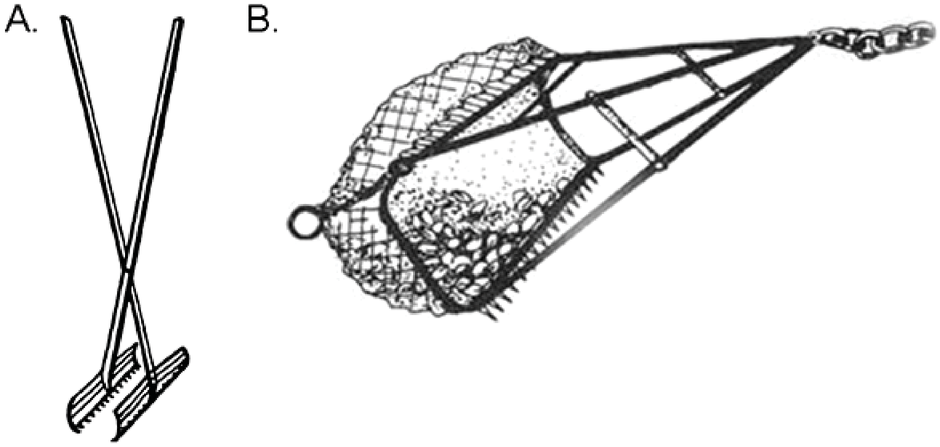


Figure 8.1 Harvesting gear used in the Gulf of Mexico; **A.** oyster tongs and **B.** oyster dredge.

pulled from a vessel. The size and weight of a dredge varies from state to state, but typically it measures approximately three feet wide and weighs about 120 lbs. See Section 7.2 for specific state legal dredge requirements.

8.2.2.1 Oyster Tonging

The first documentation of the use of oyster tongs in North America was as early as the mid-1700s (de Charlevoix 1744). Tongers originally operated out of wooden canoes and dugouts (MacKenzie 1996) but today, tonging is conducted from small, wooden skiffs 16-20 feet in length and powered by outboard motors. The skiffs are constructed with wide beams and flat bottoms and typically have a large deck and wide railing on which to stand while tonging (Figure 8.2).

With practice, an experienced tonger actually feels the oysters being picked up by the teeth of the rakes as he works the handles back and forth, opening and closing the mouth of the rakes. When the tonger feels that the rake is full, he closes the handles and lifts the rakes from the water onto a culling deck. He then opens the handles to release the oysters and other collected material.

Figure 8.2 Typical tonging skiff

Tong fishing generally involves one or two people in which one person tongs while the other culls. ‘Culling’ is the separating of market-size oysters from smaller oysters and associated shell or other cultch material. The small oysters and cultch material are then pushed back overboard and returned to the reef. Ideally, the procedure involves tonging for several hours by both people and, when the deck is substantially full, the tongers move to the edge of the reef area to cull. Later the tongers may return to the reef and repeat the process. Tonging in one area and culling in another reduces labor by precluding repeated collection of undersized oysters and associated cultch material. One benefit of this practice is that the process redistributes shell and allows the reef to expand.

8.2.2.2 Oyster Dredging

The oyster dredging operation generally involves pulling a dredge by chain or rope from the side or stern of a vessel, over the oyster reef, until the bag portion of the dredge is full of oysters and associated cultch material. The dredge is brought back on board, dumped on deck or a culling table, and then dropped back into the water to continue harvesting while workers cull shell and small oysters from the previous load. The first vessels used to pull dredges in the early 1800s were sailing vessels (MacKenzie 1996). In the Northeast, the skipjack and bugeye sailboats were the most common vessels for dredging in the Atlantic until the turn of the century (MacKenzie 1996). In the Gulf region, schooners, and sailed luggers were the preferred fishing vessels for both oystering and shrimping (Ingersoll 1881).

Eventually, the widespread use of the steam powered dredging boats replaced sailing vessels. In 1933, the Mississippi Seafood Conservation laws approved power boat dredging in Mississippi waters and the oyster schooner lost its economic importance and went the way of other outdated equipment (Schmidt 1995). By 1940, powered oyster luggers (Figure 8.3) had replaced sailed schooners almost completely on the Gulf's oyster grounds (Schmidt 1995).

Dredging is conducted in larger boats, designed with wide decks and shallow draft, which can be taken into deeper waters. Today, dredge boats (Figure 8.4) and oyster luggers are generally larger than tonging boats and range from approximately 25-60 feet in length.

The most common dredging methods involve maneuvering the vessel in a small circular pattern over a reef and deploying the dredge from either or both sides of the boat (Figure 8.5). The crew size also varies, but typically ranges from two to five persons including the captain. Team work between the captain and dredge crew is needed to increase efficiency and avoid accidents. Experience and skill are needed to dredge oysters in a manner to reduce labor and prevent unnecessary reef damage. Determining proper chain length and when the dredge is full are important factors.

Typically, dredges are attached to a chain operated by a winch. The dredge is usually raised and lowered from the side of the vessel slightly forward of midship, or pulled astern. Pipes (approximately three to four inches in diameter) are fashioned into vertical and horizontal rollers, where the dredge comes aboard, to facilitate raising, lowering, and dumping.

Based on water depth over a given reef, the dredge is rolled overboard and sufficient chain is released from the winch to allow the dredge teeth to scrape and lift oysters into the bag. Proper

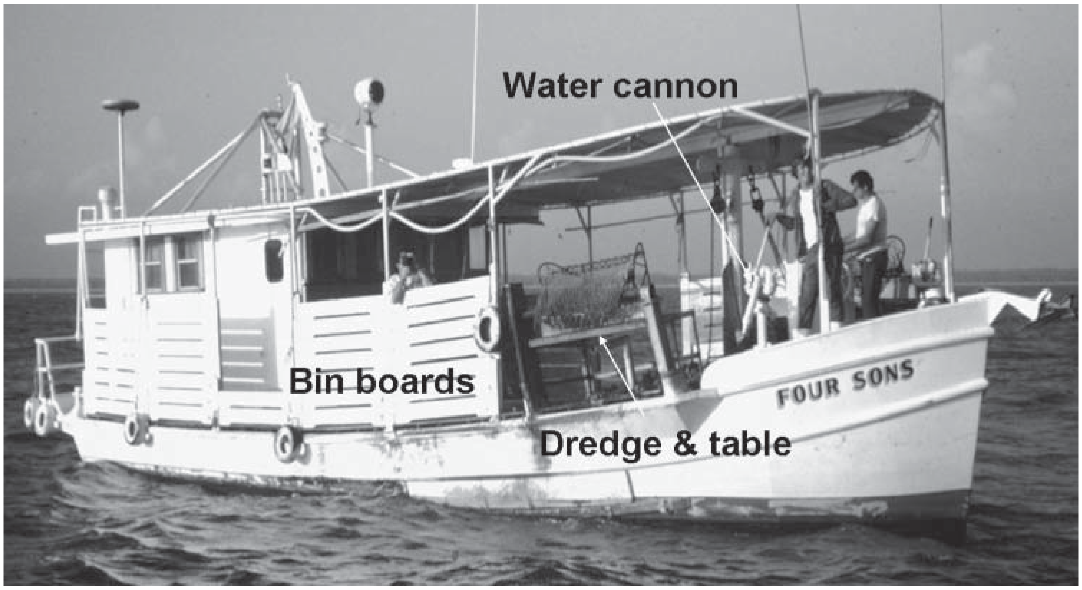


Figure 8.3 Typical powered oyster lugger

Figure 8.4 Typical small dredging vessel.

chain length must be maintained to allow proper dredge function. Excessive chain will result in the dredge bogging or simply scraping over oysters without them entering the bag. Insufficient chain will cause the dredge to bounce over the reef preventing the dredge teeth from digging under the oysters to lift them from the reef.

8.2.2.3 Other Oyster Fishing Methods

Oysters may be harvested from shallow tidal areas by hand using SCUBA gear. Oysters are also harvested from marsh and water edges at low tide by hand. In some areas, the latter method is referred to as oyster 'cooning' because raccoons are frequently seen eating shellfish in this manner. These gear and methods have a limited use in the commercial fishery.

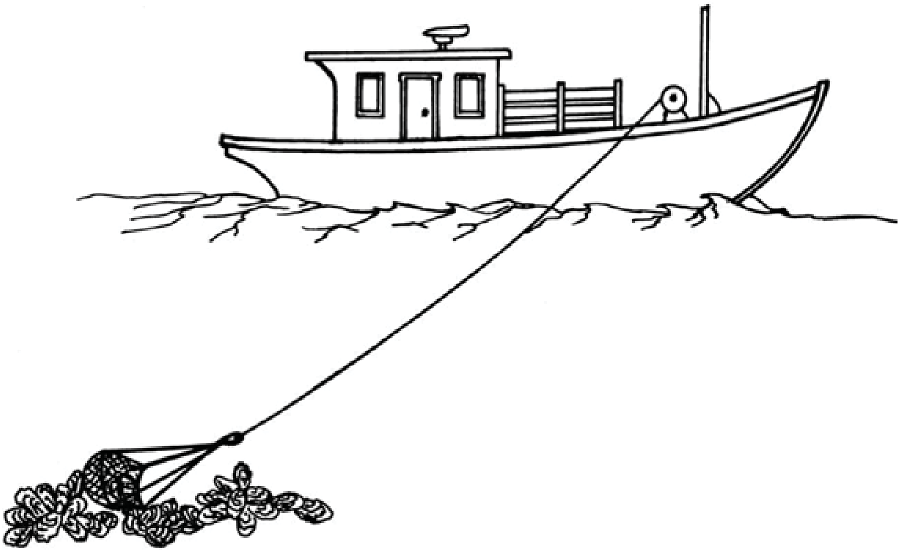


Figure 8.5 Typical oyster harvesting operation with a dredge towed by a luger.

8.2.3 Adoption of Standard Commercial Size-Limits

Currently, the market size limit of 3.0 inches is accepted by all of the Gulf states for oysters harvested from public reefs; however, the harvest size is less important from the biological perspective of protecting spawning stocks because oysters are often reproductively mature before they reach the legal 3.0 inches (Section 3.3.1). This size limit may have originated from the standard size in the Chesapeake Bay oyster fishery. Rothschild et al. (1994) reported that in 1890, there was concern over declining oyster catches in the bay, so a 2.5 inch minimum size was imposed to conserve the resource, but with little effect. In 1927, the minimum size in the Chesapeake was raised to 3.0 inches and has remained despite continuing declines.

One of the earliest size limits established in the Gulf was in Louisiana in 1902, based on the recommendations of H.F. Moore of the U.S. Fish Commission (Louisiana Board of Commissioners 1912). Moore (1899), at the request of the Louisiana legislature, investigated oyster conditions and recommended that the size limit should be increased from 2.5 inches to 3.0 inches. The Louisiana size limit was initiated more to protect reproductive ability and to conserve younger oysters, although Moore (1899) did report that oysters less than 3.0 inches were of little market value during the economic climate of that time.

Texas, in 1925, maintained a minimum size of 3.5 inches (Texas Penal Code) however, the size limits of oysters in Galveston Bay were moved to the current 3.0 inches in February 1963. The remainder of the Texas coast followed suit August 1, 1963. The stated reason by Hofstetter (1963) for the size reduction was

> "…to prevent waste of oysters between three inches and three and one-half inches which were subject to considerable mortality (caused by *Dermocystidium marinum*) before they could normally be harvested. Because of the extensive mortalities among seed stock, as well as market oysters, in Aransas, San Antonio and Lavaca Bays, the reduced size limit provided only slight benefit to the harvest from these areas. It was, however, beneficial in Galveston Bay where abundant market stocks were exposed to an increasing incidence of the parasite."

The other Gulf states' size limits may have similar conservation reasons or the limits may have been market-driven (for shucking) since that size was better for handling by processors and generated the best yield. Today's processing demands include an increased desire for smaller oysters for the half-shell market as well as the larger oysters for shucking. In addition, as oyster prices have gotten higher, smaller oysters provide restaurants and other establishments more oysters by weight, thereby increasing the number of pieces to be served by the dozen and a lower cost per piece. However, in the U.S. southeast, there is a minimum size at which the product is usually acceptable to restaurant patrons. Anecdotally, this size seems to be on order of 2.5 inches shell height and oysters smaller than these often generate consumer complaints. However, the current management scenarios do not allow for a smaller wild-caught oyster entering the market.

Oysters at the 2.5 inch size is common from Atlantic and Pacific coast oyster aquaculture operations but are sold in smaller volume and at higher prices. Aquaculture operations, particularly those with containerized grow-out facilities, benefit from being able to sell small oysters and avoid the extra expense of maintaining larger oysters in the grow-out containers. Container or cage grown oysters also often have lighter, thinner shells yielding a larger meat-to-shell ratio. Thus an aquaculture-grown oyster under the 3.0 inch minimum may provide edible tissue as large as, or larger than, wild-caught legal sized oysters.

In the Gulf, the standard size limit is not necessarily uniform for public grounds and leases. In Louisiana, Florida, and Alabama, the size limit does not apply to lease-product, allowing leaseholders to provide a smaller product for the half-shell market. Because the majority of Louisiana's landings come from private leases, many oysters smaller than 3.0 inches are legally introduced into commerce. Texas requires oysters harvested from private leases to match size limits from public reefs only during the public season. In addition, all the states have allowances for undersized oysters harvested from public grounds and, in some cases, private leases. Florida has a 15% tolerance for undersized, attached oysters, and a 5% tolerance for undersized, unattached oysters, while Alabama only has a 5% allowance for undersized oysters and cultch material combined. Mississippi has a 10% tolerance of undersized oysters by number in relation to any culling, and Louisiana allows 15% of dead shell and/or undersize oysters when sacking from public reefs which does not apply to lease harvest. Texas does not allow more than 15% of oysters under the 3.0 inch minimum. These tolerances for undersize oysters allow some dealers to sort and combine oysters for markets seeking smaller oysters.

8.2.4 Historical Catch Statistics

This section relies primarily on historical NMFS catch data. Catch data from individual states may vary, principally because of timing and methodology of collection.

8.2.4.1 Total U.S. and Gulf of Mexico

U.S. oyster landings for the eastern oyster have been declining steadily since at least the 1950s with a peak in 1952 at 72.2 million lbs (Table 8.1). The two periods with the most substantial declines were in the New England region starting in the mid-1950s, resulting in a 32% overall decrease from the peak, and another in the Chesapeake Bay region (Chesapeake), starting in the early 1980s resulting in an additional 37% decrease in total production from the peak down to an average of 46.6 million lbs annually (Figure 8.6).

In the five-year period just prior to the Gulf hurricanes (2000-2004), the total U.S. landings of eastern oyster had declined to 28.3 million lbs which was about a 40% total reduction from the average harvest from the early 1950s (NMFS unpublished data). However, these figures do not take into account other oyster species in the total U.S. production. Generally, even with all oyster species combined, the Chesapeake was the nation's largest producer of oysters from the earliest landings records in 1880 until the mid-1970s. The Gulf generally ranked second in production followed by the Pacific region (Pacific).

Oyster production from the Pacific includes several species (including the Pacific oyster *C. gigas*, European flat oyster *Ostrea edulis*, Olympia oyster *O. conchaphila*, and the eastern oyster) has remained relatively stable from 1950 through 2009 with reported total oyster landings ranging from 5.1 million lbs in 1974 to 15.1 million lbs in 1987 (Figure 8.7). An increase in the late 1990s to present represents a directed effort in the Pacific to increase production in response to the reduction in oysters in the Chesapeake. There was a similar increase in the early 1990s in New England as the Chesapeake continued to decline (Table 8.1).

The remaining eastern oyster production in the U.S. (South Atlantic, Mid-Atlantic and New England) has historically represented around 10% of the total domestic supply with a few notable highs in the early 1950s and 1990s. However, since 2000, the combined landings for these three regions have totaled less than 5% on average.

The Gulf has dominated U.S. oyster production since the early 1980s when the northeast began their decline. Total Gulf production increase from this time period to present, and despite

Table 8.1 Five-year average landings (lbs of meats) of eastern oyster by region 1950-2009 (NMFS pers. comm.).

Years	New England	South Atlantic	Mid Atlantic	Chesapeake	Pacific	Gulf	U.S.
1950-54	2,135,820	3,751,800	16,036,900	34,500,400	19,920	12,545,120	68,989,960
1955-59	437,400	3,030,760	6,396,360	36,639,000	12,440	13,166,120	59,682,080
1960-64	378,478	4,063,460	1,548,720	22,983,980	9,360	20,139,800	49,123,798
1965-69	283,628	3,139,440	1,144,700	22,610,780	13,340	20,917,340	48,109,228
1970-74	267,280	1,766,900	2,526,980	24,943,560	8,580	17,206,040	46,719,340
1975-79	620,220	1,940,041	2,941,240	21,152,660	2,776	18,978,066	45,635,003
1980-84	1,245,660	2,438,736	2,228,180	17,184,700	462	23,357,919	46,455,657
1985-89	1,162,178	1,580,296	370,520	9,030,011	32	20,294,850	32,437,887
1990-94	5,624,089	773,492	845,210	2,356,109	2,287	15,902,540	25,503,727
1995-99	2,465,268	507,927	825,208	1,969,435	8,408	22,760,376	28,536,622
2000-04	433,476	588,632	832,557	1,000,412	725	25,516,329	28,372,131
2005-09	337,167	801,178	601,069	604,004	43,020	21,017,328	23,340,168

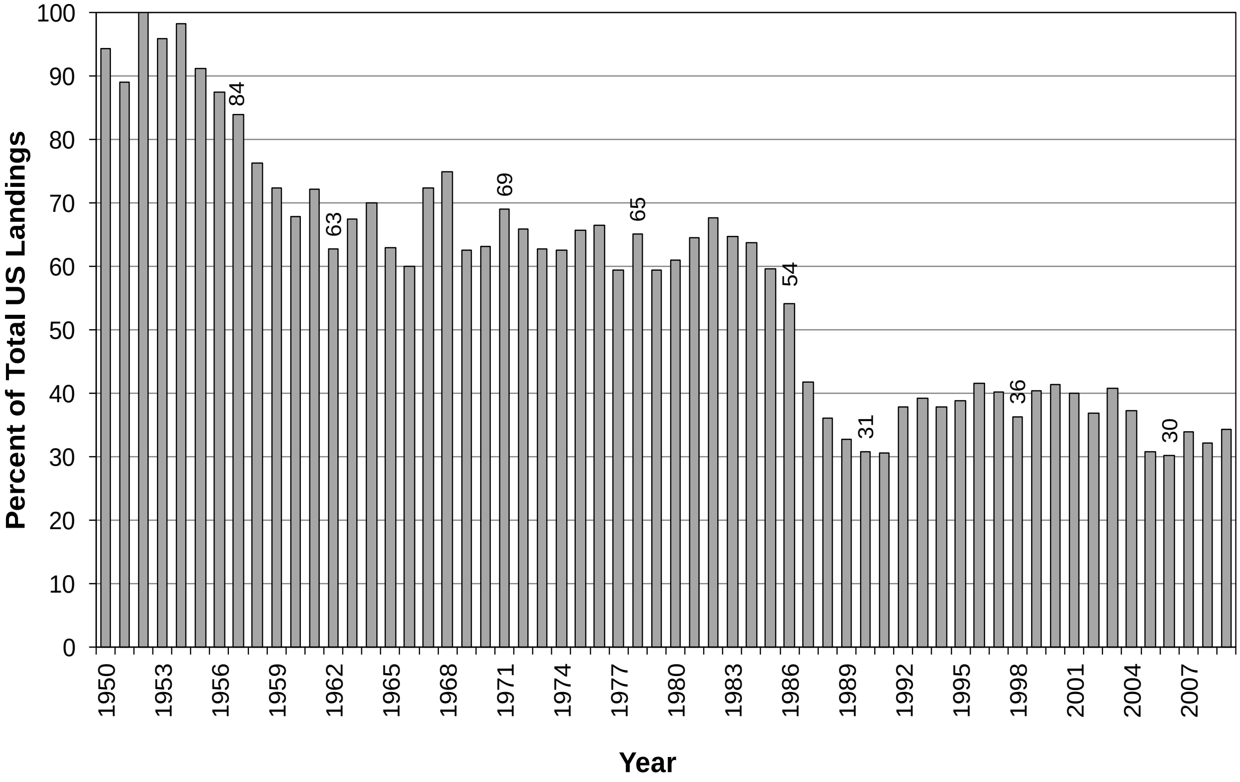


Figure 8.6 Percent decline from 1952 peak in total US production of eastern oysters from 1950-2009 (all regions combined). Peak production in this time period was 72.2 million pounds in 1952 (NMFS pers. comm.).

the hurricanes of 2004 and 2005 which destroyed a number of reefs in the northern Gulf, has remained fairly stable (Table 8.1). The Gulf's share of U.S. eastern oyster production averaged about 40% until 1980. Since then, it has increased from 50% in the early 1980s, 60% through the mid-1990s, and represents 80-90% of the total U.S. production today (Table 8.2). In fact, today, the Gulf contribution to the total U.S. landings for all oyster species is around 60%. By comparison, production from the Chesapeake represented 40-50% of the nation's total oyster supply until the early 1980s and today, has fallen to less than 2-3%.

8.2.4.2 Commercial Gulf Landings by State

The legally defined units of measure for oyster catch vary from state to state. Terms such as 'barrels', 'bushels', 'sacks', and 'boxes' are used to describe the oyster catch in all of the Gulf States but, while these units are legally standardized within each state, the volume of a sack in one state is unequal to the volume of a sack in another state (Table 8.3).

The production data among Gulf States from 1880-2009 (Table 8.4) and 1950-2009 (Figure 8.8), are given in terms of landings in pounds of meats rather than catch. Oystermen in the Gulf generally harvest using either dredges or tongs with a few noted exceptions, but the magnitude of harvest by either gear varies greatly between states and even within individual state reefs. Each state's fishing effort, gear, and catch by gear are taken from NMFS records. Because oysters may be harvested in the boundaries of one state and landed in another state, the landings and catch statistics may differ. Catch statistics, however, are presented by water body and are not always unique to a given state.

From 1880-2009, total Gulf landings of eastern oysters have fluctuated from less than 10.0 million lbs (1800-1889, 1949) to well over 29.0 million lbs (1983) (Figure 8.8 and Table 8.4). A number of significant tropical storms and hurricanes have driven the major fluctuations in the commercial landings primarily as an artifact of reef loss due to burying and rainfall or as a reduction in effort due to losses by the fishery participants of vessels and infrastructure (Hurricanes Ivan in 2004 and Katrina/Rita in 2005). Hurricane Ike struck Galveston Bay, Texas in 2008 and silted over and destroyed approximately 64% of the public grounds in Texas. In addition, over the last 40 years other storms covered or killed oyster reefs directly and include Hurricanes Fredrick (1979), Elena (1985), and Opal (1998) (Figure 8.8).

8.2.4.2.1 Florida

Oysters are known to have been harvested from Florida's coastal waters since European settlers originally inhabited the Gulf of Mexico coastal zone (Dugas et al. 1997), and evidence from archeological investigations suggests a much longer history of oyster harvest throughout Florida (e.g., Rouse 1951, Marquardt 1992) and the United States (Hargis 1999) by indigenous people. Florida's commercial fishery also has a long history, and oyster harvesting was an active business in Apalachicola Bay, the Cedar Key region, and in the Indian River in the late 1800s (Wilcox 1896, Swift 1897, Danglade 1917, Hepburn and Glassen 1977). The distribution and abundance of oyster populations has been described for the Cedar Key area (Ingle and Dawson 1953, Hepburn and Glassen 1977), Crystal River (Dawson 1955), Lee County on the west coast of Florida (Woodburn 1962), the Indian River region (Wilcox 1896), and Volusia County on the east coast (Grizzle 1990). However, the most dense, abundant, and productive oyster reefs in the state occur in Apalachicola Bay in the Florida panhandle. Apalachicola Bay historically has contributed approximately 90% of the Florida oyster harvest (Dugas et al. 1997). The confluence of the Apalachicola River, with the northern Gulf of Mexico renders Apalachicola Bay ideal in many critical biological aspects, particularly salinity, relative to oyster life history.

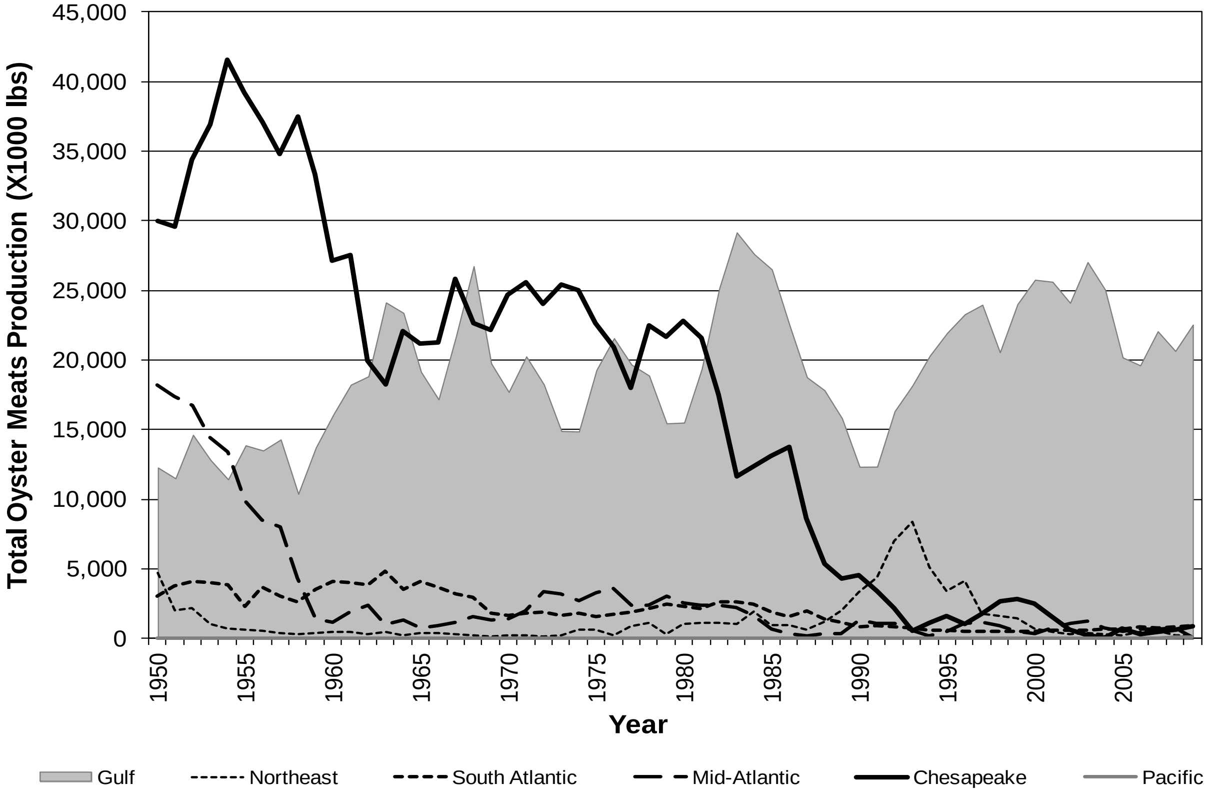


Figure 8.7 Total U.S. oyster landings for all species (Eastern, Pacific, European Flat, and Olympia) in lbs of meats by region from 1950-2009 (NMFS pers. comm.)

Table 8.2 Five-year average percentage of total U.S. landings for eastern oyster by region 1950-2009 (NMFS pers. comm.).

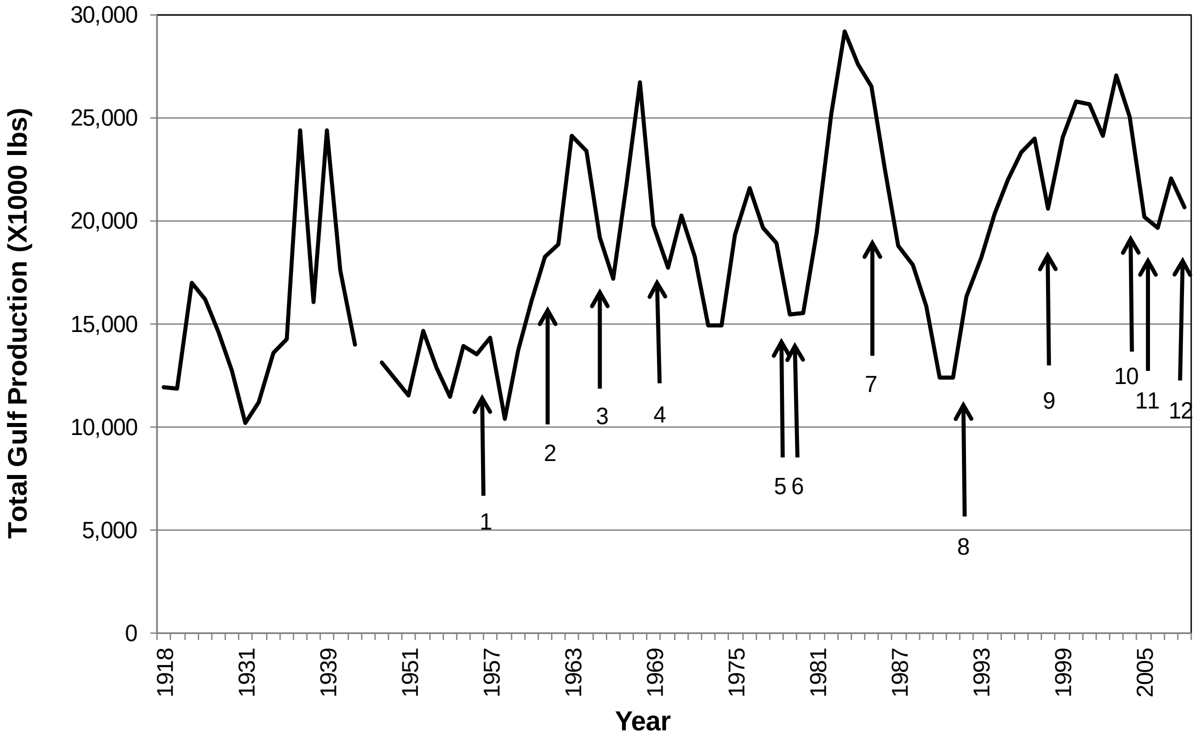
Years	New England	South Atlantic	Mid Atlantic	Chesapeake	Pacific	Gulf
1950-54	3.1	5.4	23.2	50.0	0.0	18.2
1955-59	0.7	5.1	10.7	61.4	0.0	22.1
1960-64	0.8	8.3	3.2	46.8	0.0	41.0
1965-69	0.6	6.5	2.4	47.0	0.0	43.5
1970-74	0.6	3.8	5.4	53.4	0.0	36.8
1975-79	1.4	4.3	6.4	46.4	0.0	41.6
1980-84	2.7	5.2	4.8	37.0	0.0	50.3
1985-89	3.6	4.9	1.1	27.8	0.0	62.6
1990-94	22.1	3.0	3.3	9.2	0.0	62.4
1995-99	8.6	1.8	2.9	6.9	0.0	79.8
2000-04	1.5	2.1	2.9	3.5	0.0	89.9
2005-09	1.4	3.4	2.6	2.6	0.0	90.0

Table 8.3 Sack volume conversions for the various Gulf states 'legal' sacks.

	AL	**FL**	**LA**	**MS**	**TX**
1 AL Sack 2119.6 in^3 (1.23 ft^3)		0.79 FL Sacks	0.66 LA Sacks	0.62 MS Sacks	0.79 TX Sacks
1 FL Sack 2688.0 in^3 (1.56 ft^3)	1.27 AL Sacks		0.83 LA Sacks	0.79 MS Sacks	0.996 TX Sacks
1 LA Sack 3225.6 in^3 (1.87 ft^3)	1.52 AL Sacks	1.20 FL Sacks		0.94 MS Sacks	1.19 TX Sacks
1 MS Sack 3421.4 in^3 (1.98 ft^3)	1.61 AL Sacks	1.27 FL Sacks	1.06 LA Sacks		1.27 TX Sacks
1 TX Sack 2700.0 in^3 (1.56 ft^3)	1.27 AL Sacks	1.004 FL Sacks	0.84 LA Sacks	0.79 MS Sacks	

Although the vast majority of Florida's oyster landings are from Apalachicola Bay in the Florida panhandle, oyster landings occur from other estuarine systems along both the Atlantic and Gulf of Mexico coasts of Florida. During some years, total landings from other areas may equal or even exceed the landings from Apalachicola Bay; for example, in 1985 when Hurricanes Elena and Kate swept through the Florida panhandle and decimated oyster reefs and the oyster industry in Apalachicola Bay (Berrigan 1988, Livingston et al. 1999), oyster landings in other counties throughout the panhandle and the peninsular west coast of Florida increased to at least partially fill the void. In the panhandle, Santa Rosa and Wakulla counties were the primary contributors, whereas Dixie and Levy counties were the primary contributors from peninsular west Florida (Arnold and Berrigan 2002). From 1999-2008, the Suwannee Sound area (Cedar Key) was the second largest producer on the Florida Gulf coast (~5%), followed by Apalachee Bay, the western Florida Panhandle (Walton, Okaloosa, and Santa Rosa counties), and the estuarine areas of Gulf and Bay Counties. Florida's northeast coastal counties also contribute about 2% to the state's landings. There are essentially no landings in southwest or southeast Florida.

During the history of oyster harvest in Florida waters, landings have been recorded from a variety of areas on both coasts of the State. However, few of those areas continue to produce significant oyster landings, and the reasons for their decline are not always clear (Arnold and Berrigan 2002). Loss of suitable shellfish harvesting waters is one contributing factor. Oysters were historically abundant in Tampa Bay, especially in that area of Old Tampa Bay north of the Gandy Bridge and the river mouths of eastern Tampa Bay. A successful fishery was pursued in the bay during the late 1800s (Finucane and Campbell 1968). However, the fishery declined during the first half of the 20th century (Finucane and Campbell 1968), and none of the historic harvest areas are even included in the shellfish harvesting classification scheme (FDACS 2000). Nevertheless, loss of shellfish harvesting habitat does not explain the collapse of the oyster fishery in most other areas of the state, because vast areas remain open to shellfish harvest in Florida (FDACS 2000) and, in many locales, additional harvesting areas have been opened in recent years (Arnold and Berrigan 2002).



1	1957 Hurricane Audrey	Cat. 4
2	1961 Hurricane Carla	Cat. 4
3	1965 Hurricane Betsy	Cat. 3
4	1969 Hurricane Camille	Cat. 5
5	1979 Hurricane Frederic	Cat. 3
6	1980 Hurricane Allen	Cat. 5
7	1985 Hurricane Elena	Cat. 3
8	1992 Hurricane Andrew	Cat. 4
9	1998 Hurricane Georges	Cat. 3
10	2004 Hurricane Ivan	Cat. 3
11	2005 Hurricanes Katrina/Rita	Cat. 4
12	2008 Hurricane Ike	Cat. 4

Figure 8.8 Total Gulf landings of eastern oyster (lbs of meats) from 1918-2008 (NMFS pers. comm.) with major tropical systems impacting the fishery and dates overlaid.

A second contributing factor results when fishermen leave the fishery in search of alternative employment and income. Although the oyster resource may eventually rebound, the fishing effort does not. Oyster harvesting areas near Panama City (Futch and Martina 1967), Cedar Key (Hepburn and Glassen 1977), and Crystal River (Dawson 1955) have been more or less productive throughout the 20th century, but unpredictable production cycles eventually forced fishermen to seek more stable sources of income (Arnold and Berrigan 2002). In many historically productive areas, oyster fishing has become more opportunistic instead of a reliable income source. Even the oyster populations in Apalachicola Bay have experienced periodic, but substantial, declines in abundance (Berrigan 1988). Following Hurricanes Elena and Kate in 1985, the oyster fishery in Apalachicola Bay was closed and remained closed until May 1986. During and following the closure, intense resource enhancement efforts were instituted in an effort to rehabilitate oyster reefs and to reestablish production in the fishery (Berrigan 1990). Those efforts were remarkably successful, and by 1987 oyster production in Apalachicola Bay exceeded 2.5 million lbs of meats annually. Since 1990, annual landings from Franklin County have fluctuated between approximately 1.4 and 2.9 million lbs of meats (Figure 8.9A). Market demand for oysters also influences the sale of raw oyster products. In recent years (2000-2007), oyster resource assessments in Apalachicola Bay have indicated that harvesting effort, rather than resource availability, may be a primary factor influencing oyster landings. Oyster population surveys indicated an abundance of market-sized oysters present on reefs, while landings remained relatively stable and much of the available resource was not harvested. Comparing assessments of oyster populations with harvest statistics

Table 8.4 Total landing of eastern oysters (lbs of meats) in the Gulf of Mexico by state from 1880-2009 (NMFS pers. comm.).

Year	*FL	AL	MS	LA	TX	Total
1880	270,000	327,000	62,000	1,189,000	324,000	2,172,000
1887	NA	NA	1,447,000	2,733,000	1,240,000	NA
1888	823,000	238,000	1,910,000	2,902,000	1,652,000	7,525,000
1889	1,229,000	1,372,000	2,105,000	3,367,000	1,745,000	9,818,000
1890	1,611,000	1,506,000	2,008,000	3,392,000	2,133,000	10,650,000
1897	797,000	798,000	1,568,000	3,866,000	1,723,000	8,752,000
1902	3,057,000	1,088,000	5,989,000	4,830,000	1,661,000	16,625,000
1908	3,670,000	1,678,000	2,657,000	11,953,000	2,369,000	22,327,000
1910	1,140,000	NA	NA	NA	NA	NA
1911	NA	1,163,000	1,621,000	12,419,000	1,766,000	NA
1918	1,511,000	376,000	3,168,000	4,522,000	2,312,000	11,889,000
1923	1,053,000	730,000	4,224,000	4,119,000	1,742,000	11,868,000
1927	1,238,000	521,000	6,693,000	6,640,000	1,910,000	17,002,000
1928	1,739,000	1,886,000	5,049,000	6,246,000	1,250,000	16,170,000
1929	1,505,000	179,000	6,643,000	4,549,000	1,729,000	14,605,000
1930	1,501,000	287,000	4,896,000	4,846,000	1,157,000	12,687,000
1931	1,406,000	769,000	3,438,000	3,590,000	982,000	10,185,000
1932	1,109,000	859,000	5,222,000	2,978,000	981,000	11,149,000
1934	1,357,000	392,000	4,904,000	5,592,000	1,312,000	13,557,000
1936	917,000	992,000	5,771,000	5,743,000	823,000	14,246,000
1937	817,000	1,235,000	12,894,000	8,048,000	1,190,000	24,379,000
1938	857,000	1,359,000	2,241,000	10,222,000	1,356,000	16,035,000
1939	742,000	1,358,000	7,706,000	13,586,000	987,000	24,379,000
1940	668,000	936,000	2,270,000	12,412,000	1,297,000	17,583,000
1945	1,496,000	1,606,000	265,000	9,884,000	719,000	13,970,000
1948	NA	1,531,000	1,309,000	9,688,000	579,000	NA
1949	1,086,000	1,586,000	462,000	8,716,000	299,000	3,121,000
1950	873,000	2,070,000	508,000	8,716,000	125,000	12,292,000
1951	681,000	2,191,000	27,000	8,164,000	456,000	11,519,000
1952	42,000	1,842,000	23,000	11,402,000	828,000	14,637,000
1953	64,000	1,450,000	318,000	9,435,000	1,069,000	12,836,000
1954	67,000	739,000	977,000	8,361,000	699,000	11,443,000
1955	630,000	1,581,000	1,731,000	9,396,000	543,000	13,881,000
1956	857,000	769,000	846,000	10,056,000	985,000	13,513,000
1957	710,000	1,291,000	863,000	10,490,000	953,000	14,307,000
1958	795,000	458,000	579,000	8,265,000	311,000	10,408,000
1959	1,415,000	895,000	333,000	9,667,000	1,411,000	13,721,000
1960	1,931,000	1,169,000	2,391,000	8,311,000	2,296,000	16,098,000
1961	3,255,000	509,000	3,241,000	10,139,000	1,096,000	18,240,000
1962	4,952,000	443,000	2,073,000	10,160,000	1,210,000	18,838,000
1963	4,283,000	995,000	4,680,000	11,563,000	2,618,000	24,139,000
1964	2,793,000	1,005,000	4,829,000	11,401,000	3,357,000	23,385,000
1965	2,789,000	493,000	2,696,000	8,343,000	4,835,000	19,156,000
1966	4,156,800	1,304,500	2,231,700	4,763,800	4,725,200	17,182,000
1967	4,578,400	2,087,400	3,785,900	7,742,900	3,553,000	21,747,600
1968	5,316,800	1,211,800	3,786,200	13,121,200	3,302,000	26,738,000

Table 8.4 Con't.

Year	*FL	AL	MS	LA	TX	Total
1969	4,911,300	480,700	1,429,800	9,178,900	3,763,700	19,764,400
1970	3,573,800	279,400	547,500	8,638,900	4,674,700	17,714,300
1971	3,528,700	249,500	1,214,500	10,527,300	4,744,300	20,264,300
1972	3,230,900	1,069,400	1,220,400	8,805,400	3,934,400	18,260,500
1973	2,409,000	590,100	611,500	8,954,100	2,348,000	14,912,700
1974	2,653,700	732,800	276,600	9,971,600	1,243,700	14,878,400
1975	2,133,600	638,100	1,080,700	13,686,900	1,756,000	19,295,300
1976	2,602,600	1,236,100	1,516,300	12,334,400	3,880,700	21,570,100
1977	4,071,700	1,549,200	1,386,000	10,065,500	2,600,500	19,672,900
1978	5,880,212	760,011	682,430	9,661,769	1,907,011	18,891,433
1979	6,124,910	460,344	272,100	7,714,450	888,795	15,460,599
1980	6,755,931	54,755	20,786	6,947,458	1,738,494	15,517,424
1981	7,170,329	1,329,925	467,070	9,092,576	1,306,584	19,366,484
1982	4,822,012	1,496,949	2,575,970	12,621,484	3,633,147	25,149,562
1983	4,326,494	335,666	3,333,010	13,224,445	7,940,749	29,160,364
1984	6,620,926	477,248	1,378,202	13,951,652	5,167,731	27,595,759
1985	4,393,367	1,441,847	1,192,650	14,347,231	5,133,937	26,509,032
1986	2,081,151	945,560	1,202,015	12,653,509	5,649,314	22,531,549
1987	3,681,371	88,307	132,103	12,026,508	2,843,619	18,771,908
1988	2,065,301	103,242	146,602	13,253,772	2,269,572	17,838,489
1989	1,698,403	11,476	100,109	11,605,856	2,407,427	15,823,271
1990	2,054,855	84,055	147,517	8,153,371	1,904,693	12,344,491
1991	1,793,191	280,959	102,076	7,265,084	2,915,986	12,357,296
1992	2,498,516	1,201,799	708,168	9,183,295	2,747,909	16,339,687
1993	2,700,963	919,618	1,257,771	10,314,823	2,964,374	18,157,549
1994	2,011,191	711,992	1,682,579	11,327,730	4,580,186	20,313,678
1995	1,458,393	709,992	1,327,100	13,800,076	4,670,598	21,966,159
1996	1,410,669	620,910	2,615,515	12,934,925	5,705,412	23,287,431
1997	1,867,839	695,320	3,499,964	13,221,705	4,687,029	23,971,857
1998	1,537,396	340,186	2,388,611	12,856,173	3,437,926	20,560,292
1999	2,306,985	376,539	2,793,201	12,128,187	6,411,229	24,016,141
2000	2,520,120	791,908	3,548,240	12,718,438	6,187,818	25,766,524
2001	2,559,242	574,902	2,653,270	15,132,631	4,700,475	25,620,520
2002	1,943,608	759,194	2,737,839	13,961,579	4,707,968	24,110,188
2003	1,752,848	815,530	4,042,136	13,608,565	6,813,469	27,032,548
2004	1,643,552	908,181	3,029,391	13,901,869	5,568,870	25,051,863
2005	1,416,522	1,041,332	610,384	12,098,654	5,007,472	20,174,364
2006	2,394,096	939,662	0	11,417,297	4,922,882	19,673,937
2007	2,959,059	768,823	299,088	12,856,632	5,187,631	22,071,233
2008	2,501,475	72,776	2,610,349	12,790,207	2,679,207	20,654,719
2009	2,866,787	22,976	2,191,724	14,730,945	2,733,150	22,545,582

indicate that landings only correlate with resource availability to a certain point. When oysters are plentiful, dealers may limit their purchases to meet daily and weekly market demands, suggesting that buyer-imposed bag limits control landings more than management-directed bag limits (Arnold and Berrigan 2002).

The commercial harvest of oysters has a rich history in Florida where commercial landings were recorded as early as the late 1800s. The commercial oyster industry in the city of Apalachicola was first described in 1881 (MacKenzie and Wakida-Kusunoki 1997). Surveys of oyster populations were conducted in Apalachicola Bay as early as 1895 and intermittently until the present. Landings data from 1895-1984 were compiled and reported by NMFS and landings data since 1985 have been compiled and reported by FWRI or one of its predecessor agencies. Since 2000, 98% of Florida oyster landings came from the Gulf of Mexico of which 88% came from Apalachicola Bay. Additionally, Florida's oyster managers have developed a scale to determine the relative condition and availability of oyster resources. The scale is based on production on designated oyster reefs and estimates population parameters, as well as, production estimates. Using this scale, production estimates exceeding 400 sacks per acre indicate a healthy bar capable of sustaining commercial harvest, while estimates of 200 sacks per acre indicate that harvests should be limited, and estimates below 100 sacks per acre indicate that a reef should be considered depleted (Berrigan 1990, Marsh 2004).

Florida's oyster landings generally reflect Gulf-wide production levels and trends. Like the rest of the Gulf, oyster production in Florida has been variable since the 1960s but has averaged 2.0 million lbs annually from 1986-2009 (Table 8.4). This represents around 10% of the total Gulf production during that same time period and ranks Florida third in long-term average annual production for the Gulf. Florida's landings did decline in 1986 due to the impacts of Hurricane Elena on Apalachicola Bay in 1985 and poor production extended into 1992 due to drought conditions from 1987 through 1989 (Figure 8.8). Production increased after 1991 and remained at relatively high levels until 1997 when it began another decline (Marsh 2004). Oyster production has been relatively stable over the past decade with landings responding to fishing effort and market demand. The discharge of freshwater from the Apalachicola River has been a long-running, interstate controversy, 'water war', in the southeast, and the extended drought and low-river discharge rates in the 2005-2007 adversely affected oyster populations on many reefs in Apalachicola Bay.

Despite fluctuating demand for oyster products and environmental perturbations, the number of licensed oyster harvesters in Apalachicola Bay has remained relatively stable. Several factors contribute to the stability of the fishery, including the consistent availability of oysters in Apalachicola Bay, low overhead requirements, and limited employment opportunities in the region. In contrast, commercially viable oyster stocks are largely ignored in other areas and fishermen focus their effort on other fisheries, aquaculture, or other employment opportunities.

Virtually all of Florida's production is harvested by hand tongs (Table 8.5). Florida law prohibits the use of mechanical dredges on public reefs, thus encouraging the dominance of hand tonging activity. Although hand tonging is the preferred gear, oysters are also harvested by hand and by diving. Overall, hand tonging accounts for more than 97% of the oysters landed in the state of Florida. The number of tongers, boats, and vessels engaged in the fishery varies annually but generally correlates with production trends (Table 8.6); the majority of Florida's oystermen fish in Apalachicola Bay and possess the required Apalachicola Bay Oyster Harvesting Licenses which began being issued in 1989. Over the last three decades, the number of harvesters has ranged from around 400 in 1976 to a peak of 1,430 in 2009 (Table 8.5; oyster harvesters in other parts of the state cannot be distinguished from the total pool of commercial fishers). There was a steady decline in fishermen from the mid-1960s to the low in 1976 followed by an increase again into early-1980s. Since 1983, the number of participants has been fairly level, averaging around 850 per year until recently. Over this period, participation has increased and decreased in response to hurricanes, environmental conditions, and economic cycles; economic pressures have influenced

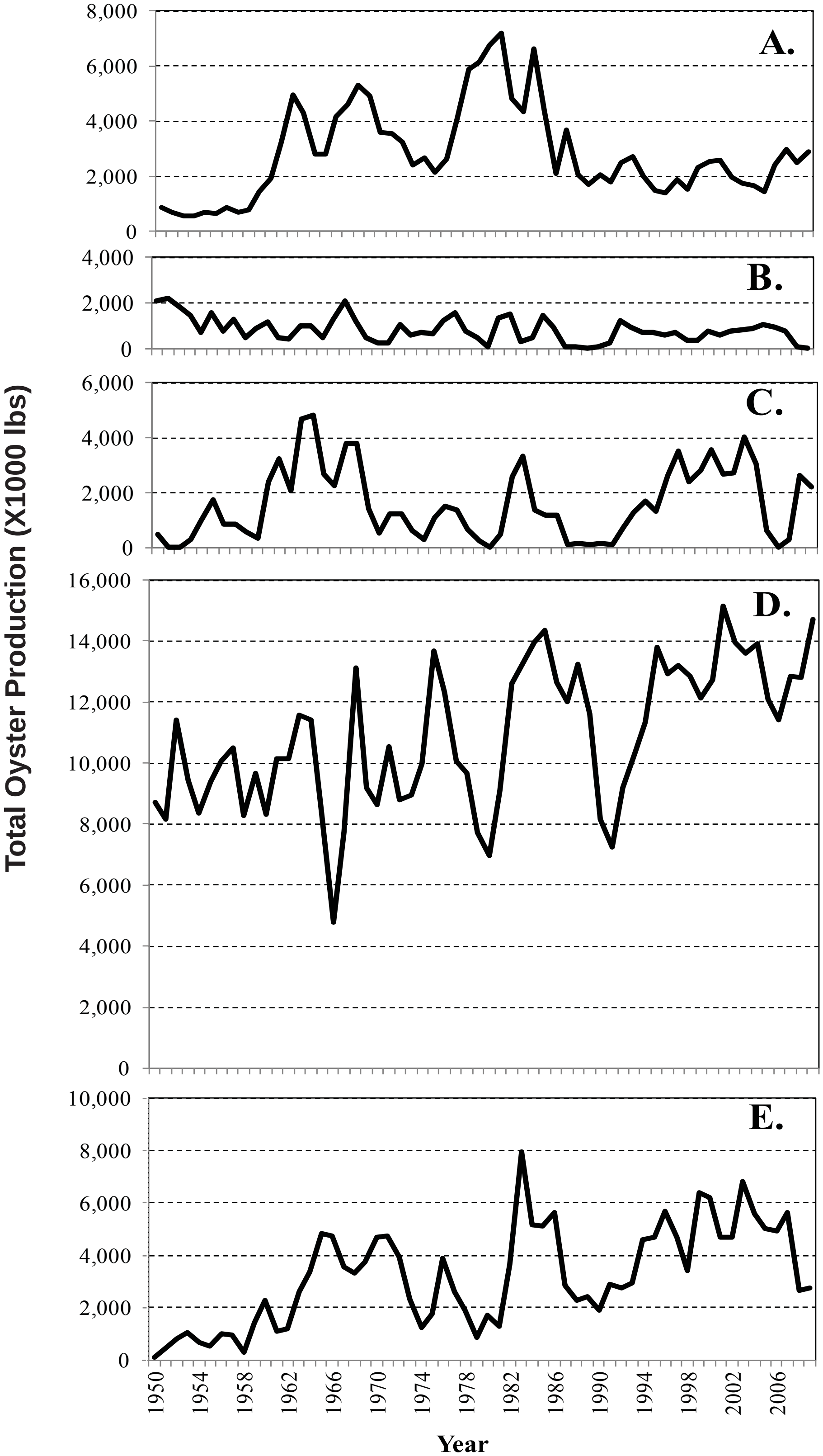


Figure 8.9 Total oyster production (lbs) from 1950-2009 along the Gulf Coast for A. West Florida, B. Alabama, C. Mississippi, D. Louisiana, and E. Texas (NMFS unpublished data).

fishermen to enter and leave the fishery in the last decade. The resident oyster harvesting license costs $100.00, while the non-resident license costs $500.00.

8.2.4.2.2 Alabama

Harvest of oysters on Alabama's public reefs is still predominantly a tong fishery with very limited mechanical dredge harvest allowed (Wallace et al. 1999). Dredging is allowed on private oyster reefs and during limited harvest periods on selected public reefs. On average, 89% of the total Alabama oyster landings came from tongs with only 11% from oyster dredge (the remaining two categories, diver and hand, made up less than 1%; Table 8.7). At present approximately 200 individuals tong oysters full or part-time. The number of tongers per boat averages between 1.5 and 1.7. Dredging on public reefs has been pursued by an average of 12 to 15 individuals with up to 25 dredgers participating in the fishery during the holiday season. In 2010, new legislation for the management of Alabama's oyster fisheries was passed which includes designated areas in Mobile Bay in which dredgers are permitted to harvest oysters.

The earliest recorded landings of oysters from Alabama waters date to 1880 and Alabama has consistently produced oyster landings almost every year for the last 130 years. Since their peak in the early 1950s, the landings in Alabama have steadily declined overall but with wide fluctuations (Figure 8.9B). Generally, annual oyster landings in Alabama have averaged around 610,000 lbs from 1985-2009, and represented about 2.9% of the Gulf total (Table 8.4 and Figure 8.9B). Between 1987-1990, landings averaged 71,770 lbs and were well below the 25-year average owing to extreme drought conditions and subsequent drill predation, but returned to the historic long-term average after 1992 (Dugas et al. 1997). From 2005-2009, drought conditions once again allowed for drill proliferation and predation which, along with the long term destructive effects of Hurricanes Ivan and Katrina, depleted Alabama's oyster reefs and reduced the average landings in 2008/2009 to 47,876 lbs. Because of the depletion of oysters, AMRD closed all public reefs to harvest in March of 2009. A number of storm events in April and September of 2009 reduced the salinity on the public oyster reefs which significantly reduced the number of oyster drills. As of the publication of this management plan, AMRD continues to monitor the recovery of Alabama's oyster reefs to determine a proper time to reopen public reefs for sustainable harvest. Cultch planting and oyster transplanting programs have been implemented by AMRD to aid in the recovery of Alabama's oyster reefs.

In Alabama, the primary oyster production area is the Cedar Point Reef which has produced the greatest amount of oysters on an annual basis for the past 30 years (see Section 17.0 for maps). Portersville Bay reefs and Buoy Reef have ranked second and third, followed by Whitehouse Reef, as top oyster producing areas in Alabama waters (AMRD unpublished data). Oyster resources on Cedar Point Reef are currently low due to the natural events described above. Though spat is present upon Cedar Point suggesting recovery of the reef, few harvestable size oysters were noted as of September 2010 (AMRD unpublished quadrat dive survey data). Portersville Bay has had little commercial harvest since late 2005 when an experimental dredging program was permitted on two designated reefs. Buoy Reef varies in its productivity due to periodic silting. Whitehouse Reef is currently unproductive due to regular hypoxic conditions upon the reef (Johnson et al. 2009).

8.2.4.2.3 Mississippi

The Department of Marine Resources manages 17 natural oyster reefs. Approximately 97% of the commercially harvested oysters in Mississippi come from the reefs in the western Mississippi Sound, primarily from the area termed the 'Square Handkerchief,' which is composed of Henderson Point, Pass Marianne, Telegraph, and Pass Christian reefs. The St. Joe Dredging

Table 8.5 Total landing of eastern oysters (lbs of meat) by gear for western coast of Florida from 1985-2009 (NMFS pers. comm. with [1]corrections from Florida Department of Agriculture and Consumer Services).

Year	Pounds Harvested By:			
	Dredges	**Tongs**	**Other**	**Total**
1985	0	4,393,367[1]	0	4,393,367
1986	0	2,081,151[1]	0	2,081,151
1987	0	3,681,371[1]	0	3,681,371
1988	0	2,065,301[1]	0	2,065,301
1989	0	1,698,403[1]	0	1,698,403
1985 - 1989 Ave	**0**	**2,783,919**	**0**	**2,783,919**
1990	0	2,054,855[1]	0	2,054,855
1991	0	1,793,191[1]	0	1,793,191
1992	0	2,498,516[1]	0	2,498,516
1993	0	2,700,952[1]	0	2,700,952
1994	0	2,011,191[1]	0	2,011,191
1990 - 1994 Ave	**0**	**2,211,741**	**0**	**2,211,741**
1995	0	1,458,393[1]	0	1,458,393
1996	0	1,410,669[1]	0	1,410,669
1997	0	1,858,079	0	1,858,079
1998	0	1,508,723	0	1,508,723
1999	0	2,212,555	0	2,212,555
1995 - 1999 Ave	**0**	**1,689,684**	**0**	**1,689,684**
2000	0	2,484,624	10,757	2,495,381
2001	0	2,513,726	3,882	2,517,608
2002	0	1,906,104	0	1,906,104
2003	0	1,630,367	0	1,630,367
2004	0	1,395,407	0	1,395,407
2000 - 2004 Ave	**0**	**1,986,046**	**2,928**	**1,988,973**
2005	0	1,291,021	0	1,291,021
2006	0	2,352,742	26,961	2,379,703
2007	0	2,942,051	16,652	2,958,703
2008	0	2,501,016	0	2,501,016
2009	0	2,865,717	1,024	2,866,741
2005 - 2009 Ave	**0**	**2,390,509**	**8,927**	**2,399,437**

Reef is the second most important producer, followed by the small tonging reefs of St. Stanislaus/Waveland. Historically Graveline Bayou and Bayou Cumbest were popular tonging reefs in east Jackson County but are currently closed to harvest due to sanitation reclassification (see Section 17.0 for maps of reef locations).

Oyster production in Mississippi averaged 1.8 million lbs annually during 1986-2005 and represented about 8.76% of the Gulf production (Table 8.4). This production is close to that of Florida over the same period (Figure 8.9C). Like Alabama, Mississippi suffered a hard drought from 1987-1991 and oyster landings rebounded with a robust harvest in 2003-2004. Landings fell sharply in 2005 after Hurricane Katrina. In 2006, there was no harvest from Mississippi waters due to the after-effects of both Hurricanes Katrina and Rita in 2005. Considerable effort was

Table 8.6 Apalachicola Bay Oyster Harvesting Licenses sold from FY 1989/1990-2009/2010.

LICENSE YEAR	NUMBER OF LICENSES SOLD
89/90	658
90/91	1,100
91/92	907
92/93	869
93/94	766
94/95	746
95/96	723
96/97	630
97/98	738
98/99	711
99/00	885
00/01	958
01/02	1,135
02/03	914
03/04	759
04/05	719
05/06	714
06/07	916
07/08	1,142
08/09	1,168
09/10	1,430

spent on moving oysters and shell from inshore closed reefs to the public grounds in a rebuilding effort. In 2007, Mississippi's oyster harvest, though minimal at an 18-year low of 299,088 lbs, was allowed to begin again.

Dredging activities traditionally yielded from 60% to more than 90% of Mississippi's annual oyster production; however, when state production was abnormally low, such as 1978-1981, tonged oysters represented the majority of the state's production. From 1985-2009, increases in production are generally related to a larger percentage of the state's production being derived from dredging (Table 8.8).

The numbers of vessels and fishermen engaged in oyster dredging declined relatively steadily during the 1960s and 1970s. Increases in oyster dredging vessels and fishermen were observed in the early 1980s, but numbers declined significantly thereafter. Overall, 200 to more than 700 fishermen were typically involved in oyster dredging in Mississippi waters in a given year. Numbers were reduced to zero in 2006 following Hurricanes Katrina and Rita in 2005 (Table 8.8).

Table 8.7 Total landing of eastern oysters (lbs of meat) by gear for Alabama from 1985-2009 (NMFS pers. comm.).

	Pounds Harvested By:			
Year	**Dredges**	**Tongs**	**Other**	**Total**
1985	0	1,441,847	0	1,441,847
1986	0	945,560	0	945,560
1987	0	88,307	0	88,307
1988	0	103,242	0	103,242
1989	0	11,476	0	11,476
1985 - 1989 Ave	**0**	**518,086**	**0**	**518,086**
1990	0	83,530	0	83,530
1991	15,435	265,524	0	280,959
1992	18,568	1,183,231	0	1,201,799
1993	23,433	893,189	0	916,622
1994	3,172	708,820	0	711,992
1990 - 1994 Ave	**12,122**	**626,859**	**0**	**638,980**
1995	0	709,992	0	709,992
1996	4,306	616,604	0	620,910
1997	3,082	692,238	0	695,320
1998	13,428	326,758	0	340,186
1999	7,484	369,055	0	376,539
1995 - 1999 Ave	**5,660**	**542,929**	**0**	**548,589**
2000	30,024	761,342	542	791,908
2001	68,880	505,928	94	574,902
2002	35,079	720,404	3,645	759,128
2003	184,161	630,821	0	814,982
2004	137,921	768,180	0	906,101
2000 - 2004 Ave	**91,213**	**677,335**	**856**	**769,404**
2005	103,282	937,254	796	1,041,332
2006	85,808	842,445	11,346	939,599
2007	45,031	723,022	0	768,053
2008	20,215	52,200	0	72,415
2009	0	18,785	0	18,785
2005 - 2009 Ave	**50,867**	**514,741**	**2,428**	**568,037**

The number of tongers in Mississippi followed a similar pattern to that observed for dredgers. In general, the number of tongers declined somewhat steadily during the 1960s and 1970s before increasing slightly during the early 1980s. Though increasing, the 399 tongers harvesting oysters on an annual basis during 1981-1983 represented almost a 40% decline from the 1961-1965 average of 628 tongers. In 2003, Mississippi sold 107 resident and non-resident tonging licenses and in 2005, when Katrina and Rita struck, only 8 licenses were sold and there were no landings reported in 2006 as part of the recovery effort. By 2007, license sales began to return at 89 total and 118 in 2008. In 2009, 146 total tonging licenses were sold which returned the tonging fleet to the pre-hurricane levels.

Although highly variable on an annual basis, landings per dredger clearly showed a pattern of decline throughout the 1960s and 1970s. An increase in production per dredger during the first three years of the 1980s was probably due to unusually good production following flooding in 1979. Immediately following the 2005 hurricanes, Mississippi did not harvest any oysters from their waters in 2006 but by 2007, tongers landed around 15,000 lbs, and over 195,000 lbs by 2009 (Table 8.8)

8.2.4.2.4 Louisiana

Louisiana is the largest producer of oysters among the Gulf States and its average annual production of 11.9 million lbs represents close to 60% of the total Gulf production during 1986-2005 (Table 8.4 and Figure 8.9D). Landings in 2006 showed a slight reduction, likely the result of reduced harvest effort following the impacts of Hurricanes Katrina and Rita in late 2005. However, harvest rebounded in 2007-2009 until extensive closures occurred following the British Petroleum Deepwater Horizon Oil Spill in 2010. Those closures severely curbed harvest effort, thereby reducing Louisiana landings below 7 million pounds for only the third time since 1950. Harvest effort is oftentimes restricted by market forces as well. True catch-per-unit-effort (CPUE) information is difficult to collect as self-imposed fishing quotas are set based on demand and processing capabilities. Generally, fishermen only harvest the amount of sacks “ordered” by the processor/dealer.

Louisiana has by far the largest amount of oyster producing area in the Gulf with approximately four million water acres within its estuarine zone. Within this acreage, several types of areas exist: (1) those areas from which a citizen can lease water bottoms for oyster production, (2) those water bottoms set aside for public harvest (Public Oyster Seed Grounds), and (3) areas that are not currently open to the harvest of oysters. These may be closed for public health reasons or considered ‘Unleased State Water Bottoms.’ An estimated 394,000 acres are currently under lease with 1,681,188 acres designated as ’Public Oyster Areas’ (Lezina personal communication).

While Louisiana’s oyster production from private grounds has remained relatively stable during 1961-1988 ranging from 8.5-10.1 million lbs, the acreage devoted to the production of these oysters has increased more than five times. For example, less than 50,000 acres were leased in 1960 compared to about 130,000 acres in the early 1970s, 230,000 acres in the early 1980s, and about 384,000 acres today. The relatively stable production in conjunction with escalating acreage used leads to one or more of the following conclusions: (1) the recently added acreage is not as productive, (2) older leased acreage is losing its productivity and productivity is being replaced by the recently leased acreage, or (3) the average productivity of all leased acreage has been declining during the past three decades. The reality may be that, given changing environmental conditions, oyster lease holders are becoming more diversified regarding lease locations.

The majority of public oyster seed grounds are located east of the Mississippi River in Plaquemines and St. Bernard parishes. Another major public area is located in the central portion of the state in the Vermilion/Atchafalaya Bay complex. This area is highly influenced by the Atchafalaya River system and production is sporadic. The other major public access area is the Calcasieu/Sabine Lake reefs. This area is limited in reef acreage and has been subjected to numerous closures due to public health concerns. There are four remaining areas referred to as ‘Oyster Seed Reservations’ which are relatively small in total acreage but contribute to overall production from the public grounds.

Historically, production in Louisiana comes primarily from leased bottoms; however, the public seed grounds exhibited sizable increases in production during the 1990s and early 2000s (LDWF 2005). Harvest of oysters from public grounds has increased since 1992 and exceeded lease harvest in 1996 and 2002 (LDWF 2010). During calendar year 2008, public areas were responsible for 49% of total harvest, yet dropped to only 23% of the total harvest in 2009. Although private leases are responsible for a significant portion of total harvest (Figure 8.10), most leased oysters begin their lives as seed oysters on the public grounds. Chatry (1987) estimated that from two to three boat loads of marketable oysters are recovered for every boat load of seed oysters bedded on leases. The department maintains an active seed ground rehabilitation program that places cultch to either create new reefs or nourish and enhance older reefs.

Table 8.8 Total landing of eastern oysters (lbs of meat) by gear for Mississippi from 1985-2009 (NMFS pers. comm.).

Year	Pounds Harvested By:			
	Dredges	Tongs	Other	Total
1985	1,156,351	36,299	0	1,192,650
1986	930,845	271,170	0	1,202,015
1987	57,983	74,120	0	132,103
1988	98,887	47,533	182	146,602
1989	25,101	74,625	383	100,109
1985 - 1989 Ave	**453,833**	**100,749**	**113**	**554,696**
1990	4,852	141,772	893	147,517
1991	61,825	40,205	46	102,076
1992	686,473	21,535	160	708,168
1993	1,018,008	178,992	0	1,197,000
1994	854,273	168,192	0	1,022,465
1990 - 1994 Ave	**525,086**	**110,139**	**220**	**635,445**
1995	1,233,638	93,462	0	1,327,100
1996	1,552,956	70,822	0	1,623,778
1997	1,909,016	184,132	0	2,093,148
1998	1,253,144	91,544	0	1,344,688
1999	1,220,384	187,425	0	1,407,809
1995 - 1999 Ave	**1,433,828**	**125,477**	**0**	**1,559,305**
2000	3,335,736	212,504	0	3,548,240
2001	2,166,208	487,062	0	2,653,270
2002	2,318,704	67,568	0	2,386,272
2003	3,532,792	509,344	0	4,042,136
2004	2,687,128	342,263	0	3,029,391
2000 - 2004 Ave	**2,808,114**	**323,748**	**0**	**3,131,862**
2005	424,928	185,456	0	610,384
2006	0	0	0	0
2007	284,080	15,008	0	299,088
2008	2,465,605	144,744	0	2,610,349
2009	1,996,468	195,256	0	2,191,724
2005 - 2009 Ave	**1,034,216**	**108,093**	**0**	**1,142,309**

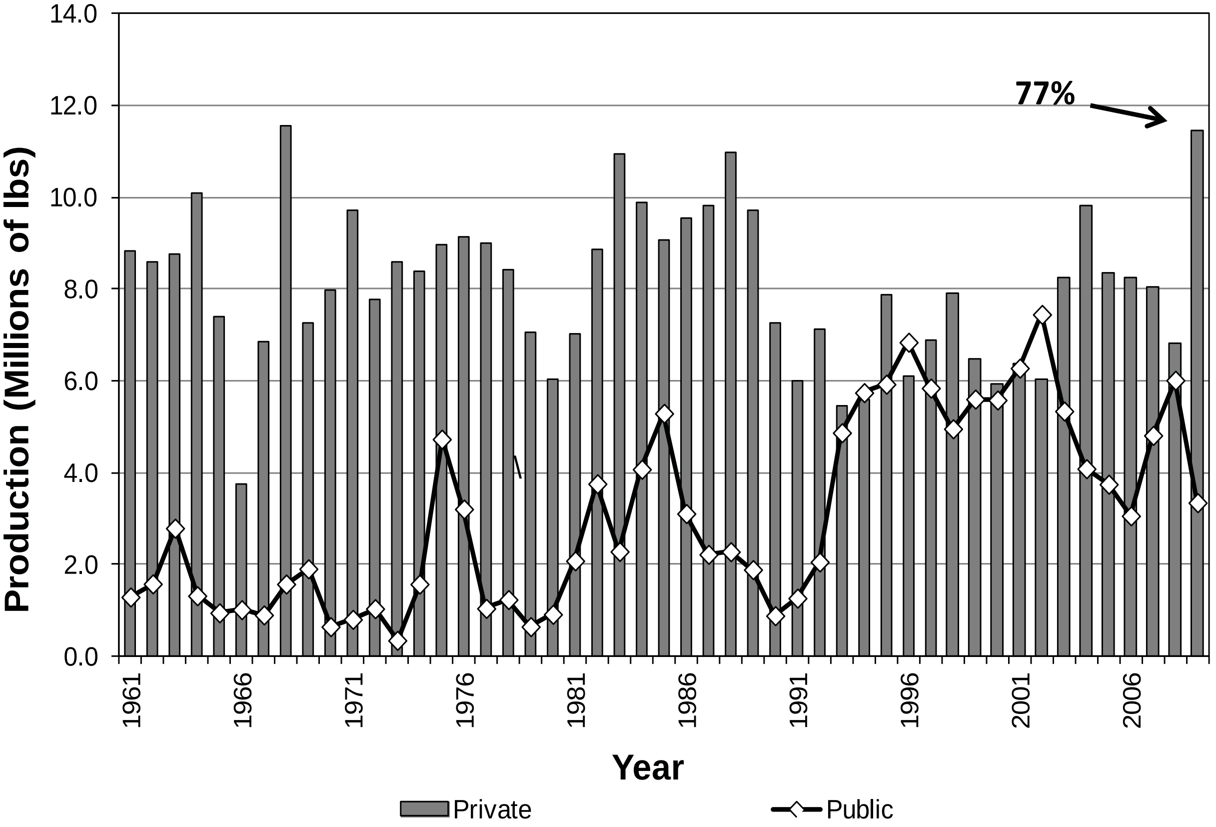


Figure 8.10 Total production of oysters from leases (private) and public grounds in Louisiana from 1961-2009 (LDWF unpublished data). *Note:* Long-term average for private landings is 8.007 million pounds and 3.065 million pounds for public.

Louisiana oyster harvest activity is dominated by the use of dredges. Landings data indicate that >90% of all Louisiana landings since 1999 are attributed to dredge harvest, although other harvest methods are employed on small scales (Table 8.9). Both tonging and hand-collection is still in use today as harvest methods, but in sparse occurrence (Figure 8.11). Until a law change in 2004 which allowed the use of small hand dredges (36" wide and less), oyster harvest in Calcasieu Lake was restricted to tonging-only. Pre-2004 harvest in Calcasieu Lake accounted for only a small percentage of overall, statewide harvest, but accounted for nearly 100% of the statewide harvest by tongs. Since 2004, almost no harvest is recorded through the use of tongs and hand-collections occur very infrequently and only on private leases.

Licensing sales in Louisiana have remained relatively stable over time, although a recent uptick has been documented for 2010 (Figure 8.12). Inherent difficulties exist when trying to determine the number of persons and the number of vessels engaged in the Louisiana oyster industry. The captain of each harvest vessel is required to hold an oyster harvester license. Therefore, this license is one indication of human participation in the oyster harvest sector, although it is likely that many persons hold licenses which do not participate on a full-time basis in the harvesting sector. Licenses issued by the state of Louisiana for oyster industry participation also include oyster dredge license, oyster tong license, oyster seed ground vessel permit, oyster cargo license, and out-of-state oyster landing permit. The oyster dredge license is required per dredge, and since Louisiana law allows for up to seven dredges in use on one vessel, multiple dredge licenses could be tied to one vessel thereby making it difficult to determine the number of vessels engaged in oyster harvest by a simple review of dredge license sales.

Table 8.9 Total landing of eastern oysters (lbs of meat) by gear for Louisiana from 1985-2009 (NMFS pers. comm.).

Year	Pounds Harvested By:			
	Dredges	Tongs	Other	Total
1985	14,246,413	79,729	0	14,326,142
1986	12,533,305	114,338	0	12,647,643
1987	11,760,469	199,348	58,929	12,018,746
1988	13,001,169	248,245	0	13,249,414
1989	11,565,744	19,631	13,654	11,599,029
1985 - 1989 Ave	**12,621,420**	**132,258**	**14,517**	**12,768,195**
1990	8,153,371	0	0	8,153,371
1991	0	0	7,265,084	7,265,084
1992	0	0	9,183,295	9,183,295
1993	0	0	10,314,823	10,314,823
1994	0	0	11,327,730	11,327,730
1990 - 1994 Ave	**1,630,674**	**0**	**7,618,186**	**9,248,861**
1995	0	0	13,800,076	13,800,076
1996	0	0	12,934,925	12,934,925
1997	0	0	13,221,705	13,221,705
1998	0	0	12,856,173	12,856,173
1999	0	0	12,128,187	12,128,187
1995 - 1999 Ave	**0**	**0**	**12,988,213**	**12,988,213**
2000	11,686,828	290,234	717,987	12,695,049
2001	14,391,585	211,666	518,768	15,122,019
2002	13,676,923	132,062	0	13,808,985
2003	13,162,815	146,835	246,360	13,556,010
2004	13,338,039	137,080	424,970	13,900,089
2000 - 2004 Ave	**13,251,238**	**183,575**	**381,617**	**13,816,430**
2005	11,463,614	293,817	337,483	12,094,914
2006	11,270,124	0	115,792	11,385,916
2007	12,670,554	453	182,447	12,853,454
2008	12,557,494	0	231,334	12,788,828
2009	14,307,234	0	416,168	14,723,402
2005 - 2009 Ave	**12,453,804**	**58,854**	**256,645**	**12,769,303**

In use since 1999, the Louisiana trip-ticket program is an additional method by which to determine both individual participation and vessel participation in the harvesting sector of the oyster industry. Trip-ticket data indicate that the number of unique vessels landing oysters since 2001 has remained relatively stable, although a marked decrease in vessel participation was evident in 2006 and is likely a result of impacts from Hurricanes Katrina and Rita in late 2005. Participating vessel numbers have rebounded, however, with nearly 850 separate vessels landing oysters during the calendar year 2010 (Table 8.10).

The Louisiana Wildlife and Fisheries Commission sets the public oyster season using oyster stock availability data along with recommendations by the LDWF and the Louisiana Oyster Task Force. Long-term population abundance data indicate the Louisiana oyster stock on the public oyster seed grounds was stable at relatively low levels from 1982 to the early 1990s, increased

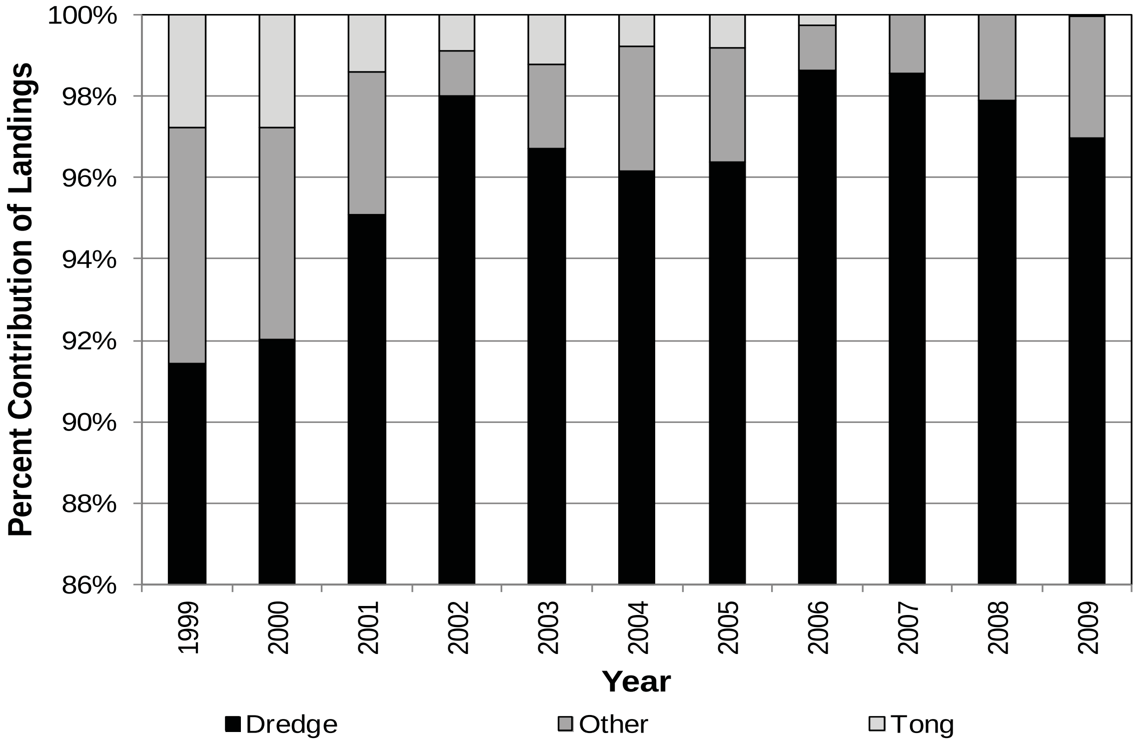


Figure 8.11 Percent contribution of total commercial oyster landings in Louisiana from lease and public grounds from 1999-2009 (LDWF Unpublished Trip-Ticket Data).

until 2001, and declined during 2002-2008 (LDWF 2009). The 2010 oyster stock availability of 1,224,377 barrels was one of the lowest stock sizes since 1990 although it did represent a small 4.7% increase over 2009 levels.

8.2.4.2.5 Texas

The Texas commercial oyster fishery is comprised of two components: the public reef fishery and the private lease fishery. The public reef fishery operates from November 1 of one year through April 30 of the next year. Only oysters occurring on public reefs are available for harvest. Public reefs are those occurring in 'approved' or 'conditionally approved' waters as determined by the Texas Department of State Health Services, Seafood and Aquatic Life Group (DSHS). All commercial oyster harvest in Texas is done using dredges.

The long-term trend in Texas oyster landings has generally trended upward since the 1960s with the highest landings (7.9 million lbs) reported in 1983 (Table 8.4, Figure 8.9A, and Figure 8.13). Following a decline in landings over the decade following this high, annual production increased to almost seven million lbs in 2003. Over the 10-year period, 1998-2007, landings averaged 5.4 million lbs representing about 23% of the total Gulf of Mexico production during this period and ranked Texas second in long-term annual production in the Gulf of Mexico. Texas landings in 2008 fell by 49.8% from the 10-year average, 1998-2007, primarily as a result of losses to oyster habitat from Hurricane Ike and the subsequent closing of Galveston Bay for part of the commercial public reef season. Sixty-four percent of the state's total reef area was located in Galveston Bay prior to Hurricane Ike (September 13, 2008). Approximately half (8,000 acres) of the consolidated oyster habitat in Galveston Bay was lost due to hurricane-induced sedimentation (TPWD unpublished data) from this storm. Matagorda Bay is second among the state's five major oyster producing bay systems with 23% of the state's total reef acreage.

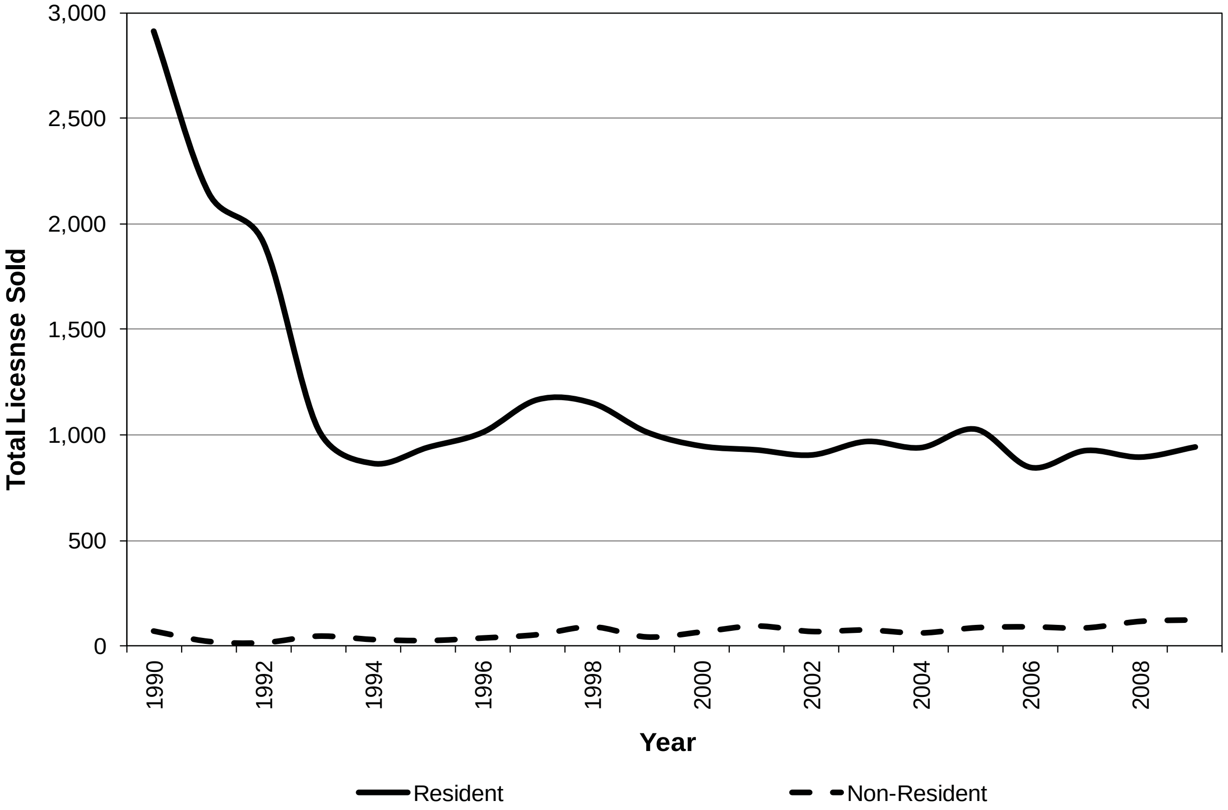


Figure 8.12 Total oyster harvesting licenses sold from 1990-2009 in Louisiana. **Note:** Beginning in 1993 only the captain was required to have an oyster harvester license.

There are approximately 41,686 acres of oyster reef in Texas: 2,680 acres in restricted waters and 39,006 acres in approved waters. The majority of Texas commercial oyster landings have historically come from Galveston Bay (Table 8.11). Hofstetter (1988) estimated that within Galveston Bay, four areas account for most of the commercial landings; Redfish Bar (75%), Todd's Reef (10%), and East and West bays (5%-10%). The San Antonio, Matagorda, and Aransas bay systems combined have produced approximately 25% (Table 8.11). Though there are a few scattered oyster reefs below Nueces Bay they are small, in shallow water and rarely fished, generally accounting for less than 1% of the total commercial landings in Texas.

Leases are found only in Galveston Bay and are utilized as depuration locations for oysters transplanted from restricted waters only. Lease harvest comprised approximately 22% of the total commercial landings in Texas over the period 1994-2008 (Table 8.12).

Historically, oysters have been harvested in Texas using a variety of fishing gears including dredges, tongs, and by hand; however, the majority of landings have been attributed to dredges (Table 8.13). During 1961-1965, an average of 537 oystermen were dredging from 135 boats and 83 vessels. By 1981-1985, the number of oystermen had declined to 349 and the number of boats had declined to an average of 54 (TPWD has not issued these types of licenses since the mid-1980s). The number of vessels increased sharply until the mid-1970s, before declining to an average of 106 during 1981-1985. Dredges have been used exclusively to commercially harvest oysters in Texas since the mid-1970s. Gear licenses (dredge and tongs) were not required after 1987.

Table 8.10 Number of unique vessels landing oysters from public and private grounds in Louisiana during the 1999-2009 time periods (LDWF Unpublished Trip-Ticket Data). **Note**: public and private columns are <u>not</u> additive to produce the total column.

Year	Vessels on Public Grounds	Vessels on Private Leases	Total Vessels
1999	1040	957	1624
2000	823	630	1117
2001	645	494	801
2002	606	381	684
2003	634	526	791
2004	594	589	834
2005	587	615	865
2006	463	437	624
2007	582	498	736
2008	576	450	719
2009	648	530	862

The Texas oyster industry is currently under a license management program whereby no new licenses are being issued by TPWD. Prior to implementation of this program the number of commercial oyster boat licenses purchased from 1995-2004 was 330 on average. When the program was implemented in 2005, the control date for qualification was set in the future, which resulted in an immediate increase in the number of licenses purchased relative to the average over the previous decade (Figure 8.14); however, the numbers of licenses that report landings during the year remain similar to the numbers prior to the implementation of this program (TPWD unpublished data). A license must be renewed each year to maintain participation in the fishery and there is no buy-back component for this license management program.

There were 685 licensed commercial oyster boats licensed during the 2008 fishing season (681 resident and four non-resident), an 11% reduction in the total number of licenses that were purchased the first year of the license management program. Of these 685 licensed commercial oyster boats, only 312 reported landings during the same year (TPWD unpublished data). Approximately 60% of the fleet was located in the Galveston Bay complex with 22% in Matagorda Bay (TPWD unpublished data); however, the fleet is highly mobile and will move between bay systems depending on the availability of oysters. The minimum legal size for oysters in Texas is three inches (7.6 cm) and boats operate on a 90 sack per day limit (110 lbs per sack). Commercial fishing is allowed from sunrise to sunset.

8.3 Non-Commercial Fishery

Recreational harvesters have utilized production beds for years, but there is very little data on the effort and landings attributable to non-commercial harvest. It is not uncommon for hunters and recreational anglers to gather and consume oysters from shoreline beds. These are not always from areas that are ‘approved’ for safe harvest but the individuals still take the risk.

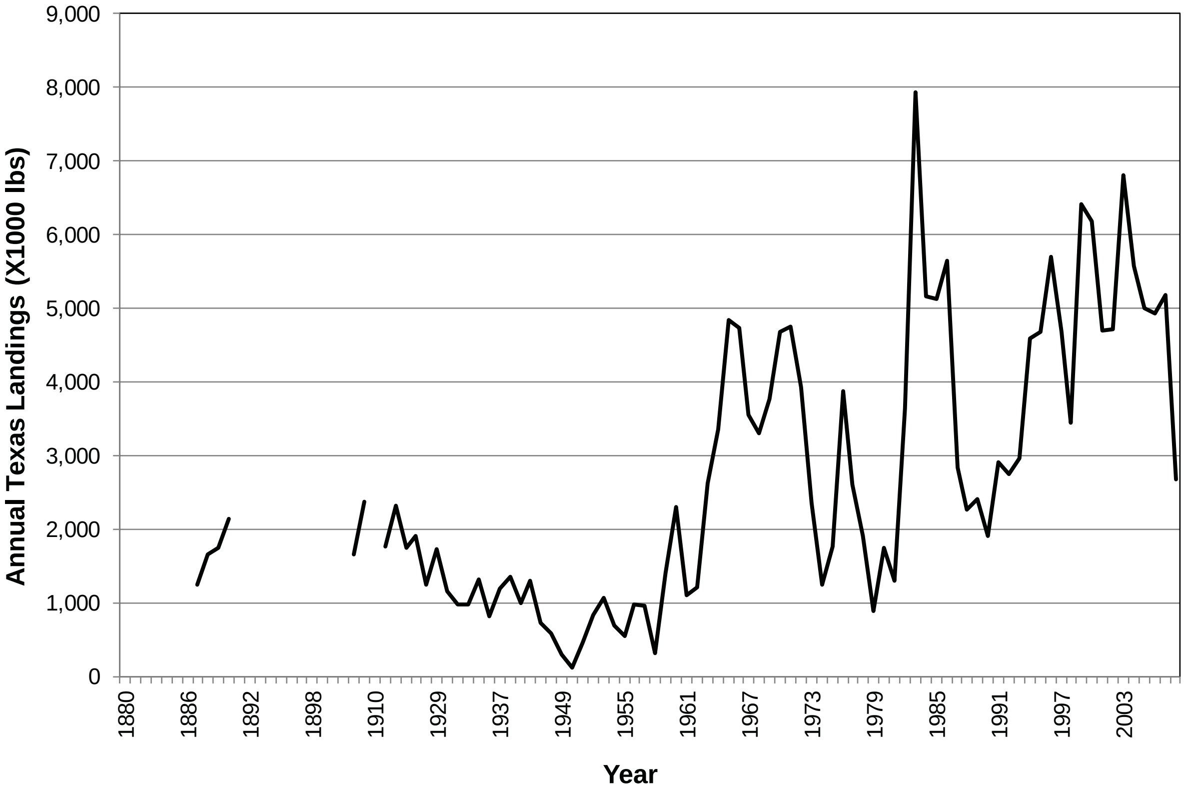


Figure 8.13 Annual commercial landings (meat-weight) of oysters harvested from Texas coastal waters from 1880-2009 (TPWD unpublished data).

Oyster gardening is a societal approach to community based habitat restoration. The general public is encouraged to 'plant' oysters either in their local area as future reefs or in containers which are 'tended' similar to large scale culturing operations. The concept is that the oysters grown by the individual provide a 'nutrient removal'/'water cleaning' function for the estuary and upon completion of the grow-out, provide additional live material for the state to relay or plant on public grounds or use in other restoration projects. For more information on oyster gardening, see Section 16.2.5.

8.3.1 Development of the Fishery

The earliest inhabitants of the Gulf coastal area to some degree, subsisted on oysters. Through history and even today, many coastal residents harvest oysters for their own personal consumption. In recent years, owing to hurricane events, commercial catches have become quite variable and prices have increased. As a result, more people have likely become involved in noncommercial/subsistence fishing in general. However, statistics are not available to validate this activity.

8.3.2 Fishing Methods, Gear, Boats, and Vessels

Gear and fishing methods employed by the commercial and noncommercial portions of the fishery are basically the same. Many types and sizes of boats and vessels may be employed and likely include a number of recreational tongers as well.

8.3.3 Historical Catch Statistics

There is very little data on recreational oyster harvesting. The 1988 Texas Oyster Fishery Management Plan presents data that indicate the CPUE for recreational harvest was 0.3 kg (0.66 lbs.) of oyster meat per hour from 1983-1986. During the same period the average annual coast-wide landings were 5,300 kg (11,684 lbs.) of meat (Quast et al.1988). Effort increased each year of the survey rising from 19,610 to 23,730 man-hours per year (Quast et al. 1988). Recreational oyster fishing activity was relatively low compared to finfish fishermen (Quast et al. 1988). Berrigan et

Table 8.11 Annual commercial landings (meat-weight) of oysters harvested, by bay system, from Texas coastal waters, 1981-2008 (TPWD data).

Year	Galveston Bay		East Matagorda Bay		West Matagorda Bay		San Antonio Bay	
	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)
1981	985.41	1,568.05	27.50	43.80	88.66	130.35	142.64	194.68
1982	3,253.77	4,781.38	-	-	270.38	389.59	53.92	63.74
1983	6,967.06	9,946.28	17.57	26.99	199.94	264.76	635.62	908.94
1984	2,360.21	4,015.27	58.32	96.49	448.64	732.03	1,937.34	2,917.68
1985	3,285.11	5,958.14	2.47	4.22	123.35	198.72	1,500.34	2,239.73
1986	3,541.05	6,956.43	-	-	383.15	597.83	1,627.79	2,774.00
1987	2,174.87	5,376.95	1.38	2.29	189.08	368.77	93.14	186.66
1988	1,452.37	3,921.79	0.89	1.84	521.06	1,023.27	8.93	22.31
1989	715.17	2,137.67	0.93	1.70	915.26	1,766.74	139.84	355.03
1990	1,166.65	4,093.49	13.14	35.73	73.24	179.64	591.15	1,410.15
1991	2,331.38	5,967.52	0.23	0.47	25.59	46.50	625.69	1,195.01
1992	2,581.13	4,874.36	-	-	55.86	91.10	65.07	111.54
1993	2,832.42	4,420.03	-	-	59.84	84.27	-	-
1994	4,230.79	7,247.43	-	-	30.33	45.98	290.78	468.55
1995	4,096.19	7,948.37	-	-	167.50	231.85	311.08	459.65
1996	4,892.24	11,012.91	3.71	6.83	238.77	503.02	421.13	689.65
1997	3,495.88	8,990.36	71.70	147.94	317.33	709.36	344.14	652.61
1998	2,969.11	7,071.14	1.70	4.07	295.23	745.29	35.93	86.28
1999	6,132.63	13,224.75	60.87	116.98	93.79	188.76	43.16	82.18
2000	6,008.54	13,484.57	0.67	1.37	146.86	282.30	5.81	11.66
2001	4,506.04	10,683.98	-	-	164.09	370.29	61.34	137.39
2002	4,228.46	10,156.80	-	-	128.79	299.24	217.34	48.37
2003	6,094.31	14,732.48	-	-	135.61	316.96	161.76	364.90
2004	4,859.89	13,109.64	-	-	373.97	925.25	143.69	400.98
2005	3,164.57	10,671.50	-	-	195.06	538.51	884.60	2,597.75
2006	2,755.30	10,626.72	-	-	501.49	1,536.93	1,284.58	4,169.13
2007	2,775.23	9,993.29	2.82	8.53	585.74	1,877.97	1,278.94	4,255.93
2008	2,005.43	6,777.52	9.71	29.97	137.33	428.15	84.81	267.93

Note: Galveston Bay includes upper and lower Galveston Bay, Trinity, East and West Bays.
Note: West Matagorda Bay includes W. Matagorda and Lavaca Bays.
Note: San Antonio Bay includes San Antonio and Espirito Santo Bays.

Table 8.11 Con't.

Year	Aransas Bay		Corpus Christi Bay		Upper Laguna Madre		Lower Laguna Madre	
	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)	Landings (lbs x 1000)	Ex-vessel Value ($ x 1000)
1981	62.37	91.65	-	-	-	-	-	-
1982	51.51	72.48	-	-	-	-	3.57	6.53
1983	117.12	183.90	-	-	-	-	3.43	5.79
1984	359.95	540.83	-	-	-	-	3.28	6.41
1985	216.82	342.30	-	-	-	-	5.85	11.73
1986	97.13	158.26	-	-	-	-	0.12	0.23
1987	433.19	944.90	0.40	1.15	-	-	4.08	8.45
1988	276.37	676.68	0.17	0.50	0.44	1.25	9.07	21.54
1989	118.62	286.50	-	-	0.26	0.72	84.49	343.60
1990	11.24	42.08	0.03	0.04	-	-	5.20	16.20
1991	-	-	0.28	1.15	-	-	5.06	12.62
1992	-	-	-	-	-	-	3.62	8.88
1993	34.60	53.24	-	-	-	-	-	-
1994	29.59	36.49	-	-	-	-	-	-
1995	95.81	148.07	-	-	-	-	-	-
1996	30.10	50.17	-	-	-	-	-	-
1997	436.82	903.43	21.16	47.15	-	-	-	-
1998	135.96	375.70	-	-	-	-	-	-
1999	80.78	207.72	-	-	-	-	-	-
2000	25.93	66.69	-	-	-	-	-	-
2001	42.89	96.99	-	-	-	-	-	-
2002	110.67	274.09	-	-	-	-	-	-
2003	435.14	1,108.75	-	-	-	-	-	-
2004	201.94	547.67	-	-	-	-	-	-
2005	817.29	2,351.02	-	-	-	-	-	-
2006	1,498.88	4,852.20	-	-	-	-	-	-
2007	993.51	3,118.93	-	-	-	-	-	-
2008	451.63	1,361.42	0.17	0.51	-	-	-	-

Note: Aransas Bay includes Aransas, Copano, and Mesquite Bays.

al. (1991) concluded that it is likely more people have become involved in noncommercial oyster fishing in the past ten years due to variable market supplies and increased prices. Harvest data are unavailable for noncommercial fisheries; however, Mississippi, Louisiana, Florida, and Texas require licenses for these harvesters and daily limits are set by all states (see Section 7.0).

8.4 Description of Leases

8.4.1 Florida

In 1881, the first action passed by the Florida Legislature was an act relating to the use of sovereignty submerged lands for oyster cultivation activities. Oyster cultivation grants were

Table 8.12 Annual landings (meat weight, lbs) and ex-vessel value of oysters harvested from Texas public reefs and private leases for the period 1981-2008.

Year	Public Reefs		Private Leases		Totals	
	Landings (meat wt.-lbs)	**Ex-vessel value ($)**	**Landings (meat wt.-lbs)**	**Ex-vessel value ($)**	**Landings (meat wt.-lbs)**	**Ex-vessel value ($)**
1981	830,900	1,273,600	475,700	754,900	1,306,600	2,028,500
1982	3,130,800	4,575,600	502,300	738,100	3,633,100	5,313,700
1983	7,076,400	10,102,800	864,300	1,233,900	7,940,700	11,336,700
1984	4,623,900	7,383,600	543,800	925,100	5,167,700	8,308,700
1985	4,748,500	8,056,000	385,400	698,800	5,133,900	8,754,800
1986	4,163,200	7,567,500	1,486,100	2,919,300	5,649,300	10,486,800
1987	1,732,700	4,120,200	1,164,400	2,771,200	2,897,100	6,891,400
1988	1,495,000	3,730,900	774,300	1,938,300	2,269,300	5,669,200
1989	1,674,100	4,199,100	717,300	1,782,500	2,391,400	5,981,600
1990	1,156,500	3,185,500	704,200	2,591,800	1,860,700	5,777,300
1991	2,085,600	4,643,600	902,600	2,579,700	2,988,200	7,223,300
1992	1,942,400	3,511,100	763,300	1,574,800	2,705,700	5,085,900
1993	2,411,000	3,715,500	515,900	842,000	2,926,900	4,557,500
1994	3,356,100	5,788,800	1,225,400	2,009,700	4,581,500	7,798,500
1995	3,519,900	6,670,700	1,150,700	2,117,300	4,670,600	8,788,000
1996	4,128,700	8,999,200	1,457,500	3,263,400	5,586,200	12,262,600
1997	3,699,800	8,884,800	987,200	2,566,100	4,687,000	11,450,900
1998	3,023,300	7,283,000	414,600	999,500	3,437,900	8,282,500
1999	4,974,000	10,774,900	1,437,200	3,045,500	6,411,200	13,820,400
2000	4,637,800	10,219,600	1,550,000	3,627,000	6,187,800	13,846,600
2001	3,497,300	8,057,800	1,278,100	3,233,600	4,775,400	11,291,400
2002	3,297,400	7,693,200	1,410,600	3,582,900	4,708,000	11,276,100
2003	5,126,600	12,048,800	1,706,800	4,488,900	6,833,400	16,537,700
2004	3,941,100	10,430,700	1,578,400	4,387,900	5,519,500	14,818,600
2005	3,927,500	12,257,800	1,134,000	3,901,000	5,061,500	16,158,800
2006	4,792,800	16,238,500	1,224,300	4,860,500	6,017,100	21,099,000
2007	4,610,700	15,431,400	1,022,700	3,814,700	5,633,400	19,246,100
2008	2,144,600	6,931,800	534,600	1,903,200	2,679,200	8,835,000

approved by the board of county commissioners in the county where the proposed grant was located. Contractual stipulations required that the grantee cultivate barren bottoms using shell or live oysters, and enabled the grantee to harvest exclusively and hold title to the cultivated bottoms indefinitely (Whitfield and Beaumariage 1977). Grant fees were $0.05 per acre, and no cap was placed on the size of shellfish cultivation grant sites. Concerns and disagreements between grant applicants, riparian upland property owners, and county commissions were common.

In 1913, the Legislature adopted a comprehensive leasing program under Chapter 370, Florida Statutes (F.S.), in order to: 1) issue leases instead of grants; 2) transfer the authority to approve shellfish cultivation activities from affected county commissions to the Commissioner of Agriculture and the Florida Shellfish Commission; 3) reduce the affected riparian upland owner's power to that of a first refusal on the lease; and 4) include a minimum production requirement.

Table 8.13 Total landing of eastern oysters (lbs of meat) by gear for Texas from 1985-2009 (NMFS pers. comm. with [1]corrections from the TPWD).

Year	Pounds Harvested By:			
	Dredges	**Tongs**	**Other**	**Total**
1985	5,133,937	0	0	5,133,937
1986	5,649,191	123	0	5,649,314
1987	2,676,245	4,081	163,293	2,843,619
1988	2,258,945	10,627	0	2,269,572
1989	2,405,029	0	0	2,405,029
1985 - 1989 Ave	**3,624,669**	**2,966**	**32,659**	**3,660,294**
1990	1,902,697	0	0	1,902,697
1991	2,915,986	0	0	2,915,986
1992	2,747,909	0	0	2,747,909
1993	2,964,374	0	0	2,964,374
1994	4,580,186	0	0	4,580,186
1990 - 1994 Ave	**3,022,230**	**0**	**0**	**3,022,230**
1995	4,670,598	0	0	4,670,598
1996	5,705,412	0	0	5,705,412
1997	4,687,029	0	0	4,687,029
1998	3,437,926	0	0	3,437,926
1999	6,411,229	0	0	6,411,229
1995 - 1999 Ave	**4,982,439**	**0**	**0**	**4,982,439**
2000	6,187,818	0	0	6,187,818
2001	4,700,475	0	0	4,700,475
2002	4,707,968	0	0	4,707,968
2003	6,813,469	0	0	6,813,469
2004	5,568,870	0	0	5,568,870
2000 - 2004 Ave	**5,595,720**	**0**	**0**	**5,595,720**
2005	5,007,472	0	0	5,007,472
2006	6,017,100[1]	0	0	6,017,100
2007	5,633,412	0	0	5,633,412
2008	2,679,207	0	0	2,679,207
2009	2,733,150	0	0	2,733,150
2005 - 2009 Ave	**4,414,068**	**0**	**0**	4,414,068

The latter action was taken because the overwhelming majority of all grants and leases were not being cultivated, and thousands of acres of sovereignty submerged lands had been removed from wild commercial oyster production. The law provided for a maximum size restriction of 500 acres. The first shellfish lease was approved by the Commissioner of Agriculture on May 1, 1914. In the late 1920s lease fees were raised to $5.00 per acre; consequently, some lessees filed suit in an attempt to prevent the State from assessing the higher fees. The Supreme Court favored the State and lessees were required to pay the higher fees. Consequently, many grants were terminated due to nonpayment of fees.

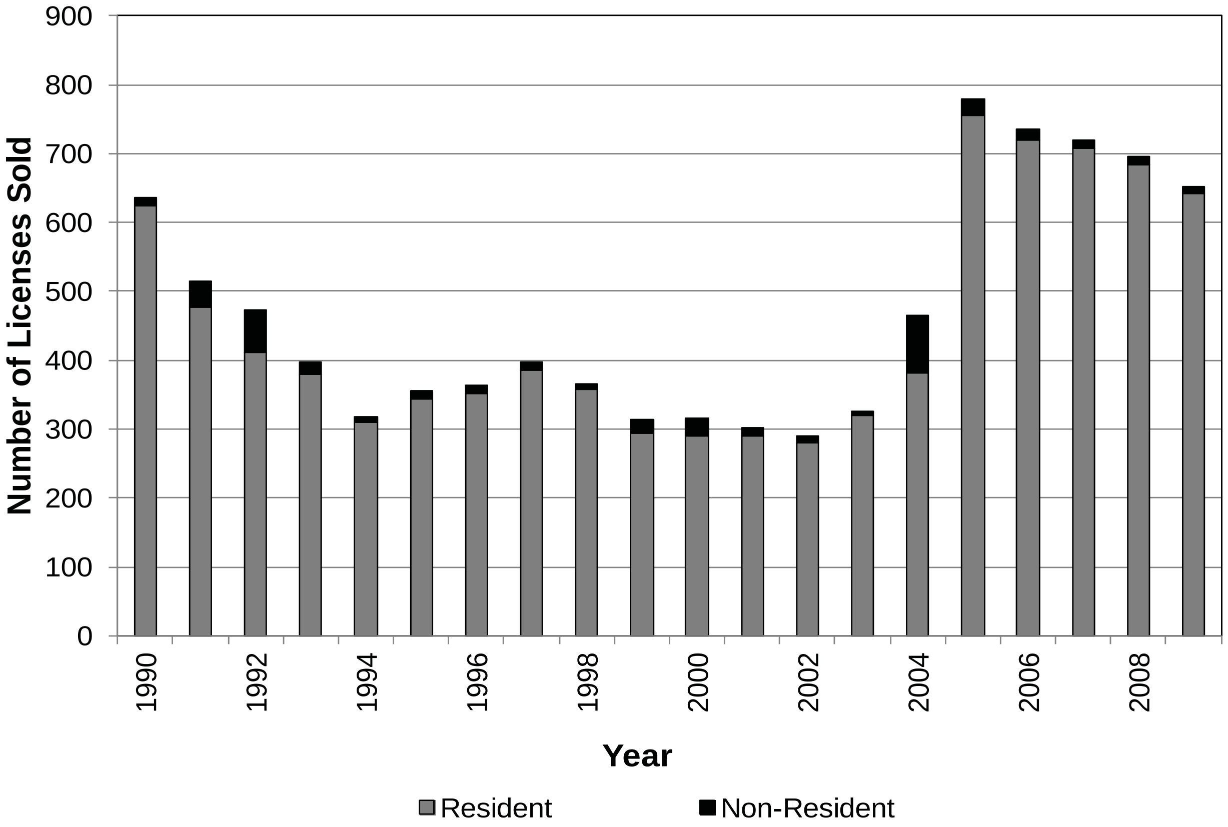


Figure 8.14 Resident and non-resident oyster boat licenses sold in Texas, 1990-2009. The Oyster License Management Program was implemented in 2005.

In 1933, the Legislature passed a law that provided for the shellfish leasing program to be transferred from the Commissioner of Agriculture to the newly created State Board of Conservation, composed of the members of the Board of Trustees of the Internal Improvement Trust Fund. In 1961, the Legislature enacted Chapter 61-502, F.S., which made the existing grants issued under the 1881 act, subject to the provisions of Chapter 370, F.S. In 1969, the Florida Department of Natural Resources assumed the duty of issuing shellfish leases authorized under Chapter 370, F.S., and the Executive Director was delegated the authority to approve shellfish leases administratively. Oyster shellfish leases were authorized under Chapter 370 until 1984, when the Department of Natural Resources (DNR) imposed a moratorium on the issuance of shellfish leases under this chapter. Subsequently, in 1989, the issuance of shellfish leases under Chapter 370, F.S. was prohibited. At that time the majority of shellfish leases were perpetual in nature, and many leaseholders have litigated shellfish lease issues in demonstration of rights that they have in their lease agreements under Chapter 370, F.S.

In 1969, the Legislature provided for a new leasing program pursuant to Sections 253.67 – 253.75, F.S. The intent of these laws was to provide for a new concept in shellfish production. In 1982, Chapter 16Q-21, Florida Administrative Code (F.A.C.), was amended to provide the initial guidelines for reviewing aquaculture lease applications. In 1984, the Legislature enacted the “Florida Aquaculture Policy Act.” which recognized that a coordination of the state’s fragmented aquaculture efforts was necessary to develop a healthy aquaculture industry. It required the Department of Agriculture and Consumer Services to develop a statewide aquaculture plan that would identify the problems of the aquaculture industry and propose possible solutions.

In 1986, amendments to Chapter 18-21, F.A.C., were adopted which included application review and approval processes for aquaculture lease application submitted to the Board of Trustees for authorization. Amendments allowed the DNR's Division of State Lands to review aquaculture lease applications, and the annual lease fee was set at a minimum rate of $15.00 per acre for a bottom lease and $30.00 per acre for a water column lease (preempts more than six-inches of the water column). In 1988, Chapter 258, F.S., was amended to include a declaration that aquaculture is in the public interest provided that resources, most prominently in aquatic preserves, are not adversely impacted. On September 13, 1988, the first two aquaculture leases were approved pursuant to Chapter 253, F.S.

During the 1989 session, the Legislature approved the new lease fee rate and prohibited issuance of new shellfish leases and the use of mechanical harvesting devices on shellfish leases in Franklin County. Later that year, several shellfish lessees in Franklin County filed a successful appeal to the shellfish lease fee increase and the mechanical harvesting prohibition. Subsequently, shellfish lease fees were reduced by the court decision back to the $5.00 per acre or fraction of acre thereof. Additionally, the Franklin County Board of County Commissioners filed complaints about the use of mechanical harvesting devices on the leases.

Chapter 253, F.S. was amended by the Legislature in 1989 creating aquaculture leases as the exclusive mechanism for using sovereignty submerged lands for all aquacultural activities. Chapter 253, F.S., provided the authority and conditions for leasing sovereignty submerged lands and the water column for the purpose of aquaculture. Subject to the limitations contained in Sections 253.67-253.75, F.S., the Board of Trustees may lease submerged lands to which it has title for the conduct of aquaculture activities and grant exclusive use of the bottom and the water column to the extent required by those activities. Chapter 18-21, F.A.C. was amended in 2009 to include the Sections 18-21.020 - 18-21.022 which provide the standards, policies, conditions, criteria, and fees for aquaculture leases (FALP/DACS 2008).

Since the first shellfish lease was approved in 1914, about 1,200 leases have been issued, but only about 50 shellfish leases remain active, and the majority of these leases are located in estuaries along Florida's Atlantic Coast. Currently, there are only about 12 active shellfish leases on Florida's Gulf Coast; one (17 acres) is located in Escambia Bay, Santa Rosa County; two (50 acres) are located in East Bay in Bay County, and eight (600 acres) are located in Apalachicola Bay, in Franklin County. These leases are used to cultivate oysters. Aquaculture leases issued under Chapter 253, F.S., are used primarily to grow hard clams and live rock, with only a few leaseholders showing renewed interest in farming oysters (see Section 17.0 for maps of reef areas).

8.4.2 Alabama

At present, in Alabama, there are no oyster leases on state regulated bottom. There are some 25 oyster leases in existence on riparian bottoms along the northern shore of the Mississippi Sound (see Section 17.0 for maps of reef areas). Only a few are producing at present. The oldest continuously harvested lease areas have been producing oysters since the mid-1980s.

The size of these riparian leases varies according to the amount of waterfront property an individual owns. The riparian rights extend 600 yards from the shoreline.

8.4.3 Mississippi

There was very little interest in leasing in Mississippi prior to 1977. At that time, the Mississippi Legislature enacted laws to allow lessees under bond to relay oysters from public reefs that had been permanently closed due to sewage contamination. This action sparked interest in leasing, and by 1979 over 50 leases were approved.

Relaying efforts began in mid-1977, and by 1980 most of these closed areas had been virtually depleted of marketable oysters. The amount of relaying continued to decline throughout the 1980s, and no relaying by lessees was conducted in 1989 or 1990.

The number of active leases has also declined. As of 2009, there were seven active leases comprising approximately 523 acres currently located in the western portion of Mississippi Sound. Some growth is occurring without the reliance on relayed oysters.

8.4.4 Louisiana

Louisiana has an extensive public/private cooperative system in which the public grounds are utilized extensively to provide seed oysters to lease holders for transplanting to privately leased beds. This system has been instrumental in making the state the leading producer of oysters. Over 2,000 people hold more than 9,000 individual, active leases encompassing approximately 394,000 acres of state water bottoms. These leases are issued for 15 year periods. The average size of a lease is approximately 36 acres. The majority of the leases are located in the eastern half of the state (See Section 17.0 for maps); while others are located in the central parishes of Terrebonne, Iberia, and St. Mary. No leases are located west of the Vermilion Bay complex.

Although the LDWF historically performed lease surveys, the lease applicant is now responsible for obtaining his own surveyor, and the department charges an administrative fee to execute the lease. Additionally, an annual rental fee of $2.00 per acre is established in state law and must be paid to the LDWF. A moratorium on the issuance of new oyster lease acreage has been in effect since 2002, although efforts are underway to lift this moratorium.

8.4.5 Texas

Private oyster leases in Texas can be traced back to the late-1800s when the earliest lease on record at the Galveston County Courthouse was issued on October 25, 1895 for 15 acres. At one time or another, leases have existed in all of the bays along the Texas coast encompassing 6,486 acres in 1907. Since the 1890's, 12,347 acres of bay bottom have been under lease at one time or another. Currently, there are 43 leases in Texas that comprise 2,321 acres, all in Galveston Bay. Individual leases range in size from 11 acres up to 100 acres. The original goal of the Texas oyster lease program was to create new self-sustaining oyster producing areas under private ownership but is currently being used exclusively as depuration sites for oysters transplanted from restricted waters. There is a moratorium in effect on the issuance of any new leases in Texas as the current management goals pertaining to leases are being met (Quast et al. 1988).

Leases are valid for a period of fifteen years as prescribed in Parks and Wildlife Code, §76.018. An annual fee of $6 per acre is required to maintain the lease. At the end of the lease term TPWD will make a determination on the need to continue a private oyster lease program based on the need for depuration of oysters from restricted areas and other goals as specified in the Texas Oyster Fishery Management Plan (Quast et al. 1988).

The Texas oyster lease fishery relies on the ability to move (relay) oysters from waters classified by the Texas Department of State Health Services (DSHS) as 'restricted' to private beds (leases) located in areas classified as 'approved' or 'conditionally approved'. Leaseholders, under special permits issued by the TPWD, are allowed to transplant oysters from restricted waters to their leases. The number of transplanting days is determined based on data collected through

TPWD fisheries independent monitoring programs, with input from leaseholders and TPWD Law Enforcement staff. Currently, nine days on average are utilized during the spring (May) and nine days during the fall (September) transplant seasons. This is down from approximately 80 transplant days per year in the early-1990s. The total number of barrels of oysters transplanted by year to private leases in Texas can be found in Table 8.14.

Harvesting off of private leases also requires a Harvest Permit issued by TPWD. Permits can be requested for up to one month at a time and must specify each vessel that will be used in harvesting operations. The monthly production (meat-weight) from private oyster leases can be found in Table 8.15. The majority of the production from private leases in Texas occurs during the months of May-October, when the public season is closed.

The number of vessels used in transplanting activities is limited to one transplant permit (vessel) per lease, plus one permit for the agent (N = 53 vessels maximum). Harvest permits that allow leaseholders to harvest oysters off of leases are issued after a minimum of 15 days has passed to allow for oysters to purge themselves of excessive bacteria levels that may have been present within transplant areas. There is no restriction on the number of harvest permits or vessels that can be used on one lease.

Table 8.14 Barrels of oysters transplanted to private oyster leases in Galveston Bay, Texas during 1981-2008. Data based on weekly oyster transplant reports submitted to TPWD by oyster leaseholders (TPWD unpublished data).

Year	Months												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1981	-	-	-	-	37,502.9	7,102.9	-	10,600.0	18,200.0	-	-	-	73,405.8
1982	-	-	-	-	21,302.9	400.0	-	24,902.9	1,200.0	-	-	-	47,805.8
1983	-	-	-	-	49,800.0	24,702.9	-	28,200.0	13,502.9	-	-	-	116,205.8
1984	-	-	-	19,502.9	27,702.9	-	-	43,502.9	16,200.0	-	-	-	106,908.7
1985	-	-	-	-	39,600.0	25,600.0	15,600.0	28,702.9	5,702.9	-	-	-	115,205.8
1986	-	-	-	-	82,108.6	22,988.6	30,314.3	30,308.6	22,257.1	7,045.7	-	-	195,022.9
1987	-	-	-	-	58,605.7	19,337.1	19,468.6	14,377.1	10,822.9	8,360.0	-	-	130,971.4
1988	-	-	-	-	81,388.6	20,617.1	-	4,600.1	4,222.9	280.0	-	-	111,108.7
1989	-	-	-	-	36,520.0	7,274.3	-	6,645.7	8,337.1	9,954.3	-	-	68,731.4
1990	-	-	-	-	47,091.4	12,188.6	-	8,382.9	39,777.1	12,925.7	-	-	120,365.7
1991	-	-	-	-	39,680.0	12,337.1	-	17,982.9	15,931.4	760.0	-	-	86,691.4
1992	-	-	-	-	33,891.4	12,022.9	-	-	25,297.1	12,680.0	-	-	83,891.4
1993	-	-	-	-	46,348.6	-	-	-	14,594.3	-	-	-	60,942.9
1994	-	-	-	-	28,017.1	-	-	-	31,611.4	-	-	-	59,628.5
1995	-	-	-	-	47,097.1	-	-	-	23,200.0	-	-	-	70,297.1
1996	-	-	-	-	66,560.0	-	-	-	18,622.9	-	-	-	85,182.9
1997	-	-	-	-	50,771.4	-	-	-	-	-	-	-	50,771.4
1998	-	-	-	-	79,931.4	-	-	-	-	-	-	-	79,931.4
1999	-	-	-	-	57,194.3	-	-	-	36,702.9	-	-	-	93,897.2
2000	-	-	-	-	65,622.9	-	-	-	70,211.4	-	-	-	135,834.3
2001	-	-	4,782.9	-	115,731.4	22,371.4	-	-	19,720.0	-	-	-	162,605.7
2002	-	-	-	-	-	-	-	-	-	10,354.3	-	-	10,354.3
2003	-	-	-	-	55,697.1	31,022.9	-	-	-	-	-	-	86,720.0
2004	-	-	-	-	70,531.4	-	-	-	60,702.9	-	-	-	131,234.3
2005	-	-	-	-	67,782.9	-	-	-	31,325.7	-	-	-	99,108.6
2006	-	-	-	-	53,017.1	-	-	-	41,394.3	-	-	-	94,411.4
2007	-	-	-	-	58,194.3	-	-	-	33,514.3	-	-	-	91,708.6
2008	-	-	-	-	58,571.4	-	-	-	17,485.7	-	-	-	76,057.1

Table 8.15 Barrels of oysters harvested from private oyster leases in Galveston Bay, Texas during 1981-2008. Data based on monthly oyster harvest reports submitted to TPWD by oyster leaseholders (TPWD unpublished data).

Year	Months												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1981	1,491.4	2,074.3	1,742.9	2,177.1	2,720.0	3,577.1	3,840.0	2,005.7	1,297.1	2,817.1	1,794.3	1,645.7	29,163.7
1982	662.9	834.3	1,497.1	2,211.4	3,708.6	3,600.0	3,451.4	3,800.0	3,674.3	5,262.9			30,684.9
1983		1,451.4	2,034.3	4,708.6	6,908.6	11,365.7	9,405.7	3,720.0	3,685.7	5,074.3	640.0	394.3	51,371.6
1984	468.6	600.0	2,108.6	2,582.9	4,794.3	7,062.9	2,422.9	2,508.6	1,668.6	5,948.6	80.0	828.6	33,058.6
1985	308.6			388.6	2,422.9	4,805.7	4,742.9	3,337.1	2,302.9	3,714.3			24,008.0
1986	2,968.0	5,669.0	6,719.3	9,161.7	6,974.3	13,574.3	13,739.6	12,323.0	4,070.9	7,406.9	154.0	2,157.7	84,918.6
1987	-	6,320.0	3,687.0	5,211.0	9,563.0	14,674.0	9,531.0	6,904.0	3,531.0	3,497.0	3,095.6	84.0	66,097.6
1988	277.0	2,938.0	5,496.0	5,512.0	1,892.0	8,538.0	7,281.0	4,185.0	1,864.0	4,633.0	642.0	687.0	43,945.0
1989	1,135.0	3,050.0	3,966.0	3,877.0	3,202.0	8,879.0	3,001.0	3,710.0	2,151.0	6,168.0	163.0	886.0	40,188.0
1990	1,165.0	2,106.0	4,402.0	4,505.0	4,632.0	7,721.0	3,975.0	1,833.0	2,435.0	6,275.0	382.0	807.0	40,238.0
1991	113.0	1,036.0	128.0	1,593.0	11,072.0	7,449.0	7,645.0	7,115.0	8,122.0	7,270.0	10.0	25.0	51,578.0
1992	808.0					2,692.0	7,268.0	6,457.0	7,139.0	7,657.0			32,021.0
1993					7,114.0	5,298.0	5,073.0	4,121.0	4,332.0	3,168.0	361.0		29,467.0
1994					9,884.0	11,596.0	13,008.0	13,362.0	10,958.0	11,218.0			70,026.0
1995					17,721.0	12,966.0	13,946.0	12,546.0	8,035.0	11,332.0			76,546.0
1996					12,221.0	14,997.0	14,397.0	14,722.0	5,728.0	21,148.0	33.0	45.0	83,291.0
1997	299.0	109.0		49.0	4,622.2	10,578.0	12,774.0	13,482.0	6,092.0	8,398.0			56,403.2
1998					10,012.0	11,131.0				2,549.0			23,692.0
1999					19,695.0	13,424.0	15,254.0	16,503.0	8,697.0	11,412.0			84,985.0
2000					22,717.0	23,154.0	17,325.0	19,970.0	2,169.0	2,636.0		593.0	88,564.0
2001	639.0	400.0	6,138.0	5,330.0	11,454.0	9,432.0	11,338.0	9,867.0	4,158.0	11,015.0		434.0	70,205.0
2002	713.0	347.0	939.0	1,232.0	10,769.0	3,587.0	14,276.0	2,597.0	8,780.0	3,459.0		0.0	46,699.0
2003		27.0	33.0	568.0	15,227.0	17,189.0	18,220.0	16,813.0	10,012.0	19,408.0		32.0	97,529.0
2004	141.0	281.0	1,501.0	5,060.0	18,462.0	13,505.0	16,014.0	15,466.0	6,770.0	11,788.0		1,208.0	90,196.0
2005	613.0	68.0			11,532.0	14,579.0	9,516.0	4,131.0	3,425.0	20,883.0		55.0	64,802.0
2006		230.0	722.0	326.0	17,530.0	4,711.0	5,179.0	17,839.0	8,949.0	11,786.0	1,513.0	1,173.0	69,958.0
2007	1,516.0	31.0	619.0	1,079.0	7,915.0	7,450.0	7,634.0	9,013.0	5,005.0	17,064.0	702.0	1,017.0	59,045.0
2008	551.0	1,029.0	1,702.0	2,214.0	7,124.0	9,546.0	8,721.0	5,211.0	4,407.0		5,184.0	2,717.0	48,406.0

9.0 GULF OYSTER ECONOMICS

With a 2008 dockside value of $122 million, U.S. oyster production represented almost 3% of the total $4.4 billion U.S. seafood (edible and non-edible) dockside value. While seemingly small, the figure becomes more impressive when compared to other established U.S. fisheries. For example, the 2008 U.S. dockside oyster value was more than 20% of that of the nation's largest shellfish fishery (crabs, with a dockside value of $562 million) and almost a third of the nation's largest finfish fishery (salmon, with a dockside value of $395 million). With respect to some other well-known U.S. fisheries, 2008 oyster production equaled two-thirds of clam production (dockside value equal to $187 million) and was approximately twice that of the squid fishery (dockside value equal to $58 million).

Considering the product only at dockside, however, provides an incomplete picture of the value of oysters and associated reef structure to society. Most obvious, additional value is generated at each step along the marketing channel as the harvested product is transported and transformed to meet the demands of the consuming public. While less obvious, but also of importance, oysters provide a multitude of ecological services (e.g., improved water clarity) that benefit society and, hence, are of value (a more detailed definition of value is presented in Section 9.2).

This section examines the economics of the Gulf of Mexico oyster industry. To do so, the harvesting sector is initially examined. Gulf production is first considered in relation to total U.S. production for all species (Eastern, Pacific, European Flat, and Olympia) and production in the other principle producing regions. Then, consideration is given to production by the individual states bordering the Gulf of Mexico (Florida west coast, Alabama, Mississippi, Louisiana, and Texas). After examining the harvesting sector, attention is turned to examining import trends and marketing and other value-added activities. Finally, some attention is given to examining non-market benefits associated with oyster reefs as part of a healthy ecosystem.

9.1 Oyster Production

9.1.1 Poundage

9.1.1.1 U.S. Production by Region

From 1960 to the mid-1980s, annual total U.S. oyster production, for all species, consistently exceeded 50 million lbs (unless otherwise noted, pounds is given on a meat-weight basis) and even exceeded 60 million lbs in some years (Figure 9.1). Since the mid-1980s, however, production has rarely exceeded 40 million lbs and, in some instances, has fallen below the 35 million lbs mark. Much of the long-term decline reflects lower production in the Chesapeake. During 1980-1984, for instance, Chesapeake production averaged 17 million lbs annually. Since 1991, however, annual Chesapeake production has never exceeded three million lbs and has consistently fallen below the one million lbs mark since 2002. By comparison, Pacific production averaged almost 13 million lbs annually during 2004-2008 compared to just eight million lbs annually during 1980-1984, while Gulf production for the two periods consistently averaged about 22 million lbs annually. Combined, these three regions represented 90% of the total U.S. oyster production during 1960-2008. Most of the remaining U.S. production is represented by New England (coastal states ranging from Maine through Connecticut) and the Mid-Atlantic (coastal states ranging from New York through New Jersey) which each accounted for approximately 3% of U.S. total and the South Atlantic (coastal states ranging from North Carolina through the east coast of Florida) which accounted for almost 4% of the 1960-2008 U.S. oyster production (Figure 8.7).

Consistency between average annual Gulf production in 1980-1984 and average

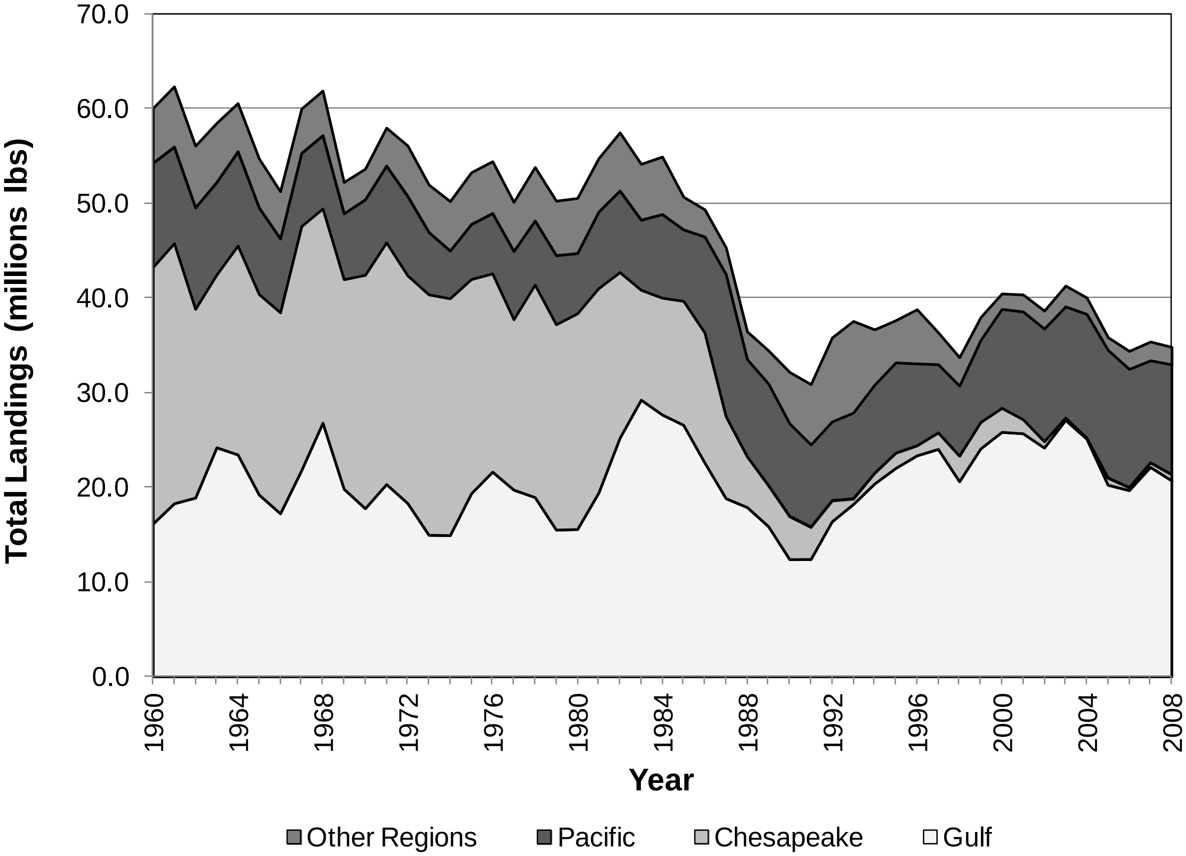


Figure 9.1 Annual cumulative total U.S. oyster production (millions lbs) by region from 1960-2008 (NMFS pers. comm.).

annual production in 2004-2008 does not, however, imply stable annual production. Changes in production from one year to the next (or over a several year period) are often moderate but are, in some instances, significant (Figure 9.2). These changes, to a large extent, reflect short to medium-term perturbations in environmental conditions that result in annual production deviating from its long term average (20.5 million lbs with an associated standard deviation equal to 4.0 million lbs). For example, the decline in Gulf production between 1985 and 1990 is generally attributed to drought conditions throughout the northern Gulf of Mexico (Table 8.4). Similarly, abnormally low production in 1966 is often attributed to Hurricane Betsy which destroyed much of the Louisiana commercial fishery infrastructure when it hit Louisiana in September 1965 (Figure 8.8). In conjunction with the hurricane, production fell from 11.4 million lbs in 1964 to 8.3 million lbs in 1965 and fell again to 4.8 million lbs in 1966. It subsequently returned to 13.1 million lbs by 1968. Likewise, the observed decline in production in 2005 and 2006 reflects, in large part, impacts associated with Hurricane Katrina which entered the northern Gulf in late August 2005. As a result of that hurricane, Mississippi closed its oyster beds to all harvesting activities for all of 2006 and Louisiana's production for the year fell by about two million lbs when compared to production for the year prior to Hurricane Katrina. Finally, Gulf production in 2008 totaled 20.6 million lbs. While the 12.8 million lbs produced by Louisiana in 2008 approached its long-run average (indicating a recovery from 2005 Hurricane Katrina), the 2.7 million lbs produced by Texas that year represented the state's lowest reported production since 1990 and was about three million lbs below the state's 2007 harvest of 5.6 million lbs. Much of the decline in the 2008 Texas

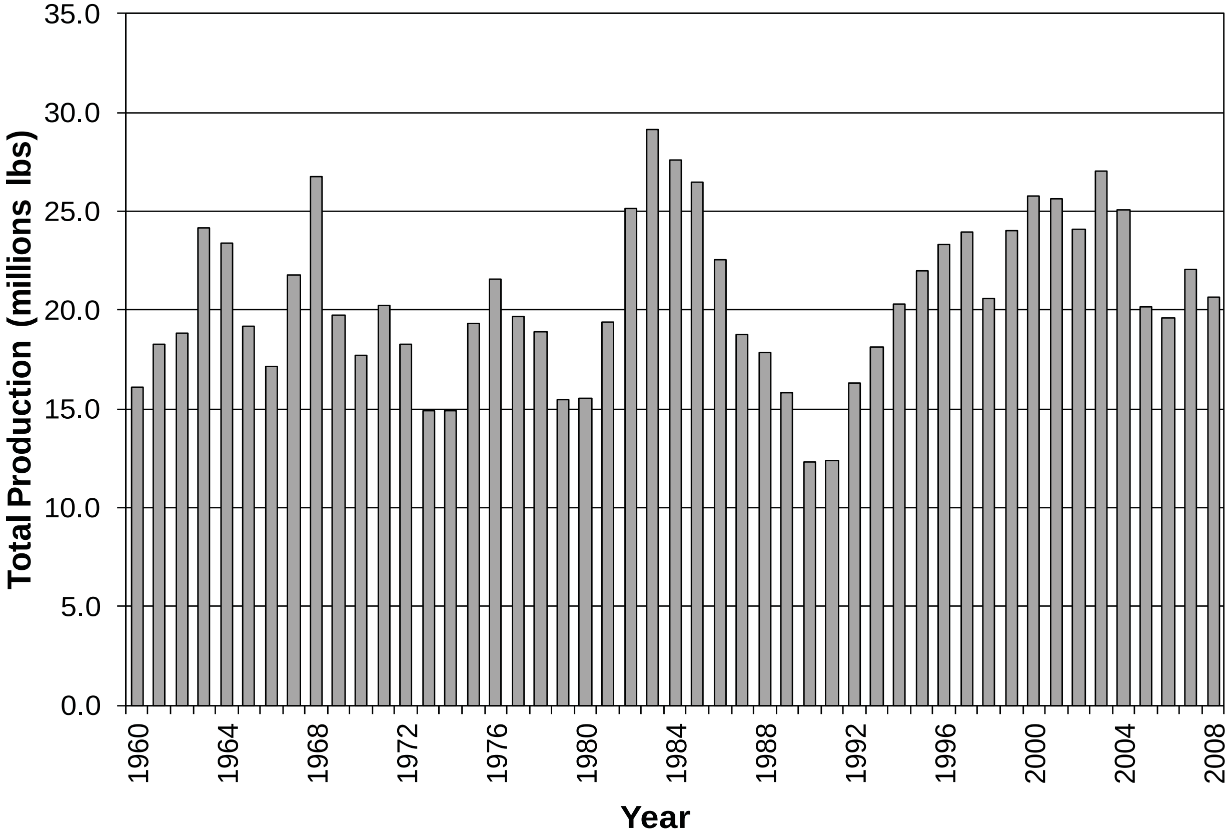


Figure 9.2 Total Gulf of Mexico oyster production (millions of lbs) from 1960-2008 (NMFS pers. comm.).

harvest is the result of Hurricane Ike which crossed Galveston Bay in September 2008, destroying much of the commercial seafood infrastructure and silting over many of the bay's oyster beds which are the main production reefs in Texas.

As indicated in Figure 9.3, the share of total U.S. oyster production represented by the Gulf generally fell below 40% prior to the early 1980s. Due to a combination of relatively high production in the region in conjunction with declining production in the Chesapeake, the Gulf's share of national output advanced to about 50% by the mid-1980s. Associated with drought conditions throughout the northern Gulf during the mid-to-late 1980s, the share of national production attributable to the Gulf gradually eroded to less than 40% by 1990. Relatively high Gulf production since the early 1990s and a further decline in Chesapeake production (and, to a lesser extent, reductions in New England and mid-Atlantic harvests) has culminated in the Gulf, in recent years, becoming the dominant oyster-producing region in the U.S. Specifically, the Gulf share of the nation's oyster production has consistently exceeded 50% since the mid-1990s and most often exceeds 60%. The slight reduction in Gulf share since 2005 likely reflects, in part, reduced harvest in the Gulf due to impacts associated with Hurricanes Katrina (2005) and Ike (2008).

9.1.1.2 Gulf Production by State

Average annual Gulf of Mexico oyster production by state for selected periods from 1960 through 2008 is presented in Table 9.1, while the respective shares are presented in Figure 9.4.

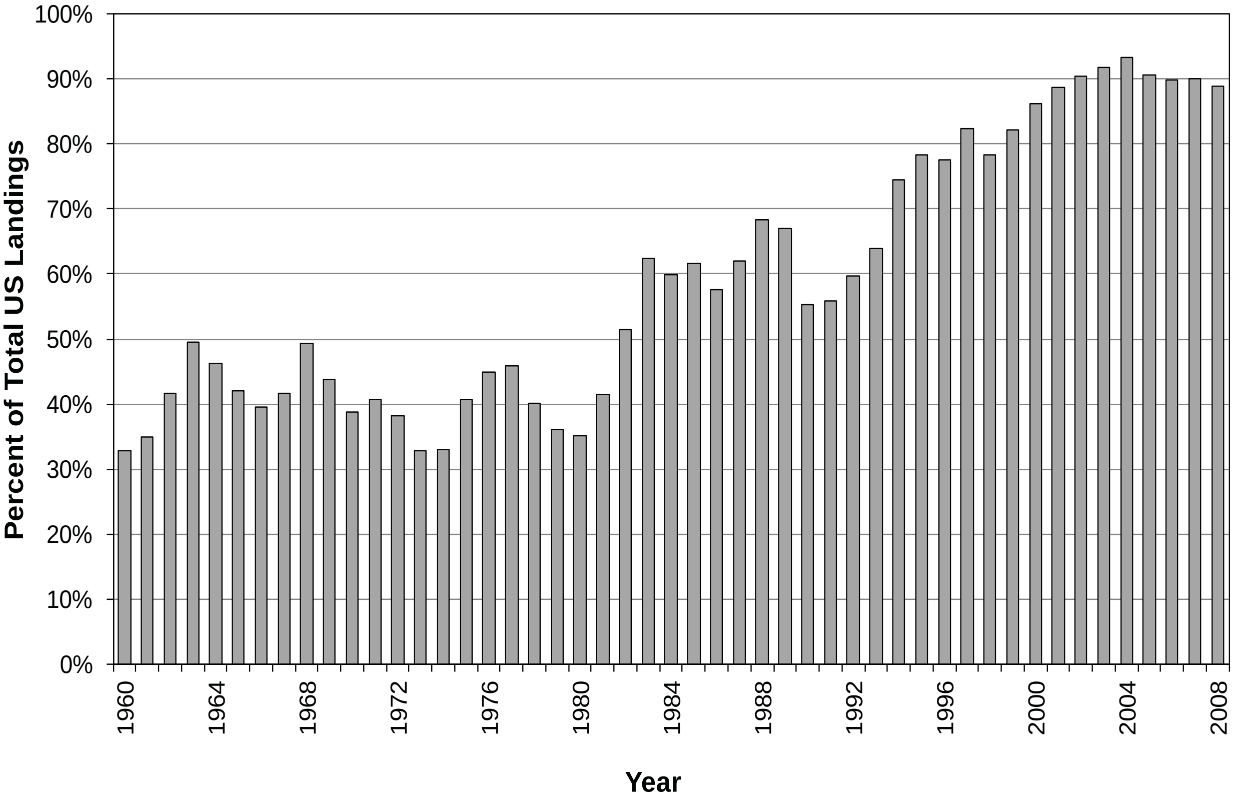


Figure 9.3 Gulf oyster production as a percent share of the total U.S. oyster production (lbs) from 1960-2008 (NMFS pers. comm.).

Production by state, and relevant changes, are briefly considered in this section. The landings and products data used in this section originate from NMFS Office of Economics and Statistics and the TPWD (unpublished data).

9.1.1.2.1 Florida

Until the 1990s, Florida's share of total Gulf oyster production consistently averaged about 20% but has more recently fallen to less than 10% (Figure 9.4). The declining Florida share represents the absolute decline in Florida production and increasing production in other Gulf States. Overall, Florida's average annual harvest during 2000-2008 (2.2 million lbs) was only about one-half of that observed during the 1980s (4.4 million lbs) and is approximately equal to that observed throughout the 1990s (Table 9.1).

From 1990 to 2008, Florida's oyster production reflected several downward trends in landings from Apalachicola Bay. Because Apalachicola Bay historically accounts for about 90% of the oyster landings in Florida, production trends in the bay are strongly correlated with statewide landings. Lower annual and average landings from the bay were generally consistent with adverse environmental conditions associated with prolonged droughts and decreased river discharge and flow rates from the Apalachicola River. Concurrently, the number of fishermen engaged in the oyster fishery and the number of fishing trips declined substantially during these lower production cycles. For example, in 2000, oystermen reported 25,550 fishing trips which resulted in landing 2.3 million lbs of oyster meats, while in 2005, the number of reported trips declined to 12,663 accounting for 1.26 million lbs of meats. Statewide, the number of fishermen actively engaged

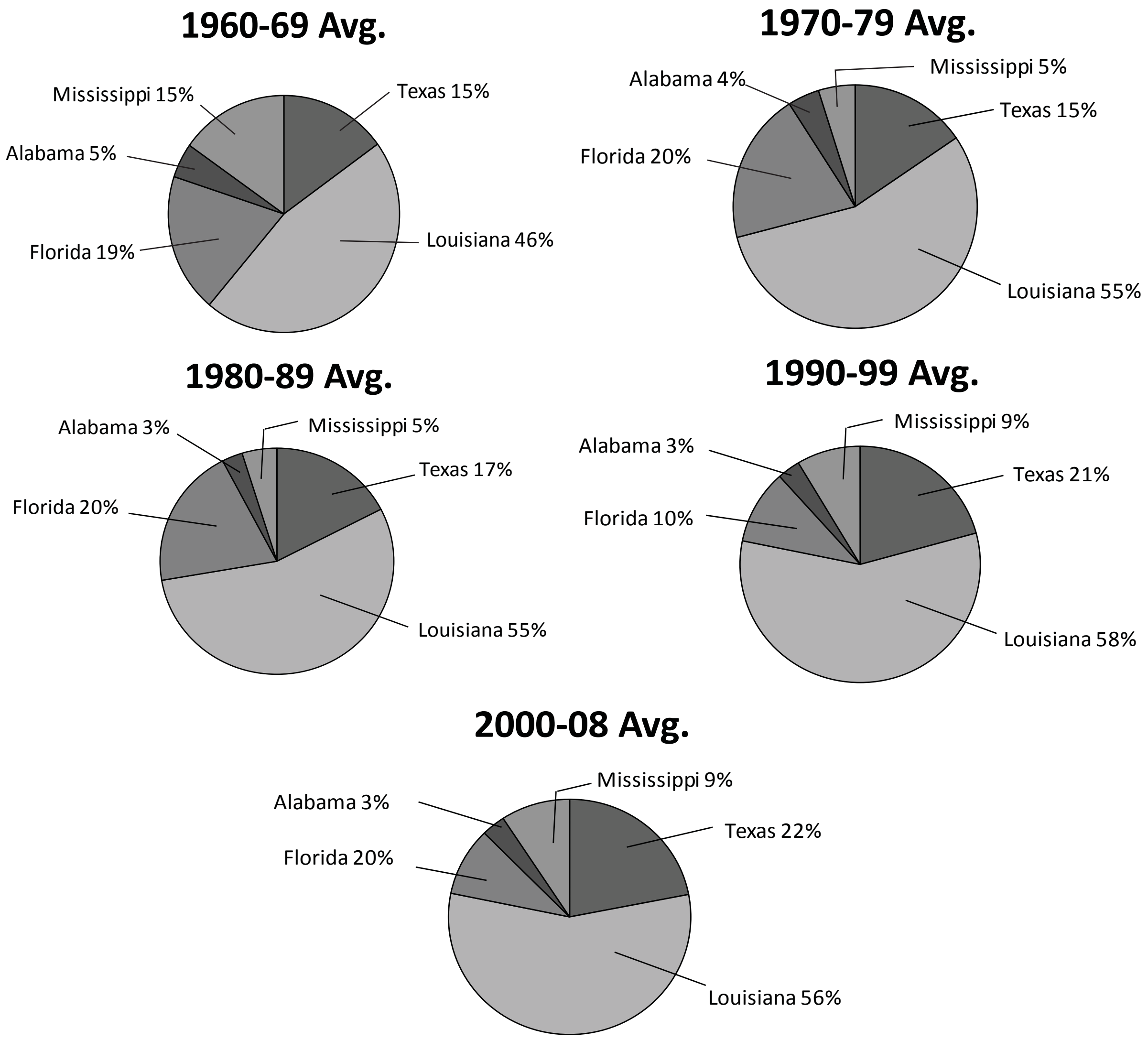


Figure 9.4 Oyster harvest shares by Gulf state (percent of total lbs) for selected time periods, 1960-2008.

in oyster harvesting declined over the past two decades as many fishermen sought alternative employment opportunities and have not returned to the fishery.

9.1.1.2.2 Alabama and Mississippi

With production averaging 738,000 lbs annually, Alabama's oyster production equaled almost 4% of the Gulf's long-term (i.e., 1960-2008) average of 20.5 million lbs. For the most recent period of analysis (2000-2008), Alabama's annual average production, equal to 741,000 lbs, represented about 3% of the Gulf production (i.e., 23.4 million lbs) (Figure 9.4). This decrease in Alabama's average yearly oyster production was due to the negative impact of Hurricanes Ivan and Katrina in 2004 and 2005 respectively, as well as, drought conditions that persisted from 2006-2009. The hurricanes caused physical damage and silting to occur on many of Alabama's oyster reefs. The drought allowed for higher average salinities to occur on the harvestable reefs, creating ideal conditions for oyster drills to proliferate and decimate the spat and young oysters upon the

Table 9.1 Gulf of Mexico Annual Oyster Production by State (expressed in thousands of lbs), 1960-2008 (NMFS pers. comm.).

Time Period	Florida	Alabama	Mississippi	Louisiana	Texas	Gulf
1960-69 avg.	3,896	970	3,143	9,472	3,076	20,529
1970-79 avg.	3,621	756	881	10,036	2,798	18,092
1980-89 avg.	4,361	628	1,055	11,972	3,809	21,826
1990-99 avg.	1,964	594	1,652	11,119	4,003	19,332
2000-08 avg.	2,187	741	2,170	13,164	5,136	23,398

reefs. Production steadily decreased on the reefs to the point in which AMRD closed the reefs to harvesting in late March 2009.

Mississippi's share of Gulf production, as indicated in Figure 9.4, has fluctuated from 5% to 15%. Its 15% share came during the initial 10-year period of analysis when state production was highest. Its share of Gulf production during 2000-2008 was just under 10% based on annual landings during the period equal to 2.2 million pounds. While landings increased to a peak in 2004, Hurricane Katrina in 2005 caused significant mortalities to market-size oysters that closed the reefs to harvest. A smaller limited season reopened the reefs in 2007.

9.1.1.2.3 Louisiana

As indicated by the information in Table 9.1 and Figure 9.4, Gulf production is dominated by Louisiana. With the exception of 1960-1969, Louisiana's share of Gulf production on a poundage basis has consistently averaged about 55% of the total. The sole exception, wherein Louisiana's share equaled 50%, reflects abnormally low production during the mid-1960s in association with the impacts from Hurricane Betsy. Despite above long-run average production during 2000-2008 (i.e., 13.2 million lbs), Louisiana's share of Gulf production during the period remained constant due to a concomitant increase in production by the other Gulf states.

Although Louisiana's absolute production and share of the region's production has been relatively stable over time, there have been large deviations from the long-run average in certain years. These deviations generally reflect fluctuations in environmental conditions. The precipitous decline in the 1966 harvest, for example, reflects the previous year's destruction of Louisiana's oyster reefs and infrastructure from Hurricane Betsy. Similarly, the 1979-1980 reduction in production can be traced to the opening of the Bonnet Carré Spillway near New Orleans which caused damage to prime bedding areas. The observed decline in 2005-2006 can largely be tied to loss of reefs and, more importantly, infrastructure associated with hurricanes Katrina and Rita. Just as adverse environmental conditions can hinder the production process, positive environmental factors can contribute to it. Diagne et al. (2004), for example, attribute the 'above normal' oyster production after 1993 and well into the 2000s to favorable environmental conditions, reflecting both natural events and wetland restoration efforts that may have increased productivity by reducing salinity levels over public seed grounds. Specifically, salinity levels tend to be lower during years of naturally heavy rainfall, and oyster growth increases due to reduced incidence of disease and predation. Much of the early-to-mid-1990s can be characterized by an increased level of rainfall. In addition, the diversion of fresh water from the Mississippi River to the wetlands east of the Mississippi River (the Caernarvon Diversion Project) was completed in the early 1990s. The operation of this diversion structure may have also contributed to reducing salinity levels over the outer reefs.

Louisiana's large annual oyster landings are derived from a combination of production from leases and public seed grounds. By providing a stable environment through its leasing policy, the state has encouraged industry investment and has provided an impetus for the preservation, rehabilitation, and expansion of existing oyster reefs. Leased acreage has increased approximately five-fold since the early 1960s, from about 75,000 acres to about 400,000 acres (Figure 9.5). Despite this sharp increase, long-run production from private leases has been very stable, averaging about eight million lbs annually during 1960-2008, or approximately 80% of the state's total production during that period (Figure 9.6). As a result of relatively stable long-run production derived from leases,in conjunction with increasing leased acreage, the estimated production fell from more than 100 lbs/acre/year in the early 1960s to about 20 lbs/acre/year since the early 1990s (Figure 9.7).

As of September 21, 2010, there were 7,846 active leases totaling approximately 385,000 acres (average size of approximately 48 acres per lease), which were held by 1,033 leaseholders. More than a third of the total (approximately 140,000 acres) was in Plaquemines Parish. The next two largest parishes in terms of leased acreage - Terrebonne Parish (approximately 92,000 acres) and St. Bernard Parish (approximately 88,000 acres) - each accounted for more than 20% of the total.

In general, there has been a shift in regional distribution of leased acreage. In 1975-76, statewide leasing totaled 193,000 acres. Leased acreage in St. Bernard Parish totaled 72,000 acres, while leased acreage in Plaquemines and Terrebonne Parishes equaled 56,000 acres and 33,000 acres, respectively. Hence, while leased acreage in St. Bernard Parish increased by only about 20% during the 30-year period ending in 2006, leased acreage in Plaquemines Parish increased

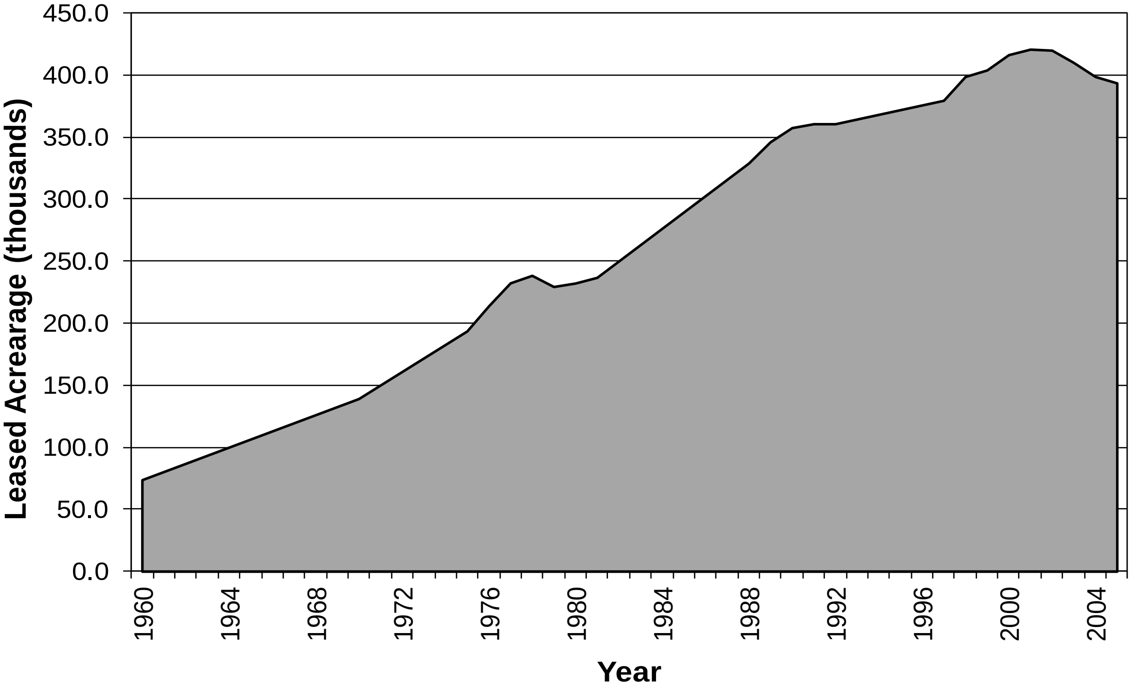


Figure 9.5 Total leased water-bottom acreage (in thousands) for the production of oysters in Louisiana, 1960-2008.

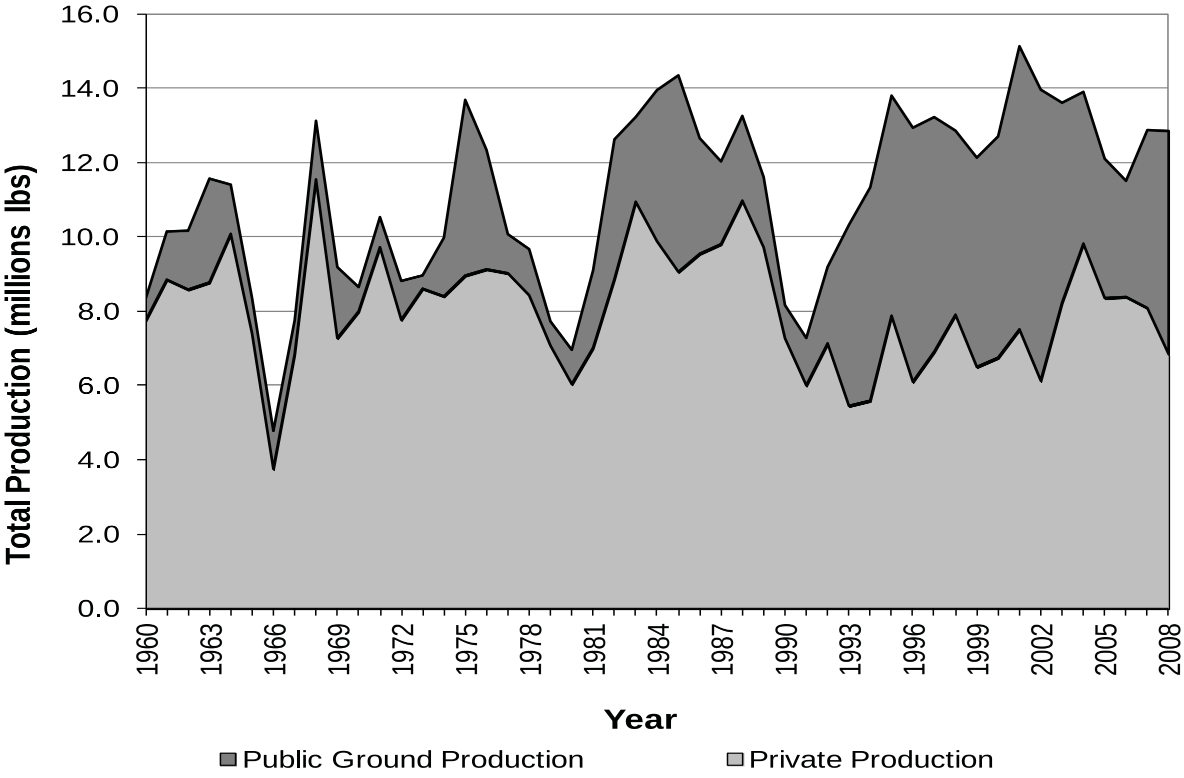


Figure 9.6 Louisiana oyster production (millions lbs) from private leases and public seed grounds, 1960-2008.

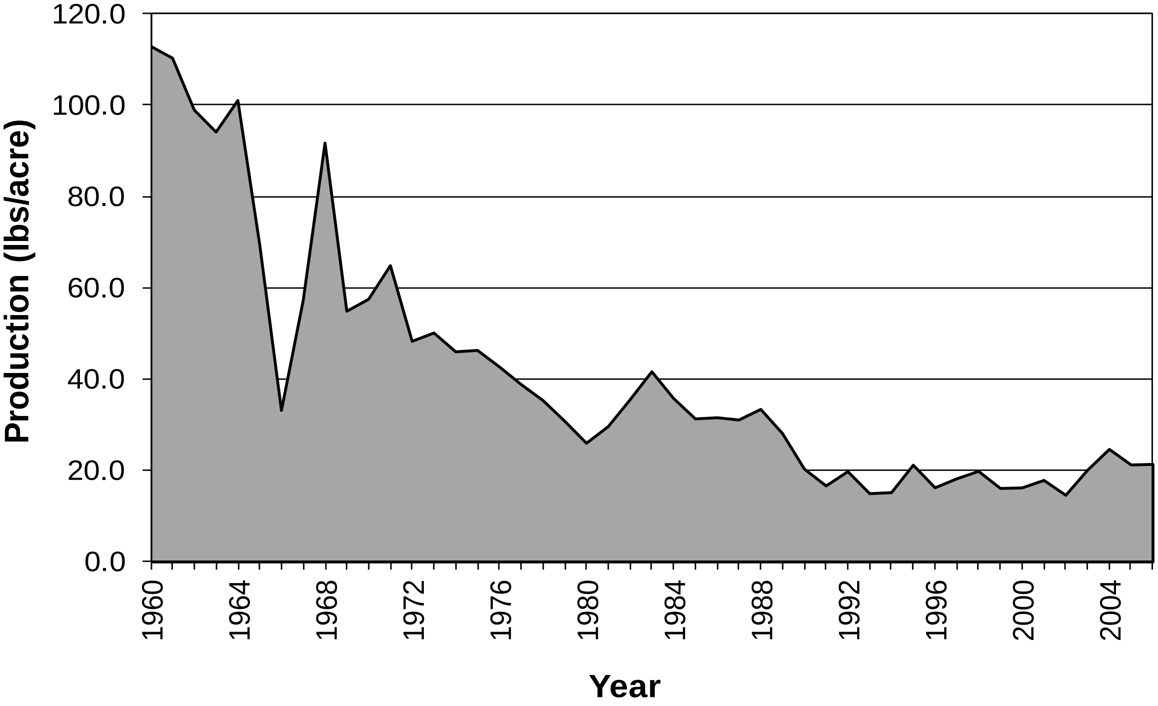


Figure 9.7 Production per acre from Louisiana oyster leases (lbs), 1960-2008.

by approximately 150%. Leased acreage in Terrebonne Parish increased by almost 200%. In addition to a changing distribution of leased acreage by parish, a northward movement in leasing activities has also been documented (Van Sickle et al. 1976). The researchers hypothesize that this movement is the result of increasing salinity associated with wetland degradation along coastal Louisiana.

Increasing leased acreage in conjunction with relatively constant production from the private leases, as noted, implies a declining productivity per acre. This raises the issue of why long-term production from the leased acreage would, in the long run, remain relatively constant when leased acreage has significantly increased. One argument that has been advanced to explain the increased acreage in association with relatively constant production is that it is in response to wetland degradation and increasing 'rapid' fluctuations in salinity regimes. Specifically, with an increasing exposure of oyster leases to open water (due to marsh deterioration), short-term salinity changes in the proximate reef area have become more common and with a higher magnitude of change. Hence, acreage which may be productive one year may not be productive in the following year. As such, leaseholders may be increasingly diversifying their lease portfolios, especially by area, as a means of protecting themselves against the vagaries associated with any single lease or group of leases subject to the same environmental perturbations. Keithly and Kazmierczak (2006) suggest that speculation for non-production income by lessees may have contributed to relatively constant long-run production in conjunction with the increased leased acreage. Specifically, oil and gas-related activities are common in coastal Louisiana and often overlap oyster leases on a geographical basis. Keithly and Kazmierczak (2006) found that compensation for oil and gas activities is negotiated with affected leasees and may or may not be based on lease productivity. Hence, the authors argue that considerable acreage of water-bottom is leased for the main purpose of receiving compensation rather than for the production of oysters. Such leasing purposes would, over time, result in a decline in harvest per acre.

In addition to the leased acreage, Louisiana maintains considerable public acreage devoted to oyster seed reservations. These public grounds, which tend to be further offshore than leases, encompass some 2.2 million acres and include some of the most productive natural leases east of the Mississippi River (Perret et al. 1991). Public seed grounds are generally opened for approximately seven months each year and serve two primary purposes; they provide a source of seed oysters that can be transplanted to leases for future harvest, and they produce market-sized oysters that can be harvested and sold. Market oyster production from public grounds has averaged 3.0 million lbs annually since 1960 and almost 6.0 million lbs annually since the mid-1990s (Figure 9.6).

Estimated public ground seed and sack (i.e., market-sized) oyster availability for 1982-2009 (LDWF 2009) is provided in Figure 9.8. As indicated, estimated sack oyster availability ranged from less than 500,000 barrels (1989 and 2006) to more than 3.0 million barrels (1995-1997 and 2001) with a long-term average of about 1.77 million barrels. This translates to a long-term annual availability of 3.5 million sacks or about 23 million lbs of meats (based on 6.47 lbs of meats per sack). A comparison of the information in Figure 9.6 with that in Figure 9.8 shows a positive relationship between sack availability on the public seed grounds and harvest of market oysters from the public grounds. For example, the 1986-1990 period can be characterized as one of abnormally low sack oyster availability on public grounds (Figure 9.8) and harvest of market oysters from the public grounds during the same period was also relatively low.

Likewise, availability of sack oysters on public seed grounds from 1992 through the early 2000s was substantially higher than long-term average and annual harvests from the public grounds during this period were likewise relatively large. Overall, the correlation between sack oyster availability in a given year and harvest in that year equaled 0.65. An argument could be made that

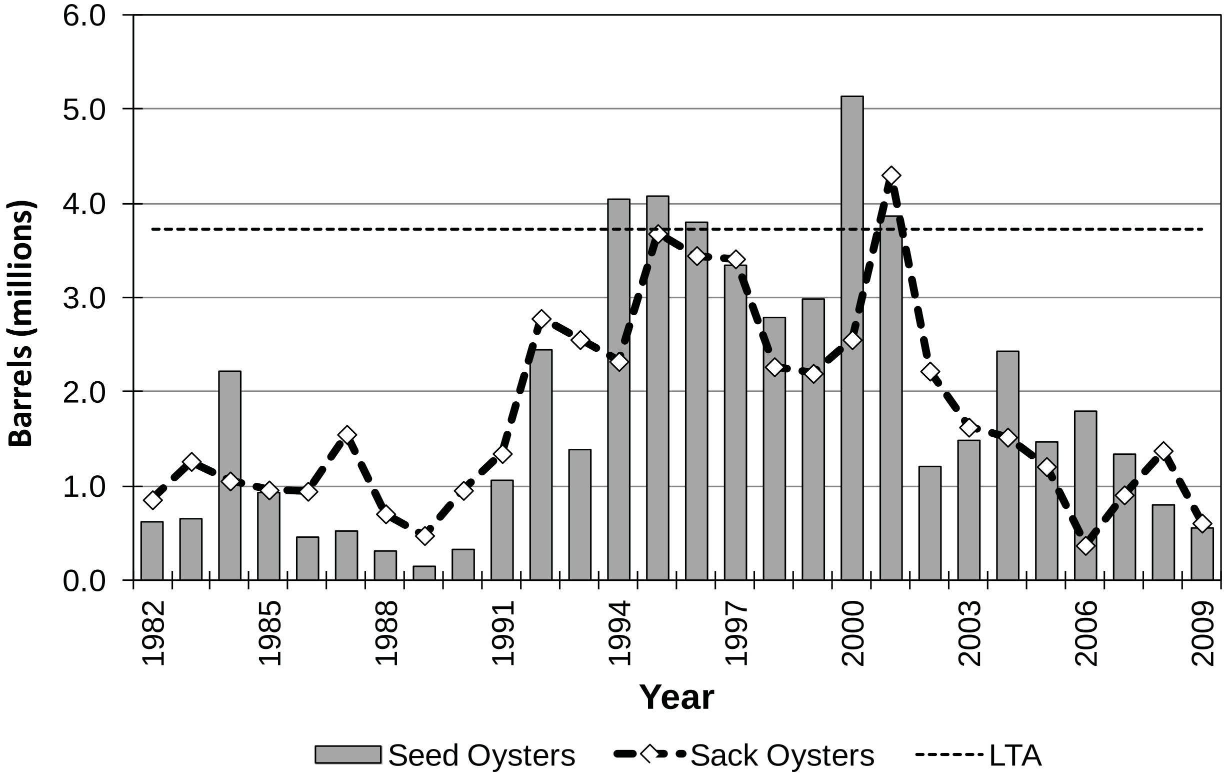


Figure 9.8 Louisiana's estimated public grounds seed and sack availability in millions of barrels from 1962-2009. ***Note:*** 1994-2004 includes CSA I data revision.

there is a lag between oyster sack availability in time period *t* and subsequent market harvest (i.e., harvest in time period *t*+1); the correlation with respect to this relationship equaled 0.737. While there is a strong correlation between sack availability and market harvest from the public grounds, the information in the respective figures suggests that large increases in sack availability do not result in a commensurate increase in harvest. Overall, approximately 20% of the sack availability is estimated to be harvested, on average, each year. One might hypothesize that infrastructure and/or marketing constraints may limit harvests from public seed grounds in years of high sack availability. While not well documented, reports of sack limits placed on individual vessels by buyers are not uncommon in years when availability is high (Keithly pers. comm.).

In addition to sack oysters, the public seed grounds, as noted, provide a source of seed oyster that can be transplanted to private leases. As expected, there is a high positive relationship between sack oyster availability and seed oyster availability in any given year (correlation equal to 0.785), whereas the correlation between seed oyster availability in year *t* and sack availability in year *t*+1 is equal to 0.805. Unlike the positive relationship between sack oyster availability and harvest from the public grounds, however, there is a negative relationship between seed oyster availability in year *t* and harvest from private leases in year *t*+1 (correlation equal to -0.46). The underlying reason for the negative relationship between seed availability in year *t* and harvest from private leases in year *t* +1, while not obvious, may relate to a number of factors. First, as noted, there is a high positive relationship between seed oyster availability on the public seed grounds and sack oyster availability. As such, increased effort associated with the harvest of sack oysters from the public seed grounds may detract from transplanting of seed oyster to private leases. Second, high levels of seed/sack oyster availability on the public seed grounds may also indicate high oyster abundance on private leases which would, one might hypothesize, result in a reduction in demand for transplanting activities. Third, as noted, there is a strong positive relationship between sack oyster abundance on the public seed grounds and harvest of market oysters from the public grounds. The increased harvest from the public grounds may result in a reduction in the expected price that one might anticipate from lease harvest and, hence, lower expected profits from transplanting activities. Finally, some amalgam of these factors (or some other factors) may explain the negative relationship between seed oyster abundance and subsequent lease-based harvest.

9.1.1.2.4 Texas

The Gulf share represented by Texas has gradually increased during the period of analysis from 15% during the 1960s to 22% during 2000-2008 (Figure 9.4). The increasing Texas share represents a combination of increasing production in Texas and decreasing production in Florida. Overall, production per year averaged 3.7 million lbs during the 47-year period ending in 2008, with a range from about 1.0 million lbs in many years (e.g., 1961, 1962, 1974, and 1979) to more than 6 million lbs in other years (e.g., 1999 and 2000). Production, which averaged just over 3.0 million lbs per year in the 1960s, increased to 5.1 million lbs during 2000-2008 (Table 9.1). About 85-90% of the Texas oyster production has historically been derived from the Galveston Bay System though, in some years, production from other bay systems in Texas can be large - equaling or exceeding that of Galveston Bay. Haby et al. (2009) provide annual Texas harvest information segregated by the Galveston Bay System and other bay systems for 1982-2007. While market forces may, to a lesser extent, influence annual production, a large portion of the variation is undoubtedly the result of fluctuations in environmental conditions that determine production and the survival of spat.

Annual indices of spat availability, small-oyster availability, and market-oyster availability in Galveston Bay for 1984-2003 are defined and provided by Martinez-Andrade et al. (2005) and are graphically illustrated in Figure 9.9. The spat availability index, as indicated, averaged 2367 with a standard deviation of 3060. For small oysters, the availability index averaged 2637 with a standard deviation of 1372. Finally, the index associated with market oysters averaged 708 during 1984-2003 with an associated standard deviation equal to 348. The standard deviation of the mean as a percentage of the mean declines as one moves from the spat index to the market-size index. Furthermore, the correlation between the spat index and the small-oyster index is very low, indicating that the spat index may not provide any meaningful measure of future oyster market availability or harvest. The correlation between the spat index in year *t* and small-oyster index in year *t* equaled 0.143 while the relationship between small-oyster index in year *t* and the lag of the spat index equaled 0.053. On the other hand, there is a strong positive relationship between the market-oyster index in year *t* and the small-oyster index in year *t*-1 (the correlation coefficient is equal to 0.714 and the correlation coefficient declines to 0.428 if a lag operator is not included in the analysis). Hence, the small-oyster index appears to provide an adequate indication of future market-oyster availability and, to the extent that it is related to availability, harvest.

As is the case with Louisiana, Texas oyster production is derived from public and private (i.e., leased) grounds. Public grounds, which encompass a total of 49,248 acres in Galveston Bay and other bay systems, are open from November-April. Production from private leases, which total 2,322 acres (all in Galveston Bay), relies heavily on transplanting activities, wherein oysters from restricted areas are relocated to private leases. There are generally two transplant seasons – a spring season (May) and a fall season (September). After waiting the appropriate two-week period for the oysters to ‘purge’ themselves, the transplanted oysters can be harvested (assuming the lease holder has the requisite permits). Given this arrangement, production from private beds tends to be strongly tied to availability of oysters in restricted waters.

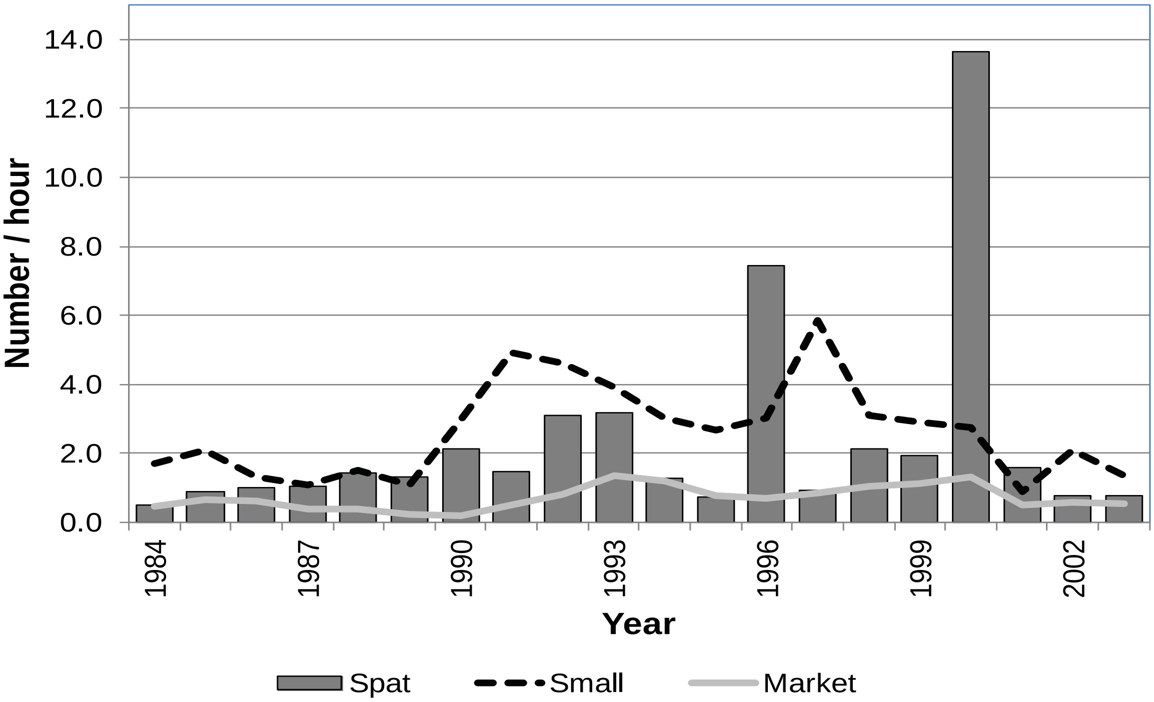


Figure 9.9 Annual estimates of seed, small, and market oysters in Galveston Bay from 1984-2003.

Between 1981 and 2008, production from public grounds ranged from 60-90% of total Texas production (Figure 9.10). Since the late 1990s, production from public grounds as a percentage of total state production has fallen in the relatively narrow range of 70-85% of the total. Since 1981 (and through 2008), production from public grounds averaged about 3.4 million lbs annually. In general, long-run variability in production from public grounds has approximated 40% of long-term (i.e., 1981-2008) average production.

Annual production from private leases for 1981 through 2008, as indicated by the information in Figure 9.11, has ranged from less than 600,000 lbs in some years (e.g., 1981, 1982, 1984, 1985, 1993, 1998, and 2008) to about 1.7 million lbs in 2003. Since 2003, production from private leases has fallen. Production in 2007, totaling about 900,000 lbs, represents almost a 50% decline from the 2003 peak. The 2008 lease-based harvest, equal to 535,000 lbs, was the lowest reported take since 1993. Much of the reduction is the result of damage to infrastructure and leases associated with Hurricane Ike.

Since 1981, the number of leases given in Texas for the production of oysters has fallen to only around 43-48 total. Since 1988, the number has been at the lower end while the total amount of water-bottoms being leased has equaled 2,322 acres. Given the relative constancy in leased acreage, production per acre mirrors total production from leases. Overall, production per acre during 1981-2007 has averaged less than 450 lbs per acre per year with a range from about 190 lbs/acre to 700 lbs/acre (Figure 9.11).

As noted, lease production in Texas depends heavily on transplanting from restricted areas. Production from leases in relation to transplanting activities during 1981-2007 is presented in Figure 9.12. As indicated, the relation between transplanting activities and subsequent harvest

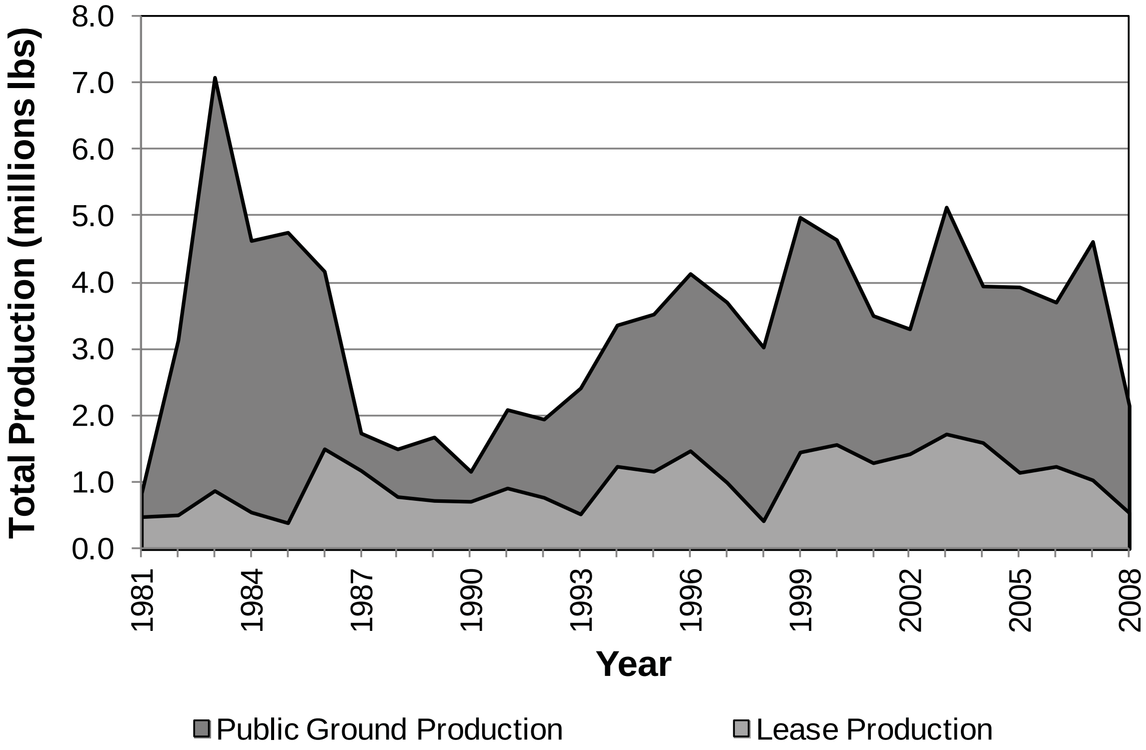


Figure 9.10 Annual Texas oyster harvests (millions of lbs) from leases and public grounds from 1981-2008.

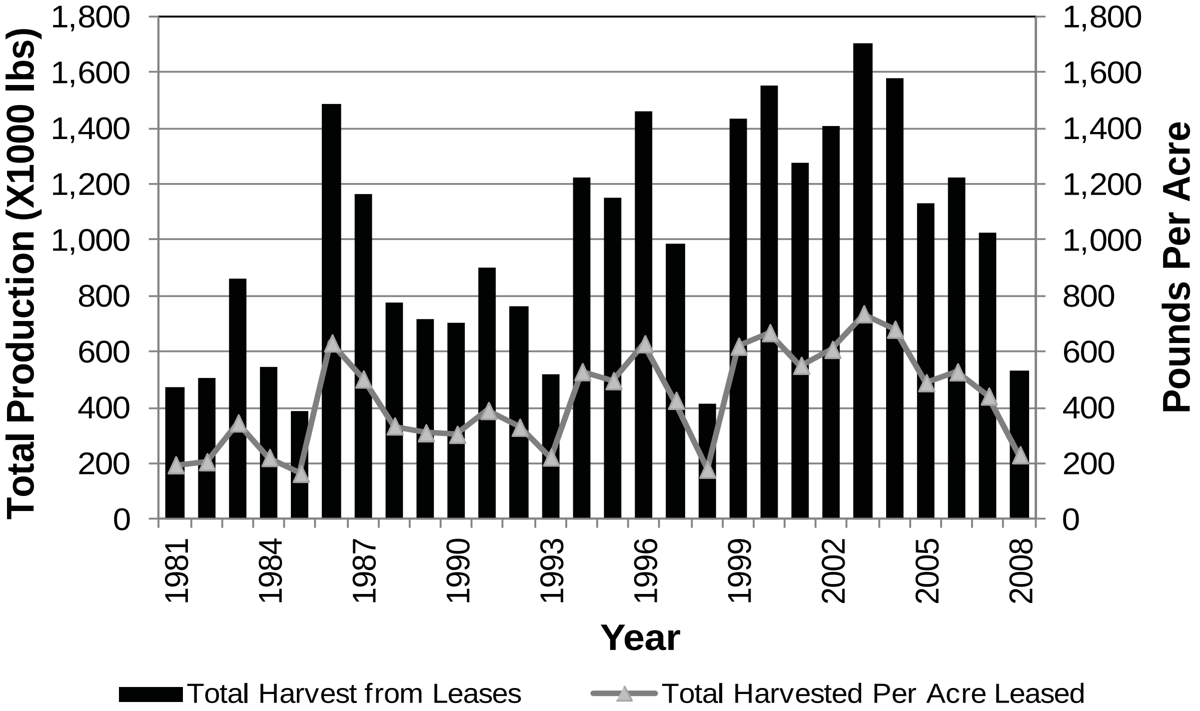


Figure 9.11 Texas production from private leases (x1000) and production per acre (lbs) from 1981-2007.

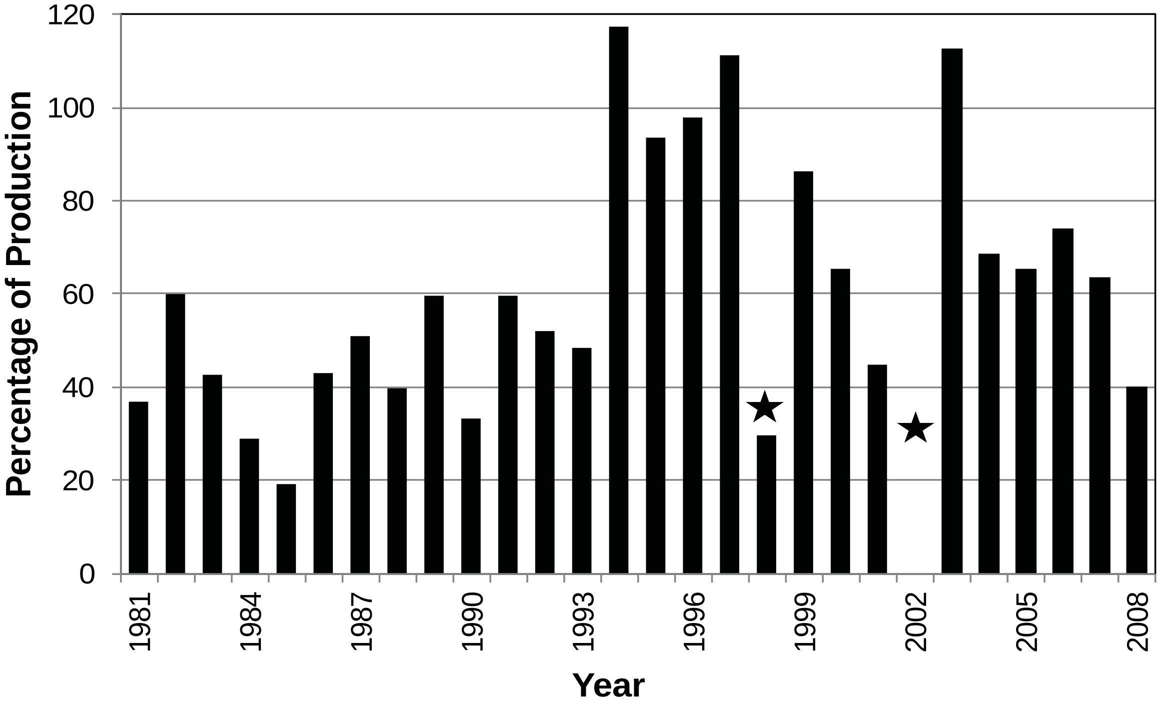


Figure 9.12 Production from leases in relation to transplanting activities, 1981-2008. **Note:** 2002 is incomplete and hence not included in the graph. In 1997, the transplant data are questionable since no fall transplants were reported and in 1998, no fall transplanting was permitted due to a red tide outbreak.

varies widely, ranging from less than 40% to more than 100%. The high variability in the observed relationship between transplanting activities and subsequent harvest can be related to environmental, regulatory, and economic factors.

9.2 Dockside Oyster Value

9.2.1 U.S Oyster Value by Region

Though the total U.S. oyster production fell from an average of almost 60 million lbs annually during the decade of the 1960s to about 38 million lbs annually since 2000, the corresponding value of these landings has increased from less than $30 million annually to about $110 million annually (Figure 9.13). Much of this increase reflects inflation. The inflation-adjusted value during 2000-2008, averaging $60 million annually (Figure 9.14), was less than two-thirds the 1960-1969 inflation-adjusted value, averaging $92 million annually (***NOTE:** unless otherwise noted, deflated values and prices are based on the 1982-1984 Consumer Price Index or CPI*). Mirroring pounds harvested, the largest observed change in deflated value by region is that associated with the Chesapeake. While long-run production from the Gulf, expressed in pounds, has remained relatively constant, there has been significant variation in the deflated value of the harvest. In the 1980s, for example, the deflated value of Gulf production averaged almost $36 million annually (based on 1982-1984 CPI). Though annual pounds landed during the 1990s were only about 10% below those observed during the 1980s (e.g., 19.3 million lbs annually vs. 21.8 million lbs annually; see Table 9.1), the average annual deflated value of landings during the 1990s ($26.6 million annually) was only 75% of the average annual deflated value of landings during the 1980s ($35.8 million annually). Similarly, though average annual Gulf production during 2000-2008 (23.3 million lbs annually) exceeded that reported in 1980-1989 (21.8 million lbs annually) by about 10% (see Table 9.1), the 2000-2008 annual deflated value of landings ($30.6 million annually) was about 15% below the 1980-1989 average annual deflated value ($35.8 million annually). Value is simply quantity multiplied by price. Given an increase in landings in 2000-2008 in relation to 1980-1989, the reduction in deflated value must be the result of a significant decline in (deflated) price per pound of the harvested product. This decline and the reasons associated with the decline are considered in more detail in Section 9.3.

Finally, two other aspects associated with the information presented in Figure 9.14 warrant discussion. First, as indicated, the deflated value of the Pacific landings increased sharply after about 1993. During the 1980s, for example, the average deflated value associated with Pacific production equaled $10.9 million annually. For the 1993-2008, the deflated value had increased to $17.3 million annually. This 50% increase was considerably larger than the approximately 15% observed increase in average annual production during the same time frame (i.e., 2000-2008 compared to 1980-1989). This would indicate a significant increase in the deflated per pound Pacific dockside price (reasons for the increased price associated with the Pacific product will be considered in more detail in Section 9.3). The second aspect associated with the information presented in Figure 9.14 that is worth considering in greater detail relates to the 'other' regions. The deflated value of oyster production from the Northeast, Mid-Atlantic, and South Atlantic was particularly large during the mid-1980s to mid-1990s. This largely reflects high production in the Northeast as well as a very high associated dockside price for the Northeast product.

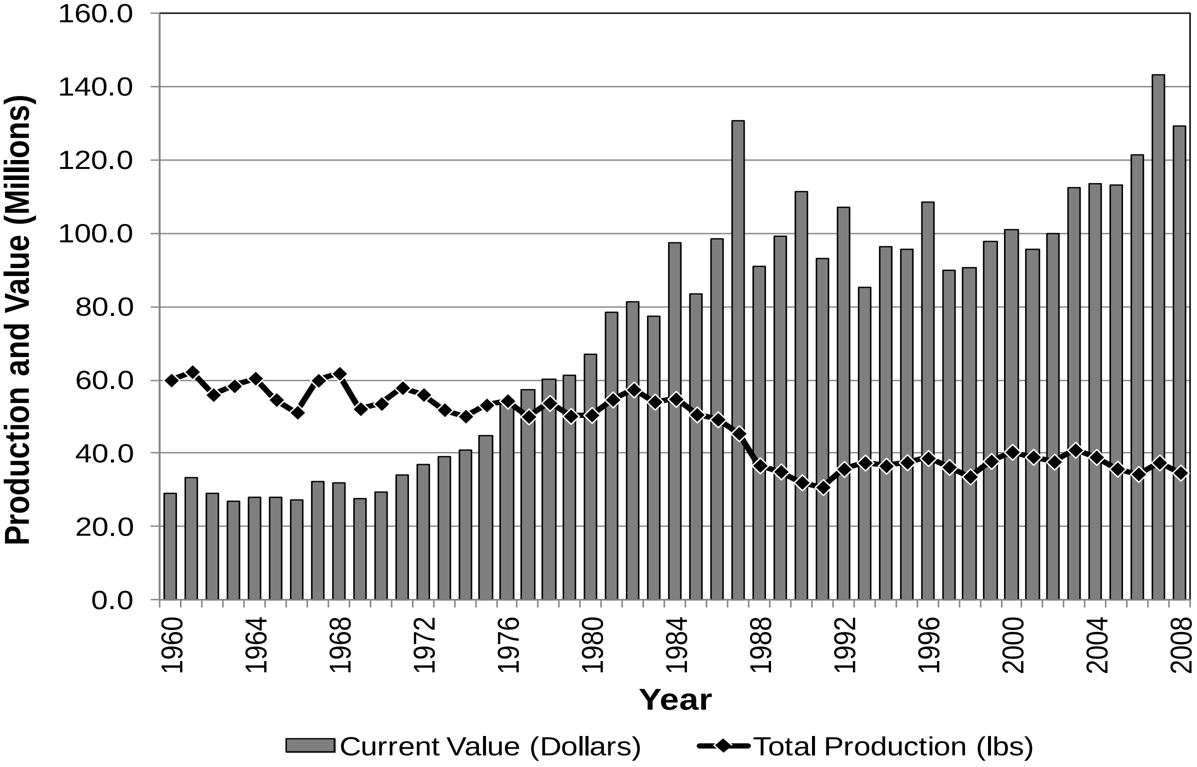


Figure 9.13 Total U.S. oyster production and associated current value from 1960-2008 (NMFS pers. comm.).

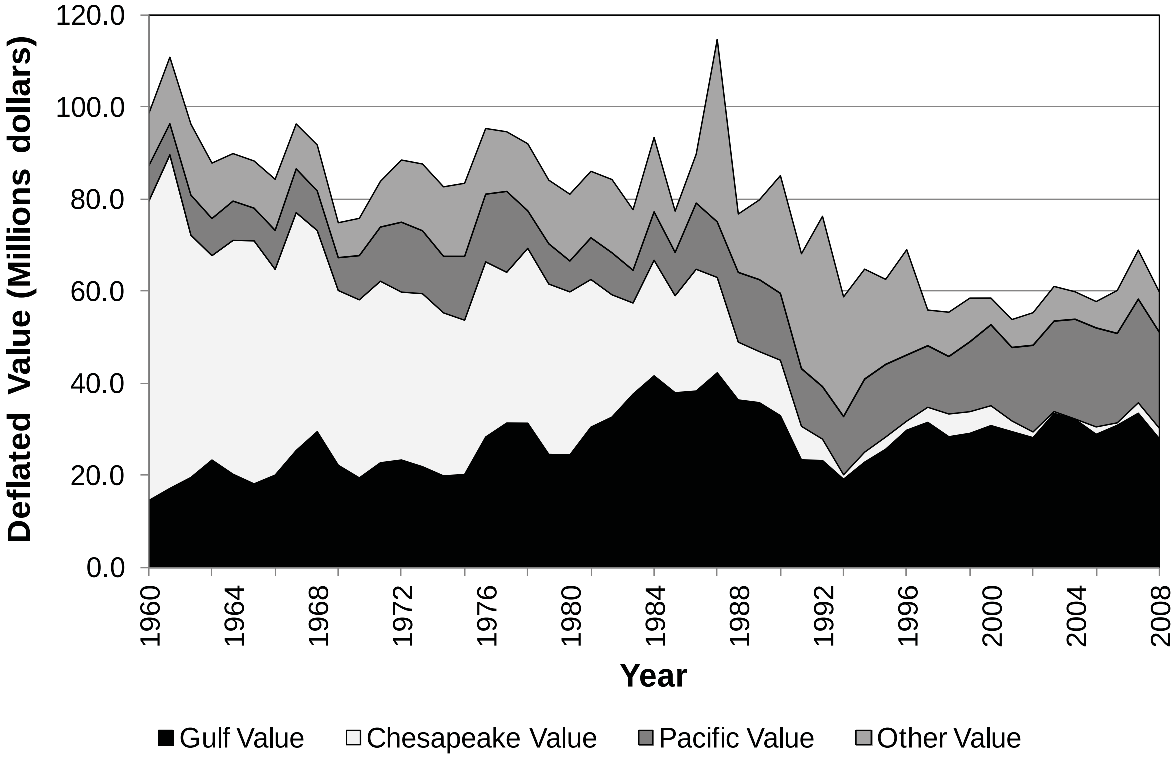


Figure 9.14 Total U.S. deflated (1982-84 base) dockside oyster values (millions) by region from 1960-2008 (NMFS pers. comm.).

9.2.2 U.S. Oyster Value by Gulf State

Current and deflated values of oyster production by Gulf state for selected time periods are presented in Table 9.2 and value shares are given in Figure 9.15. In general, the value shares closely mirror the poundage shares (Figure 9.4). This is to be expected and, if prices were the same among all Gulf states, poundage and value shares would be exactly equal. Any differences between the two, therefore, reflect price differentials among the respective states.

Table 9.2 Gulf of Mexico Annual Oyster Value by State (expressed in thousands of dollars), 1960-2008 (NMFS pers. comm.).

Time period	Alabama	Florida	Louisiana	Mississippi	Texas	Gulf
	Current / Deflated	Current / Deflated	Current / Deflated	Current / Deflated	Current / Deflated	Current / Deflated
1960-1969	400 / 1,233	1,219 / 3,756	3,241 / 10,053	790 / 2,469	1,138 / 3,493	6,789 / 21,004
1970-1979	675 / 1,249	2,303 / 4,176	7,429 / 13,690	553 / 1,050	2,070 / 4,147	13,031 / 24,311
1980-1989	930 / 922	5,899 / 5,723	23,076 / 21,578	1,260 / 1,223	6,724 / 6,356	37,888 / 35,803
1990-1999	915 / 607	3,422 / 2,355	25,380 / 17,347	2,471 / 1,573	8,547 / 5,613	40,734 / 27,494
2000-2008	1,993 / 1,042	4,114 / 2,129	34,009 / 17,740	4,113 / 2,207	14,327 / 7,507	58,580 / 30,627

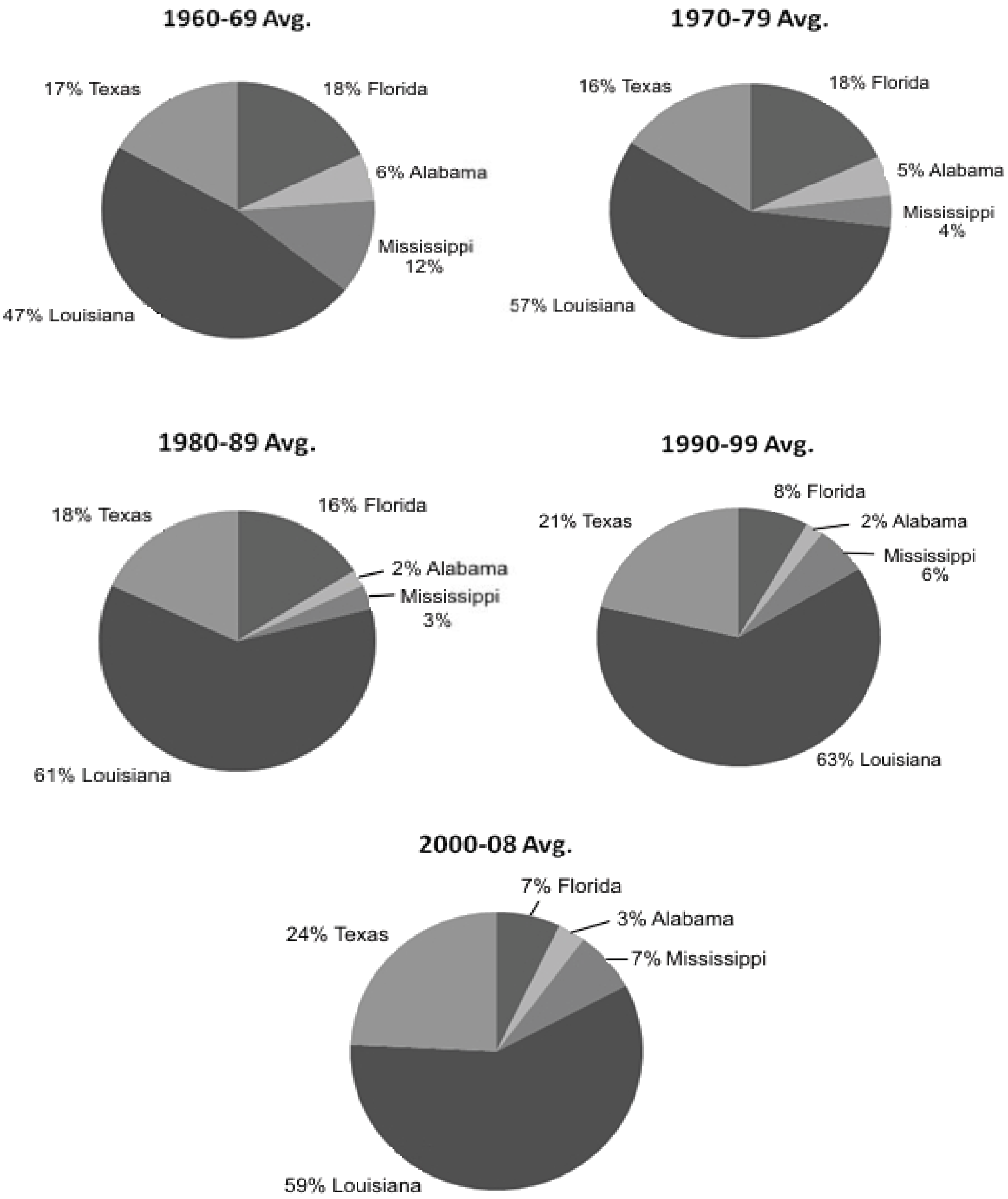


Figure 9.15 Oyster harvest shares (value) by Gulf state, selected time periods from 1960-2008 (NMFS pers. comm.).

9.3 Dockside Oyster Price

9.3.1 U.S. Dockside Oyster Price

The current and deflated average U.S. oyster dockside prices for 1960-2006 are presented in Figure 9.16. As indicated, the current average U.S. price advanced from approximately $0.50/lb in the early 1960s to more than $3.00/lb by 1990 but, thereafter, fell sharply to less than $2.50/lb

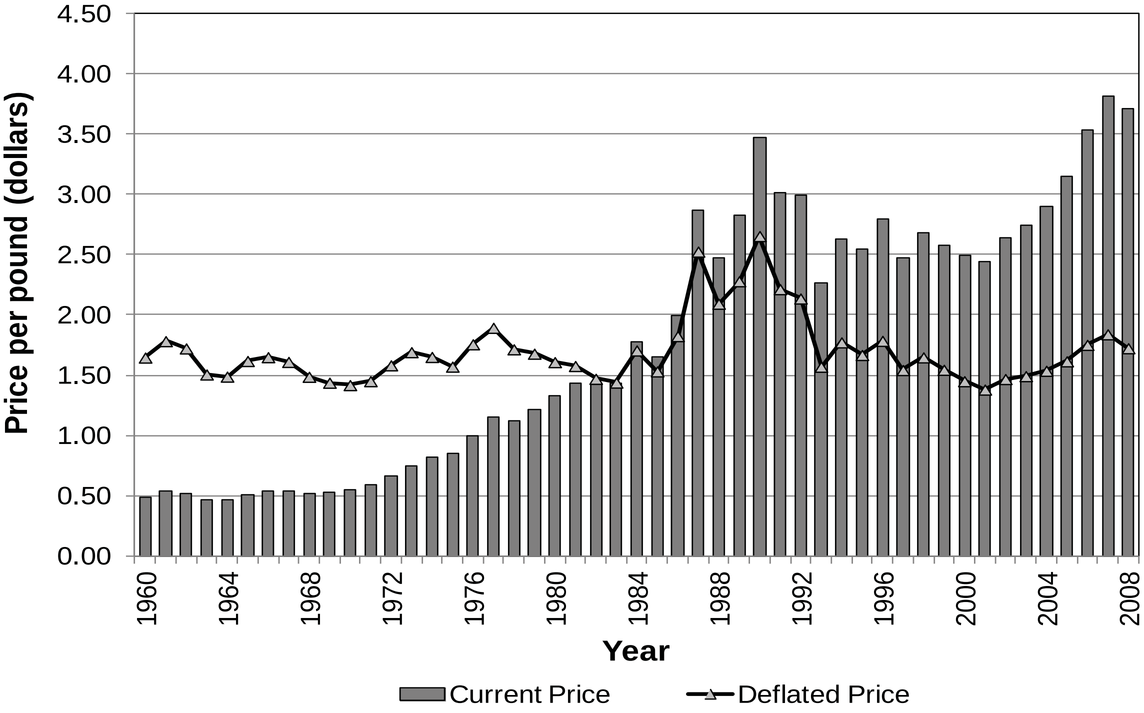


Figure 9.16 Current and deflated US oyster dockside prices from 1960-2008 (NMFS pers. comm.).

during many of the years during the 1990s. Beginning in 2002, the current price began to advance rapidly, exceeding $3.50/lb in 2006.

While there have been some short-run changes, the long-run deflated U.S. dockside oyster price can best be characterized as stable (Figure 9.16). In 1960-1964, the average annual deflated price (unweighted by poundage) equaled $1.59/lb. Since 2000, the unweighted deflated price has averaged $1.53 per lb. Interestingly, this long-run stability exists despite average U.S. oyster production declining from almost 60 million lbs annually to less than 40 million lbs annually since 2000 (as discussed later in Section 9.4, imports also contribute to price determination).

Despite the apparent long-term stability in the average U.S. deflated dockside oyster prices, there are some obvious short-term deviations from the long-term average. The most notable of these is the period from approximately the mid-1980s to the early 1990s when, as indicated, the deflated price rose rapidly before falling even more rapidly. As discussed below, much of the rapid increase during the mid-1980s represents a reduction in oyster supply relative to demand. The rapid decline in the early 1990s, on the other hand, largely represents consumer reaction to publicity associated with *Vibrio vulnificus* (*V.v.*) and related labeling requirements in California and some of the Gulf states.

9.3.2 Regional Dockside Oyster Prices

Annual deflated dockside prices for the historically principle oyster-producing regions – the Gulf, the Chesapeake, and the Pacific – are presented in Figure 9.17 for the period beginning in 1960 and ending in 2008. Given the similarity between the Gulf oyster and the Chesapeake oyster (i.e., both Eastern oysters), one might expect the two regional prices to mirror one another.

Instead, the annual Chesapeake price was significantly higher than the Gulf price during the 1960s. While not documented, the reason for the high Chesapeake price, *vis-à-vis* Gulf price, likely reflects a combination of two factors. First, the region surrounding the Chesapeake had a much higher population than the Gulf and hence, all else equal (e.g. per capita income, tastes, and preferences), a higher demand. Second, the transportation system in the 1960s was less developed than it is today and, as such, there was likely little interregional trade in shell oyster. According to Reily et al. (1985), large quantities of Louisiana oysters (and presumably Gulf oysters) were not transported to the East coast until 1981/1982. With advances in transportation, including the interstate system that facilitated trade from the Gulf region to the East coast, the price differential between the Gulf and Pacific dockside prices narrowed throughout the 1960s and 1970s until prices became roughly equalized in the early 1980s. In line with an increasing amount of Gulf product destined for the East coast market, the deflated Chesapeake dockside price fell sharply throughout the 1960s and into the 1970s, while the deflated Gulf price advanced. Throughout the 1980s, the Gulf and Chesapeake prices mirrored one another (Figure 9.17). This came to an abrupt end when, in 1991, the Gulf price fell sharply despite relatively low landings (Gulf landings in 1991 equaled 12.4 million lbs or only about 60% of the 1960-2008 average 20.6 million lbs annual landings). Throughout the remainder of the 1990s and continuing until present, the Chesapeake price exceeded the Gulf price by a significant margin.

Keithly and Diop (2001) attribute the decline in Gulf dockside price to the enactment of mandatory warning labels and the associated negative publicity. Specifically, California, in response to health concerns, initiated a program on March 1, 1991, requiring anyone selling raw eastern oysters from the Gulf of Mexico to notify potential consumers that there may be a risk associated with consuming raw product. California's mandatory warning received considerable

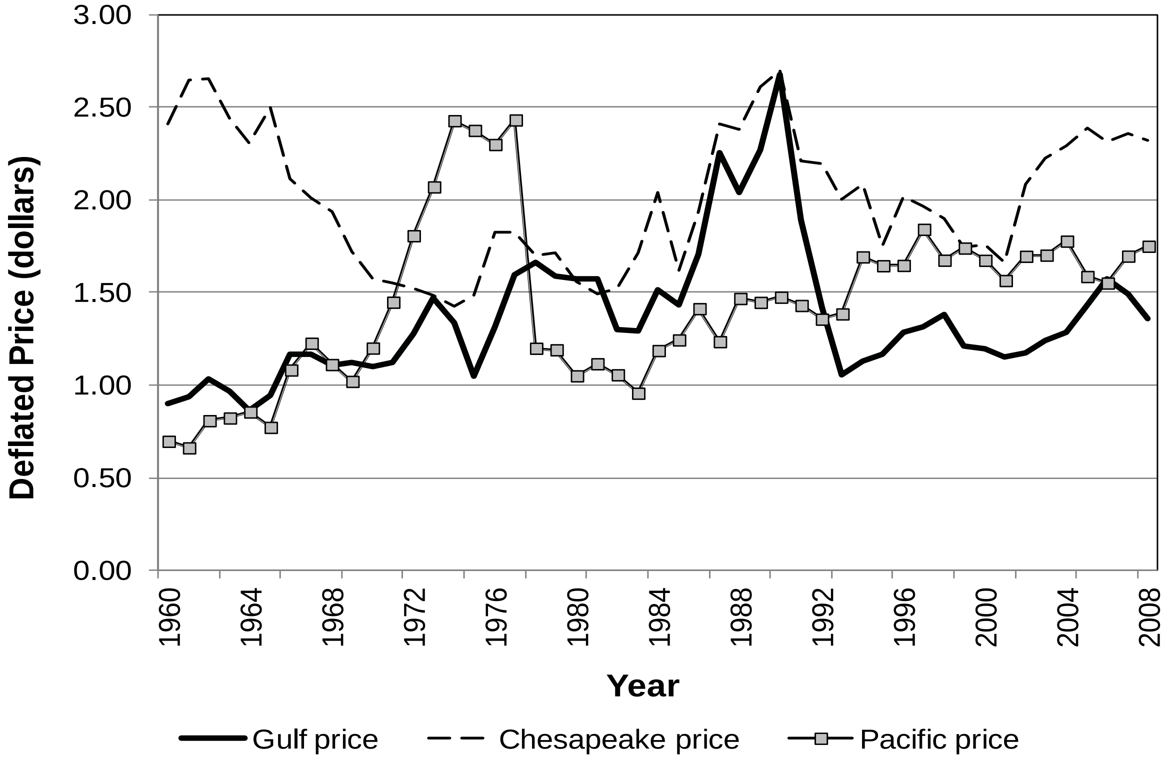


Figure 9.17 Deflated (1982-84 base) annual oyster dockside price ($/lb) by region from 1960-2008 (NMFS pers. comm.).

attention and, shortly thereafter, some Gulf states, including Louisiana and Florida, followed suit, requiring similar warning labels.

This mandatory warning was prompted by a number of California residents becoming ill, with some dying, from consuming raw Gulf oysters contaminated with *V.v*. The abundance of this bacterium, which is naturally occurring, is highly correlated with temperature and, in the warmer summer months, virtually all Gulf-harvested oysters contain some concentration of it. While harmless to the majority of the population, *V.v.* can cause illness and even death among individuals with weakened immune systems (See Section 6.0). The warning labels, as noted, received considerable attention, much of it in the form of negative publicity. Keithly and Diop (2001) concluded that this negative publicity resulted in a significant reduction in the demand for the Gulf product. This reduced demand culminated in the long-run dockside price of the harvested product falling by 30-50%, with the percentage of decline depending upon the season (i.e., the Gulf of Mexico dockside price is 30-50% less than would be the case if warning labels and/or negative publicity did not occur).

More recently, Dedah et al. (in press) expanded on the work by Keithly and Diop (2001) by examining the impact of warning labels and negative publicity on demand, for not just the Gulf product, but also other oyster products expected to compete in the market with the Gulf product. The study employed a complete demand system using quarterly data covering the 1985(1)-2008(4) period and included in the analysis was Gulf oyster production, Chesapeake oyster production, Pacific oyster production, and oyster imports. Only those imported products hypothesized to compete directly with domestic production (i.e, fresh and frozen meats) were included in the analysis and other imported products, such as smoked oysters, were excluded. Dedah et al. (in press) similarly found that the Vibrio event resulted in a statistically significant and permanent decline in the demand for the Gulf product. Specifically, the authors concluded that the long-run market share for the Gulf product declined by approximately 15% as a result of mandatory warning labels and negative publicity. Conversely, demand for both Pacific product and imported product was found to increase as a result of the Vibrio event. As indicated in Figure 9.17, the dockside price of the Pacific product was generally significantly lower than the Gulf price throughout the 1980s and into the early 1990s. By 1993, however, the Chesapeake price exceeded the Gulf price by a wide margin. This finding implies that the reduction in demand for the Gulf product was offset, at least in part, by increased demand for the Pacific and imported products. The Chesapeake price was not found to be statistically significantly influenced by the Vibrio event.

Dedah et al. (in press) also estimated all own-and-cross price flexibilities or elasticities associated with the developed model (Table 9.3). Own price flexibilities refer to changes in the quantity or harvest of a particular good (e.g. Gulf oysters) and the change in the price for that same good (e.g. Gulf oysters). For example, how does the price for Gulf oysters fluctuate as the quantity or harvest of Gulf oysters changes? Cross price flexibilities, on the other hand, calculate how changes in the quantity or harvest of one good (e.g. Pacific oysters) result in changes in the price for another type of good (e.g. Gulf oysters).

Own-price flexibilities (calculated at the means), which provide an estimate of change in own-price associated with a 1% change in quantity, are presented along the main diagonal. As indicated, a 10% increase in Gulf harvest was found to result in a 6.4% decrease in the Gulf dockside price and the relationship was found to be statistically significant. Conversely, a 10% decrease in Gulf harvest would result in a 6.4% increase in the Gulf dockside price. Similarly, a 10% change in Chesapeake production was found to result in an 8.2% change in the Chesapeake price of opposite direction while a 10% increase in Pacific production was found to culminate in only a 2.8% reduction in its own dockside price, all other things being equal.

Table 9.3 Uncompensated price flexibilities (SE parentheses).

	Gulf Quantity	Chesapeake Quantity	Pacific Quantity	Import Quantity	Scale
Gulf	-0.683*	-0.048*	-0.155*	-0.126*	-1.011*
	(0.038)	(0.009)	(0.025)	(0.020)	(0.062)
Chesapeake	-0.424	-0.639*	-0.209*	-0.052	-1.322*
	(0.239)	(0.064)	(0.105)	(0.073)	(0.400)
Pacific	-0.205*	-0.033*	-0.273*	-0.154*	-0.634*
	(0.056)	(0.014)	(0.066)	(0.039)	(0.103)
Import	-0.574*	-0.025	-0.340*	-0.283*	-1.223*
	(0.077)	(0.019)	(0.066)	(0.071)	(0.129)

* Denotes that parameters are significant at 5% level of significance

The analysis by Dedah et al. (in press) also suggests that the Gulf dockside price is significantly influenced by production in other regions as well as imports (i.e., cross-price flexibilities). Specifically, a 10% increase or decrease in quarterly Pacific production was found to result in an inverse reduction or increase in Gulf price equal to 1.6%. While changes in Chesapeake production were not found to statistically influence the Gulf price, this finding is likely only an artifact of the small quantity being harvested from the Chesapeake in recent years.

The analysis conducted by the authors also indicates that Gulf production influences dockside prices in other regions and the import price. Specifically, a 10% increase in Gulf production (evaluated at the 1985-2008 mean) was found to result in a 5.6% reduction in the Chesapeake price, a 2.2% decrease in the Pacific dockside price, and a 6.7% decrease in the import price.

Finally, the analysis can be used to examine how dockside prices (import price) respond to a simultaneous change in all supply sources. This estimated response is given in the 'Scale' column (see Table 9.3). For example, the analysis found that a 10% increase in all supply sources (i.e., Gulf, Chesapeake, Pacific, and imports), evaluated at the 1985-2008 mean values for all variables, resulted in a 9.8% decrease in the Gulf dockside price, a 6.3% decrease in the Pacific dockside price, and an almost 20% decrease in Chesapeake dockside price.

An examination of the information in Figure 9.17 also reveals that, after falling in the relatively narrow range of about $1.15-1.35/lb from 1994-2004, the deflated Gulf dockside price increased significantly during the most recent four-year period of analysis (i.e., 2005 through 2008). This recent increase is likely the result of a sharp decline in Gulf production.

9.4 Oyster Imports

Since 1991, U.S. oyster imports have averaged 19 million lbs annually (product weight) and have ranged from less than 15 million lbs to almost 25 million lbs (Figure 9.18). While seemingly a large amount, much of the imports reflect canned and smoked products that likely do not significantly compete with domestic product in the U.S. market. Subtracting these products (i.e., canned and smoked oyster products) from total imports likely provides a more reasonable approximation as to the quantity of imports that are likely to compete with domestic product (live, fresh, frozen, salted, and brine products). The resolution of the import data does not permit further differentiation of products (e.g., subtraction of only salted or brine products). For purposes of discussion, these will be referred to as fresh/frozen products. As indicated, imports of fresh/frozen oysters generally ranged from about three-million lbs to five-million lbs annually throughout the 1990s but have increased significantly since 2000 (Figure 9.18). Annual imports of fresh /frozen oyster products peaked at 11.4 million lbs in 2006 before falling to 8.1 million lbs in 2008. On a percentage basis, fresh/frozen oyster imports in relation to the total gradually increased from about 15% in 1991 to almost 50% in 2006 before falling to about 40% in 2007 and 2008. In general, Canada and South Korea account for the majority of fresh/frozen oyster imports to the U.S. market but product from China and Japan can also be significant in some years.

One means of examining the potential substitutability of the fresh/frozen imported oyster product with the Gulf product is to examine the difference in annual prices between the two products. This examination, presented on a deflated basis, is presented in Figure 9.19. Throughout much of the 1990s, as indicated, the deflated fresh/frozen imported price tended to exceed the deflated Gulf of Mexico price by a considerable margin (1991 being the primary exception with the Gulf price exceeding the import price by about 25%). From 1998-2002, however, the fresh/frozen import price and the Gulf dockside price were essentially identical. Beginning in 2003, the spread between the Gulf of Mexico 'per pound' dockside price and the 'per pound' fresh/frozen import price widened ($0.13/lb) with the differentiation reaching a maximum of $0.48 in 2006. By 2008, the differentiation had fallen to less than $0.30/lb.

9.5 The Distribution and Value-Added System

Following Muth et al. (2002), the oyster industry can be partitioned into three 'primary' sectors: the harvesting sector, the wholesaling/processing sector, and the retail sector. The

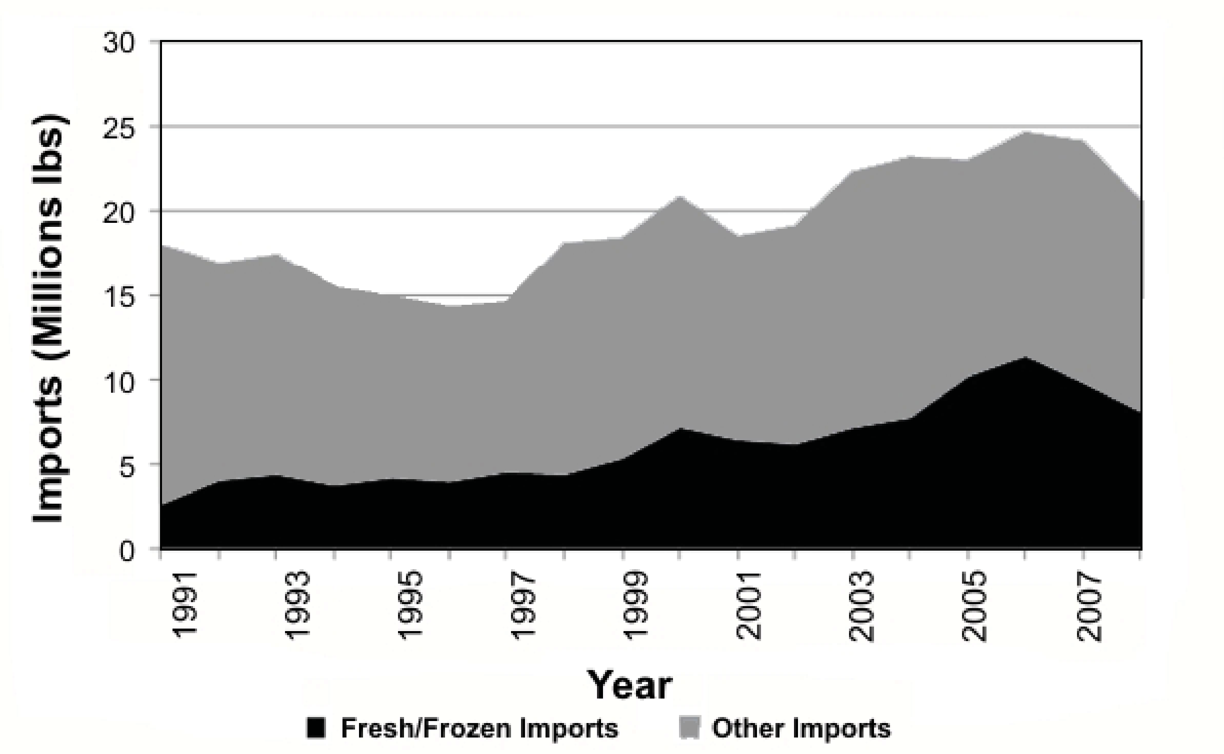


Figure 9.18 US oyster imports by product form (expressed on a product weight basis) from 1991-2008 (NMFS pers. comm.).

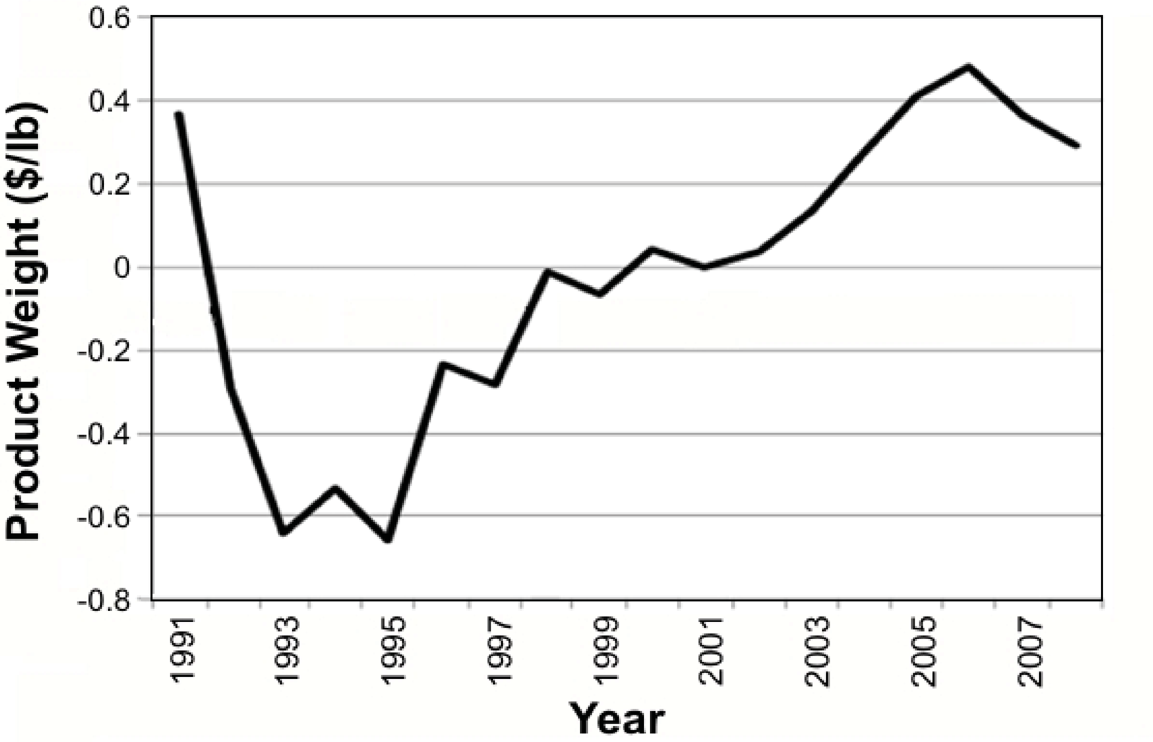


Figure 9.19 Estimated price ($/lb) differential between US import price (fresh/frozen product) and Gulf dockside price from 1991-2008 (NMFS pers. comm.).

distinction between wholesalers and processors is that wholesalers do not make a significant physical transformation of the raw product. These three sectors and the relationships between the different sectors are illustrated in Figure 9.20. In the first stage, the raw product is harvested. This product, as discussed earlier in this chapter, can be derived from public grounds or private leases. Upon arrival at dock, the product is generally delivered to wholesalers and/or processors but, on some occasions, the product is delivered directly to restaurants and/or grocery outlets. While varying from one Gulf state to another, there is also a considerable amount of vertical integration between the harvesting sector and the wholesaling/processing sector (a large number of Gulf establishments will perform both wholesaling and processing activities). This is particularly true in Louisiana and Texas where a number of the larger lease holders also maintain large wholesaling/processing operations.

If the product is delivered to a wholesaler, the product may be retained in its original condition or, alternatively, may be washed and repacked into boxes or smaller sacks/bushels. It will then be resold to other wholesalers, processors, or retail and/or grocery outlets (Figure 9.20).

9.5.1 Gulf Processing Activities in Pounds

The NMFS collects oyster shucking activities in gallons and converts it to pounds of meats using a conversion ratio of 8.75 lbs of meats to a gallon which was estimated based on the weight of a gallon of water, not actual oyster meats (Keithly pers. comm.). This conversion seems high and, as such, an estimate of 7.5 lbs of meats to a gallon seems more appropriate and is used throughout the remainder of this section (Keithly pers. comm.).

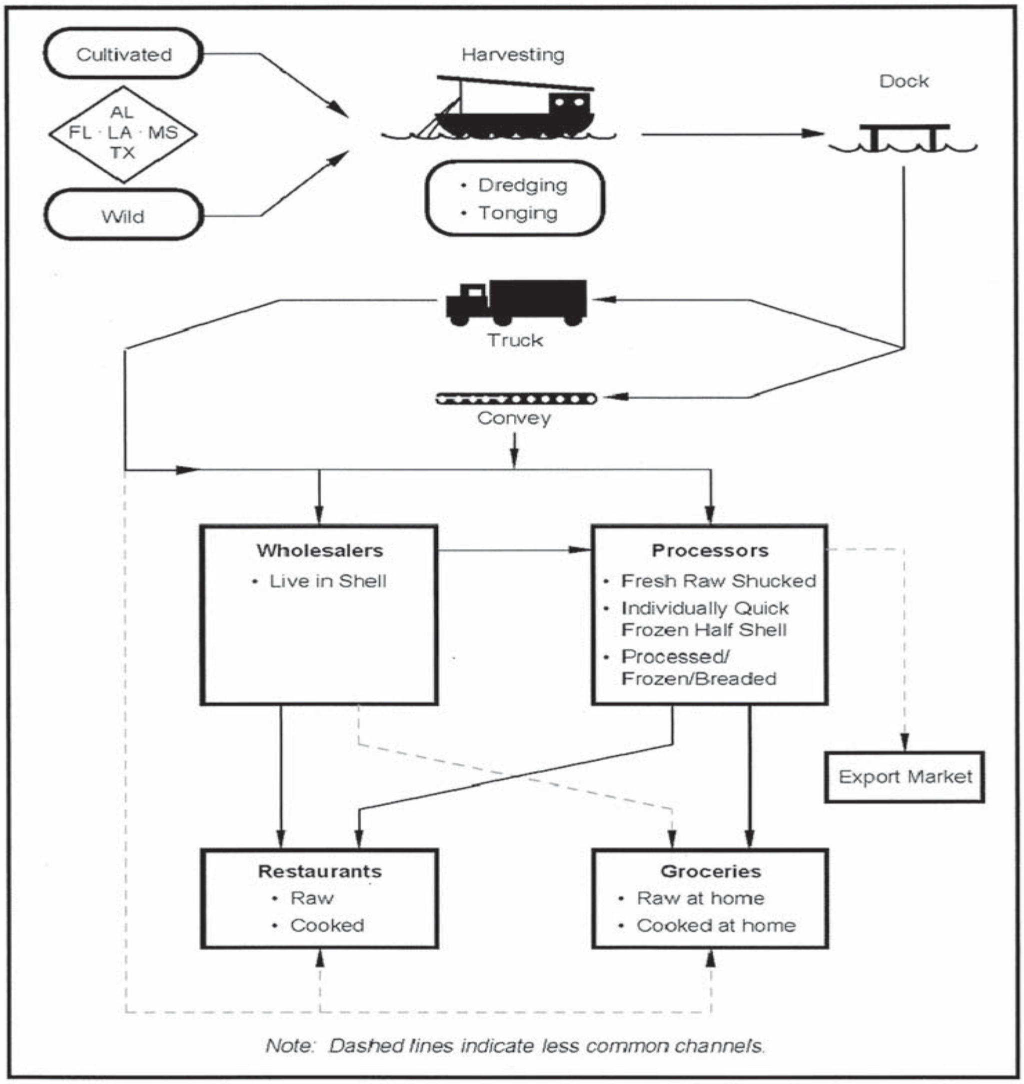


Figure 9.20 Marketing channels for Gulf harvested oysters (*from* Muth et al 2000).

Gulf of Mexico oyster harvest averaged 21.4 million lbs during 1980-2008. This product can be moved directly for the half-shell market or can be processed (primarily shucked). Processing, furthermore, can occur either in the Gulf or elsewhere such as the Chesapeake region. Based on responses to a voluntary end-of-the-year survey conducted by NMFS, Gulf oyster processors reported shucking an average of 13.2 million lbs of meats per year during this time period. This would indicate that a minimum of about 60% of the Gulf harvested product is shucked by Gulf processors. It is also considered a minimum because only shucked product is considered in the analysis. Other products, such as breaded oysters, are reported by processors but are not included in this analysis in an attempt to avoid any double counting (e.g., one establishment may sell shucked product to another establishment where it is subsequently breaded). In general, Gulf of Mexico processed poundage closely mirrors landings in the region (Figure 9.21) with increased landings implying increased processing activities.

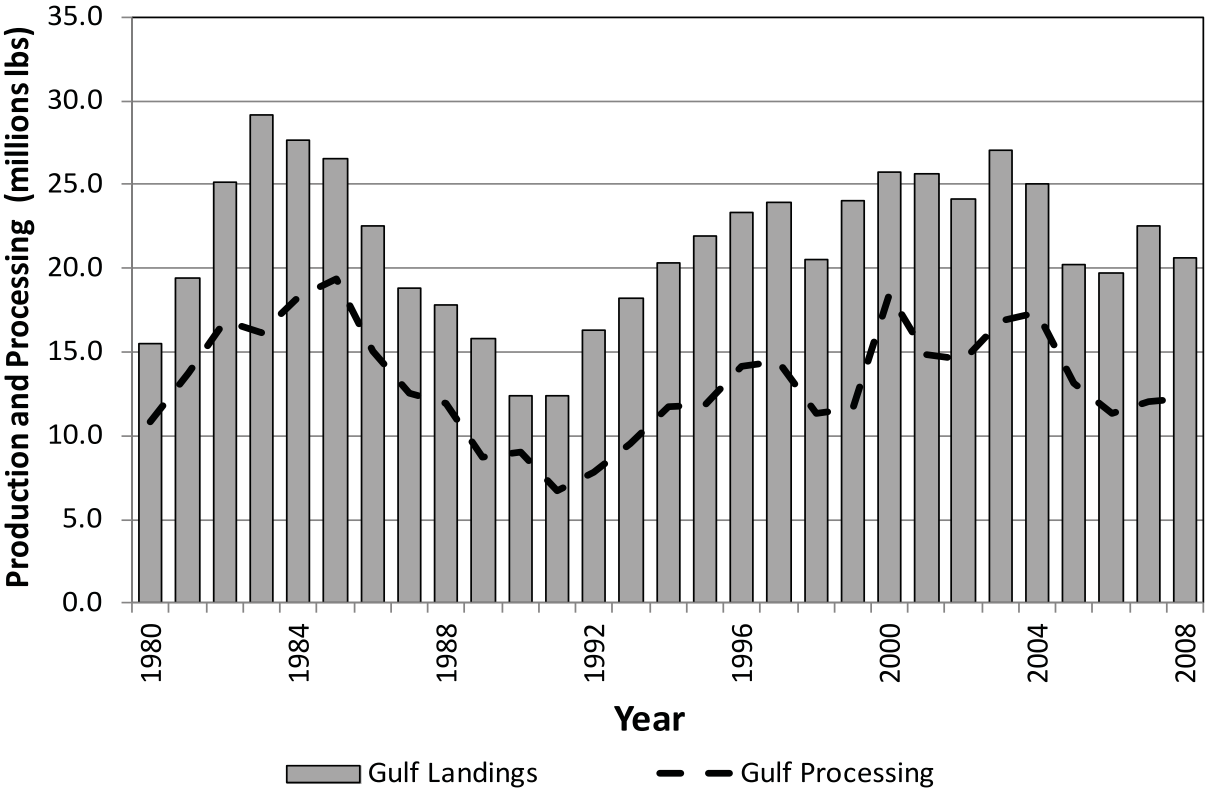


Figure 9.21 Gulf of Mexico processed oyster meats in relation to lbs harvested from 1980-2008.

While Alabama and Mississippi (combined for confidentiality purposes) generally account for less than 15% of total Gulf oyster harvest (see Figure 9.4), processors in those states have historically accounted for more than 30% of total Gulf processing activities and, since the early 1990s, have accounted for more than 40% of the total (Figure 9.22). By comparison, Louisiana generally processes less than one-third of its harvested product and the absolute quantity of product processed in Louisiana has fallen since the early 1990s (Figure 9.22). While not documented, a large amount of Louisiana harvest is known to go to Alabama where it is processed. Prochaska and Keithly (1985) also showed that a large amount of Louisiana harvest went to Apalachicola for processing in the mid-1980s.

In addition to intraregional movements of shellstock for processing activities, Gulf shellstock is also known to be shipped to the Chesapeake for processing. For example, a 1991 survey of Chesapeake processors found that 53% and 31% of the Virginia and Maryland respondents, respectively, handled Gulf oysters (NRC 2004b). This study was conducted during a year of abnormally low Gulf production and suggests that Chesapeake dependence on oysters from outside the region has increased since 1991. The study also indicated that Pacific oysters are used in Chesapeake Bay processing activities but to a lesser extent than Gulf product (NRC 2004b).

The increased dependence on out-of-region shellstock by Chesapeake processors is illustrated in Figure 9.23. Prior to the early 1990s, as indicated, Chesapeake processed pounds were roughly equivalent to landings. Since the early 1990s, however, the difference between the region's processing activities and landings has increased and, based on the paucity of landings in recent years, almost all of the region's processed product would have been derived from out-of-region shellstock. Most of this shellstock likely originates from the Gulf.

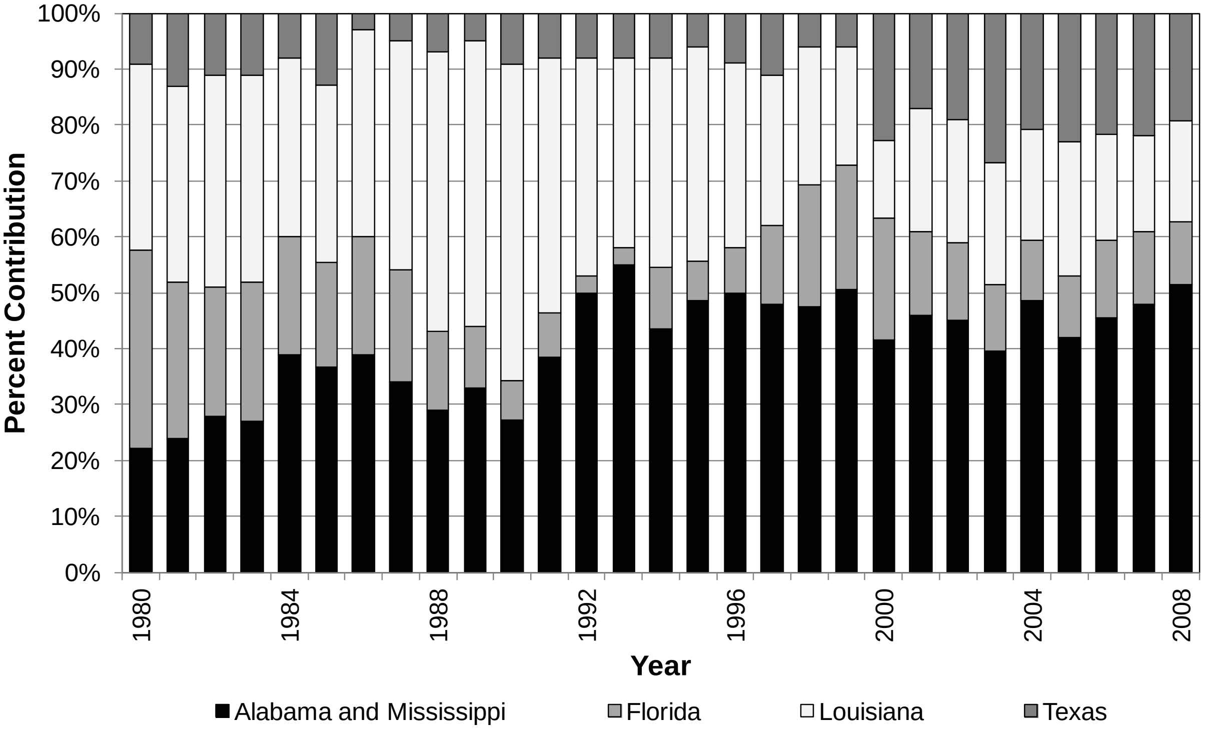


Figure 9.22 Share of Gulf oyster processing activities by state from 1980-2008.

9.5.2 Value and Price of Gulf Processing Activities

As indicated by the information in Figure 9.24, the current value of Gulf processing activities advanced from about \$30 million in 1980 to more than \$60 million during the most recent decade. Much of this increase, however, is inflation based. After adjusting for inflation, no growth in the value of Gulf processing activities is observed. Given the relative constancy in long-run Gulf processing activities as measured on a poundage basis (Figure 9.21), long-run stability in deflated value implies a relatively constant long-run deflated price per pound associated with the processed product. The deflated per-pound price of the processed product (based on 7.5 pounds of meat per gallon) is presented in Figure 9.25.

Processing requires both labor and other inputs that add value to the product. Hence, one would expect the processed price to exceed the dockside price by the cost of these additional inputs (plus a profit associated with the value-added activities). The price differential between the processed price and the dockside price (assuming 7.5 pounds of meats per gallon), on a deflated basis, is given in Figure 9.26. As indicated, there is little long-term trend in the deflated price differential implying a relatively constant long-run price markup. The correlation between the dockside price and processed price during the 1980-2008 period is equal to 0.80.

9.5.3 Establishments and Activities Per Establishment

Oyster processing activities are conducted by a number of establishments throughout the Gulf of Mexico. In the early 1980s, approximately 180-190 establishments were engaged in oysters processing activities on an annual basis (Figure 9.27). The number has gradually fallen over time, averaging slightly more than 100 during the early-to-mid-1990s and less than 70 since 2006. A declining number of processing establishments, in conjunction with a relative long-run stability in industry output (see Figure 9.21), implies an increasing output per establishment over time. Prior

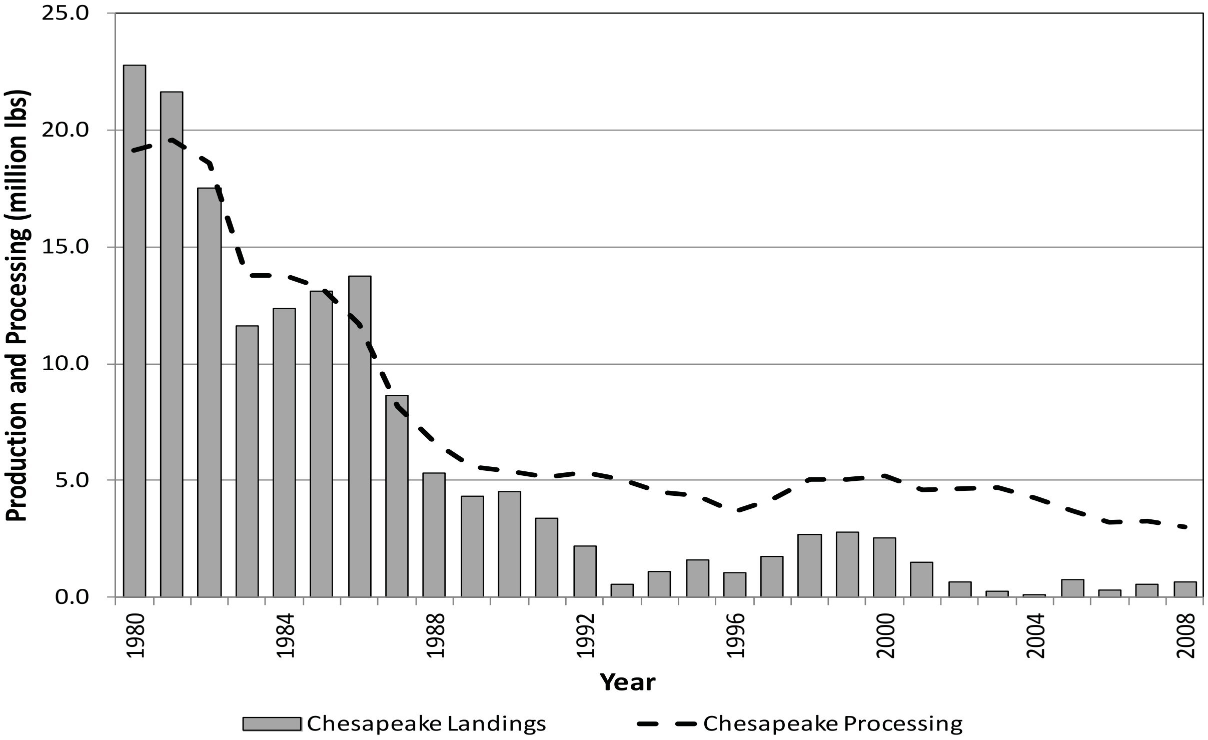


Figure 9.23 Chesapeake landings (lbs.) in relation to Chesapeake processing activities from 1980-2008.

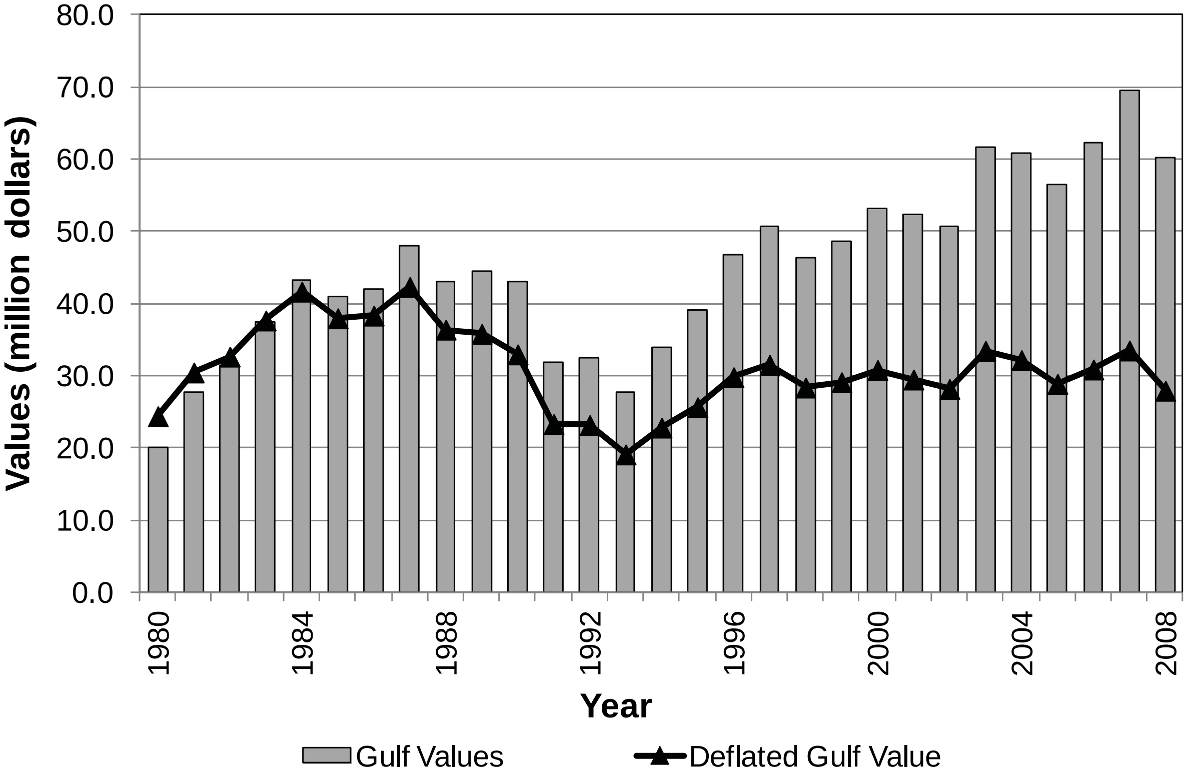


Figure 9.24 Current and deflated values (millions $) associated with Gulf oyster processing activities from 1980-2008.

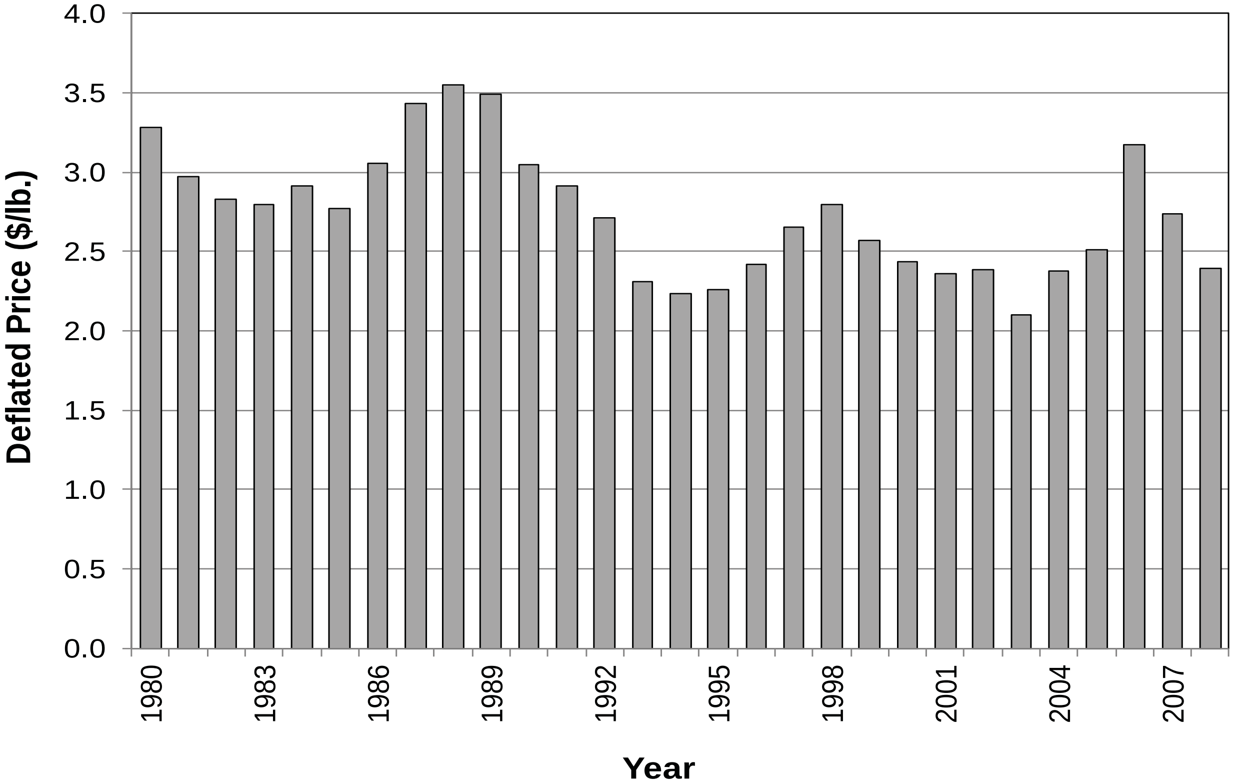


Figure 9.25 Deflated price associated with Gulf oyster processing activities ($/lb) from 1980-2008.

to 1994, as indicated by the information in Figure 9.28, production per firm measured in terms of pounds, exceeded 100,000 lbs only once and in many years fell below 80,000 lbs (based on 7.5 lbs of meats per gallon). Since 1994, however, production per firm has never fallen below 100,000 lbs and has generally exceeded 175,000 lbs since 2004.

In conjunction with an increase in the average pounds processed per firm over the 29-year period of analysis, the current revenues generated from oyster processing activities among Gulf establishments increased from about $250,000 per firm in the early 1980s to more than $1 million since 2006; roughly a quadrupling in average revenues generated per firm over the period of analysis (Figure 9.29). After adjusting for inflation, revenues generated per firm approximately doubled (Figure 9.29). The increase in deflated revenues generated per firm can be attributed to the increased poundage produced per firm, given the relative long-run stability in the Gulf deflated processed oyster price (Figure 9.25).

9.5.4 Post-harvest Treatment

As noted in previous sections, *Vibrio vulnificus* (*V.v.*) is a naturally occurring bacterium found in the marine environment. The bacterium is particularly prevalent in the waters of the Gulf of Mexico and virtually all oysters harvested from these waters during the summer months exhibit some concentration of it. While consumption of Vibrio laden oysters is relatively innocuous among healthy individuals, it can lead to serious illness and even death among individuals with immunocompromised systems (FAO/WHO 2005) (see Section 6 and Section 16.3 for more detail).

There are currently four technologies approved by the FDA for post-harvest treatment for reducing *V.v.* to nondetectable levels. These include cryogenic individual quick freezing (IQF), cool

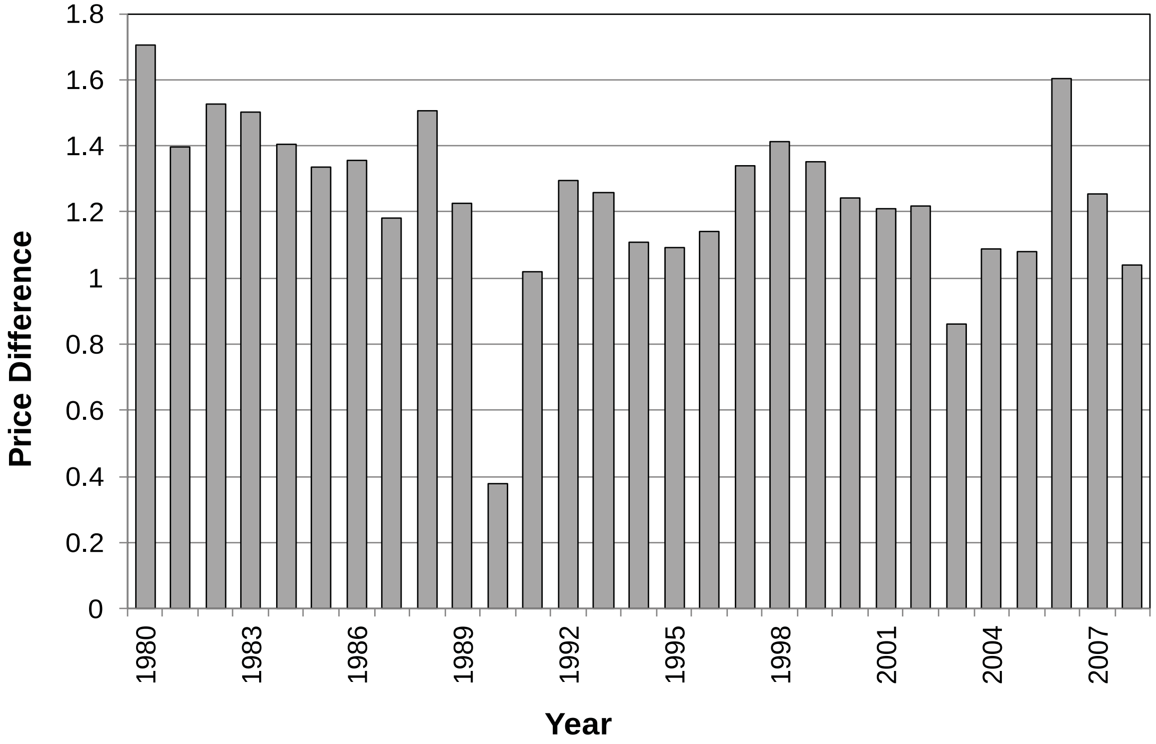


Figure 9.26 Differential between the Gulf deflated processed price and deflated dockside price from 1980-2008.

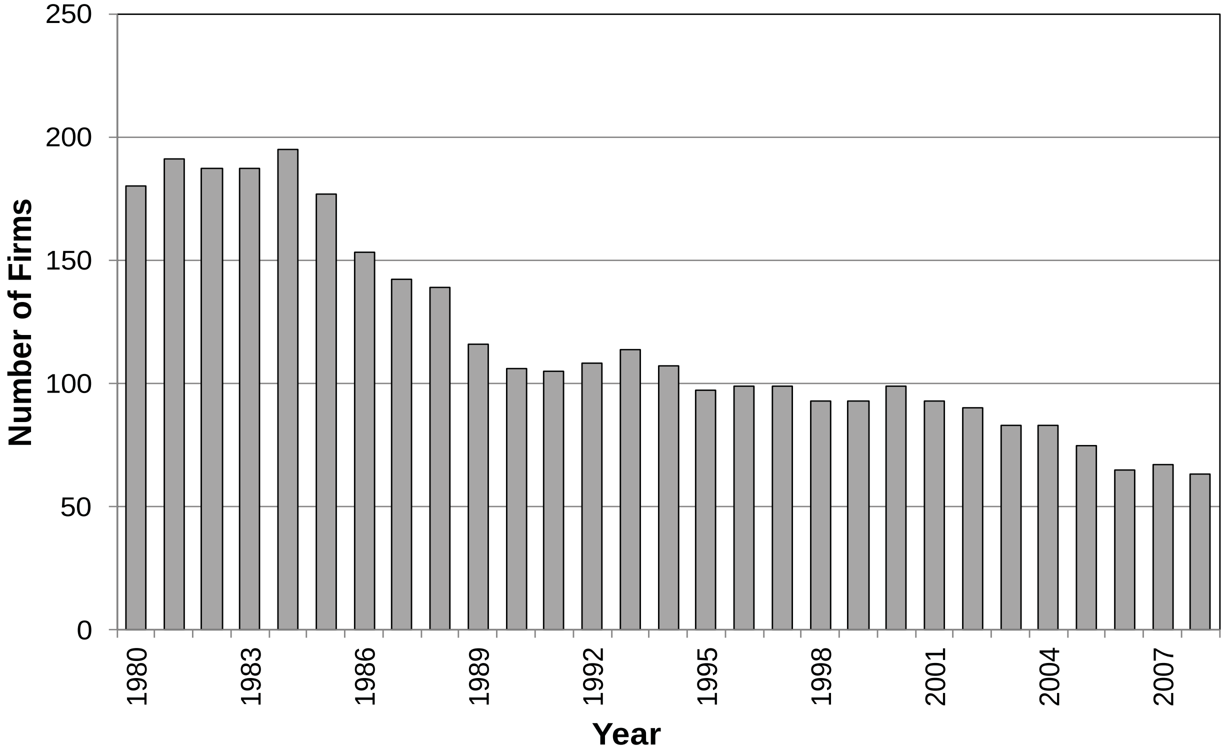


Figure 9.27 Number of Gulf of Mexico oyster processing establishments from 1980-2008.

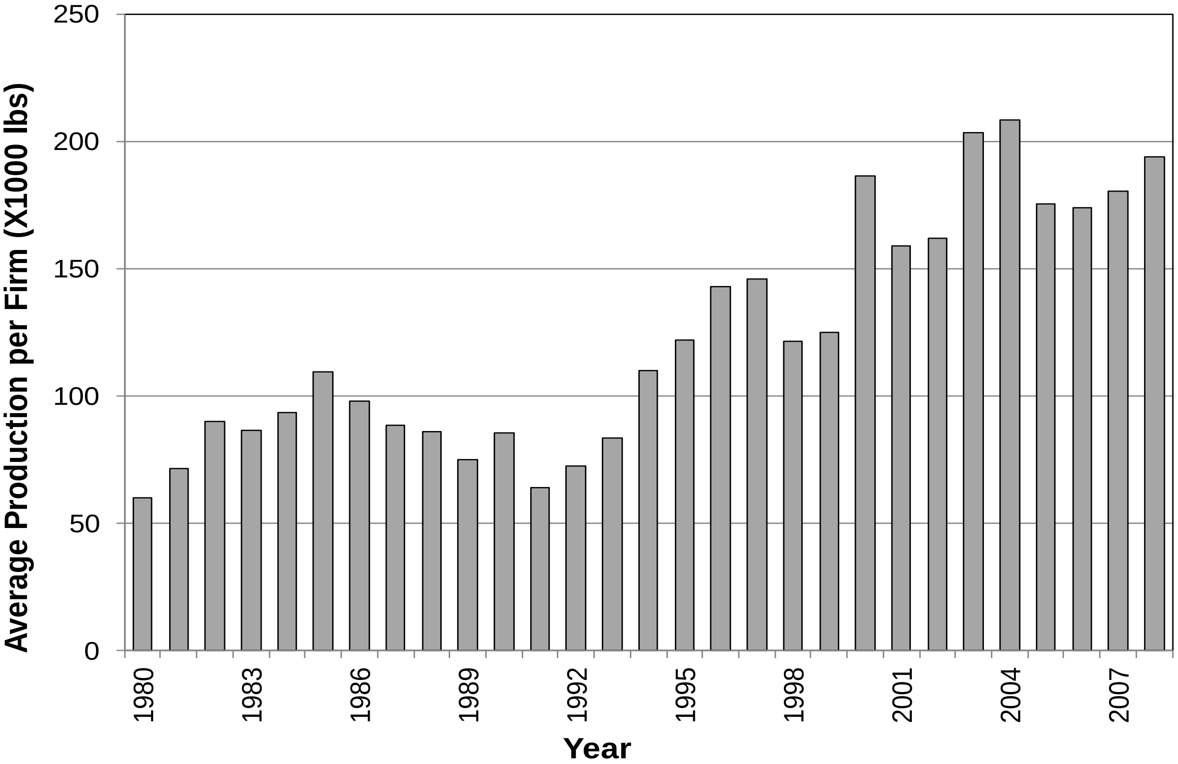


Figure 9.28 Average production per firm of processed oysters from Gulf of Mexico, 1980-2008.

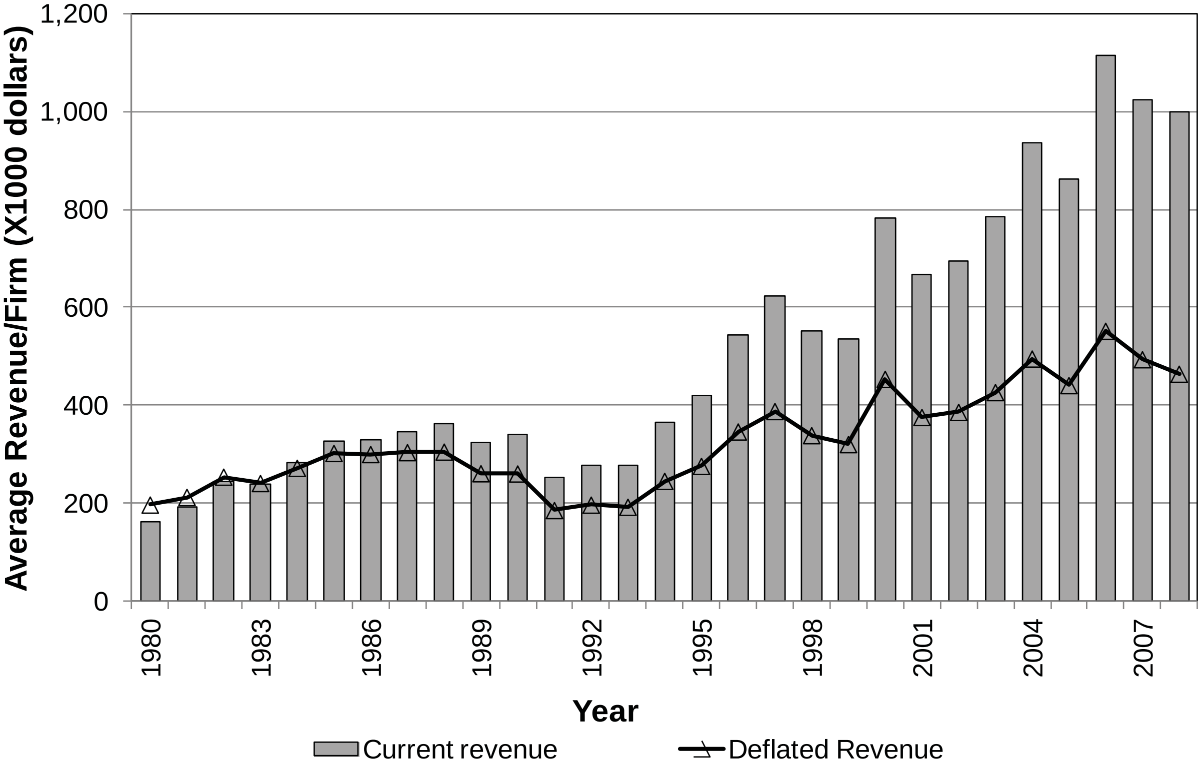


Figure 9.29 Average current and deflated revenues per Gulf processing establishment generated from oyster processing activities from 1980-2008.

pasteurization, hydrostatic pressure, and irradiation. The first three of these techniques, and their use by processors throughout the Gulf, are discussed in Muth et al. (2002). As noted by the authors, the IQF process had been in use for more than a decade at the time of the study. This process involves passing the half-shell oyster through a freezer tunnel which thereby freezes the oysters using liquid CO_2. The cool pasteurization process, by comparison, was first used by a Louisiana firm in 1997. This technique involves submerging banded oysters in a computer-monitored tank of warm water after which they are immediately cooled in cold water. The hydrostatic pressure technique was first commercially used by a Louisiana firm in 1999 (Muth et al. 2002). The technique involves the use of pressure (via loading oysters in a pressure chamber which is then sealed and pressurized) to reduce *V.v.* to nondetectable levels. Finally, irradiation post-harvest treatment involves passing low doses of gamma rays through live oysters. This technique was first commercially employed by a firm in Florida in 2009. Unlike the other described techniques, irradiated oysters can be marketed as live oysters for approximately one week following irradiation. Currently, about 15% of the Gulf product is believed to be subjected to post-harvest treatment (FDA 2009).

From their analysis of the benefits and costs associated with post-harvest treatment associated with IQF, cool pasteurization, and hydrostatic pressure techniques, Muth et al. (2002) concluded that

> "…the per unit costs of post-harvest treatment of Gulf-harvested oysters are generally small and in some cases negative, and that the demand for treated oysters either will be unaffected or may potentially increase relative to the demand for untreated oysters."

Based on the premise that post-harvest treatment would only be required for Gulf product, the authors further conclude that

> "price increases of 19% or less are predicted and, in some cases, price decreases in the Gulf region. In other regions, prices are predicted to change by 3% or less"

with differences being based, in part, on the technology adopted. These findings, however, premised on demand remaining unchanged and the authors state that

> "predicted price and quantity effects are much greater."

These results, they warn, are more tenuous and may require an increase in harvest volume which is infeasible. Finally, the researchers argue that

> "[w]hile the aggregate economic model shows somewhat moderate effects of treatment requirements, the effects on individual plants may be different from the aggregate model predictions. In particular, individual plants may shut down either because the revenue of the plant is not sufficient to cover its production costs plus the cost of treatment, or because it is technically infeasible for the plant to install treatment equipment."

Given the relative newness of some of these techniques at the time of the study and the relatively small number of firms employing the techniques, the benefits and costs of post-harvest treatment as reported in the study should now be considered with some caution.

In addition to the approved FDA methods, there may be other technology, such as high salinity relaying that may prove useful at reducing *V.v.* to nondetectable levels. Motes and DePaola (1996) tested this technique by harvesting oysters naturally contaminated with 10^3 to 10^4 Most Probable Number (MPN) of *V.v.* per gram from lower salinity inshore waters (15-25ppt). The oysters were placed in containers and relayed to high salinity (30-34‰) offshore waters that had non-detectable levels of the bacterium. Reduction of *V.v.* to <10 MPN/gram occurred after a 7-17 day period in five of their six studies. Oyster mortality was reported to be <6% after treatment. The advantages of this process are: 1) the end product is alive, unlike most PHPs, and it could logically have a better shelf-life than irradiated product; 2) it is available to a larger segment of the industry; harvesters or dealers or both could be involved in the enterprise; 3) the process may purge other pathogenic bacteria and viruses; 4) it cleans the oyster of mud and silt that is common to bottom-raised oysters; and 5) it results in a saltier product which is more appealing to many consumers.

9.6 Non-Market Benefits

While the commercial harvest tends to be the most recognized value, there are other benefits such as habitat provision that are not as readily recognized due to the fact that the ecological services generating these benefits are not traded in the market. Numerous recent reports describe the ecological importance of oyster reefs (Dugas et al. 1997, Coen and Grizzle 2007, EOBRT 2007, Beck et al. 2009) and identify specific ecological impairments that result when oysters and oyster habitat are removed or impaired. As noted by Kasperski and Wieland (2010):

> "Oysters play an important water quality role, filtering out particles that block the movement of sunlight through the water column, thus increasing the amount of light that reaches submerged aquatic vegetation and, consequently, improving benthic habitat for species that need places to hide (Coen et al. 2007, Fulford et al. 2007, Grabowski and Peterson 2007). The habitat created by the submerged vegetation is thought to create a very large value through its role in recreational fisheries (Kahn and Kemp 1985). In their filtering, oysters also concentrate nutrients in pseudo-feces, which, with help from other benthic organisms, are either buried in sediment or denitrified out of the water column (Newell et al. 2005)."

This statement was made in terms of examination of the benefits of increasing the Chesapeake Bay oyster population, but the general concept would also apply to the benefits associated with the Gulf of Mexico oyster population. However, while economists have devoted a significant amount of time and effort in terms of measuring these non-market benefits, empirical studies tend to be relatively scarce and subject to some concerns related to the reliability of the estimates.

In terms of the value of oyster reefs to recreational fishing, arguably the most thorough and reliable treatment of the subject is a study conducted by Hicks et al. (2004). In an analysis of some of the benefits and costs associated with oyster reef restoration in the Chesapeake Bay, Hicks et al. (2004) linked bottom condition (hard oyster bottom) to site quality (fishing success) and found that relatively high concentrations of oyster bottoms resulted in higher catch rates and a preference for fishing over these hard bottoms after controlling for all other relevant factors. After establishing a relationship between oyster bottoms and fishing preferences, Hicks et al. (2004) then estimated the willingness to pay (WTP) by anglers associated with a specific restoration project involving 73 sites totaling 1890 acres in and around medium to large tributaries in the Chesapeake Bay. This restoration project would cost an estimated $27.97 million ($14,800/acre). Based on their analysis, the authors estimated that anglers would be willing to pay approximately $640,000/year for the specific restoration project. Based on the assumption that the services and benefits of these services to anglers would continue for 30 years, they concluded that

> "benefits to recreational anglers alone [would] account for roughly 50% of the total cost of restoration project within 30 years [assuming a 3% discount rate]."

Hicks et al. (2004) suggest that their results are likely conservative in nature because anglers are assumed not to increase the number of trips in association with improved bottom conditions. Finally, they stress that their results relate only to a single specific restoration project and transfer of these results to a project of different scale in the Chesapeake would be inappropriate. Similarly, results could not be transferred to evaluation of restoration projects in the Gulf given different initial conditions associated with the amount of bottom reef, the population of anglers, incomes between the two regions, etc.

In a study to examine the value of Louisiana oyster reefs to recreational anglers, Isaacs et al. (2004) asked during the MRFSS intercept survey "Did you fish over an oyster reef on this trip?" In total, 23% of the intercepted respondents indicated that they had fished over an oyster reef on the interviewed trip while another 15% were uncertain. An attempt was subsequently made to elicit additional information from those individuals who responded during the intercept portion of the survey via a follow-up telephone survey. Telephone respondents were asked to estimate the percentage of angling time spent over oyster reefs and, as reported by Isaacs et al. (2004), the average reef user spent 35% of angling time over oyster reefs, which when multiplied by the average number of days engaged in saltwater fishing over the past 12 months, yields an average number of 11.65 days spent over oyster reefs in the past year. Furthermore, while only 23% of the respondents indicated fishing over an oyster reef on the day of intercept, information elicited from the follow-up telephone survey indicated that about 63% of the Louisiana respondents indicated having fished over an oyster reef in the past year. This figure, according to Isaacs et al. (2004), represents the percentage of resident anglers who use oyster reefs.

When telephone respondents were asked why they fished over oyster reefs, about 40% indicated that they did so for the increased quantity of fish while the same percentage indicated they did so for the increased variety of fish present. About 12% of the respondents cited both the increased quantity and variety as the reason for fishing over oyster reefs.

As part of the telephone survey, Isaacs et al. (2004) elicited information on WTP "…for the right to fish over clearly marked oyster reefs and maintain the current catch rate per trip?" It was further stated that the fee would be attached to the cost of the usual fishing license and that the "..privilege would be granted only to recreational fishermen who paid the extra fee and the fee would be used to maintain oyster reefs at current conditions." Estimated WTP per angler (who reports fishing over an oyster reef) was found to be approximately $13/year (over and above the existing license fee). In general, the angler's WTP to maintain access to oyster reefs increased with the rate of use of the resource in question. The aggregate value was estimated to range from about $1.1-5.4 million, depending largely upon the assumed participation rate, with a median value of $2.9 million. Finally, as noted by Isaacs et al. (2004):

> "The average willingness to pay for access to Louisiana oyster reefs is low compared to some other studies [not specific to the benefits of oyster reefs]. This may be the result of the relatively broad area included in the valuation study. Higher values tend to be associated with selected or specific sites for which fewer comparable substitutes exist. For oyster reefs along the entire coast of Louisiana, there are numerous substitute angling opportunities, likely suppressing the value of oyster reefs as recreational fishing areas."

While there are no estimates of benefits of the Gulf oyster population to improvements in water quality via their ability to remove nitrogen and phosphorous from the water column, some work on this issue has been conducted in the Chesapeake Bay. Newell et al. (2005) report that one million oysters in the Chesapeake Bay can reduce approximately 753 kg of nitrogen and

272 kg of phosphorous from the water column, on average, per year. Kasperski and Wieland (2010) further state that the cost of reducing a kilogram of nitrogen delivered to the bay, while varying widely depending upon the practice employed (e.g., planting crops, erosion, and sediment control structures) is estimated to average approximately \$24/kg; implying an ecological services value of more than \$18,000 per million oysters (this value would decrease in conjunction with an increasing oyster population). While this value may have no bearing to the ecological services value of the Gulf oyster population for filtering nitrogen out of the various bay systems throughout the Gulf, it does help to illustrate the possible non-market values associated with a healthy Gulf oyster population ecosystem.

Future investments into oyster aquaculture throughout the Gulf may also provide water quality enhancements, in which values for such ecosystem services could be established. Again, as there are no estimates of the benefits of Gulf oyster aquaculture enterprises, the Chesapeake Bay can be used as a proxy. Miller (2009) evaluated the cost and effectiveness of commercial oyster aquaculture in the Chesapeake Bay as a nutrient control strategy. Miller (2009) developed a firm level bio-economic simulation model to estimate the compensation needed by a commercial oyster aquaculture firm to expand oyster aquaculture production. The amount of compensation needed is interpreted as the cost of providing nutrient removal services via oyster aquaculture. Results indicate that, under contemporary realistic production and cost scenarios, a representative oyster aquaculture cage and float enterprise in the Bay would provide nutrient removal services for less than \$30.00 per pound of nitrogen (N). Again, while the cost to remove nutrients may not be indicative of oyster aquaculture firms in the Gulf, it does identify the ecological services that oyster aquaculture provides.

9.7 Commercial Oyster Aquaculture Economics

The economics of commercial oyster aquaculture is important to consider as the oyster fishery throughout the Gulf continues to be challenged by habitat loss, disease, and pollution, as well as natural and manmade disasters. Commercial culture of oysters may be a more attractive option for the industry as a means to ameliorate stochastic environmental and market conditions. Understanding the economics of such a venture may help guide this transition into mainstream adoption.

In the Chesapeake, Miller (2009) conducted an economic evaluation of the nutrient assimilation potential for commercial oyster aquaculture in Chesapeake Bay. Contemporary realistic production and cost scenarios for cage and float oyster aquaculture enterprises in Virginia's Chesapeake Bay were used to represent oyster aquaculture firms. It was estimated that the average number of oysters to make it market per year for a representative cage enterprise was 1,449,000 with an average production cost of \$0.20 per oyster. The average number of oysters to make it to market for a representative float oyster aquaculture enterprise was 438,750 with an average production cost of \$0.29 per oyster. The ten year internal rate of return (IRR) for cage culture was 11.6%, while the IRR for float culture was 10%. The start-up costs were significant in the Chesapeake as they included capital investment costs for cages and floats. Annual labor costs to maintain culturing equipment and grow-out operations were also significant.

9.8 Trade Organizations

9.8.1 Purpose and Need

Oyster resources provide many benefits in terms of employment and revenue at local, state and national levels. Oystermen, processors, distributors, and dealers are economically dependent upon these resources and have a vested interest in the conservation and perpetuation of the resource. All sectors of the oyster industry should strive to promote judicious management of oyster resources by participation in the development of fisheries management policies. Oyster industry members should work together and cooperate with agencies regulating the industry to promote industry needs.

Many industry members, particularly in the harvesting segment, feel they lack significant input into resource management decisions. The oyster industry is often represented by local associations or cooperatives, but these associations are fragmented and represent specific industry segments. As an example, local associations may be comprised exclusively of oyster harvesters or oyster dealers who approach specific issues as antagonists. This diversity of opinion makes it difficult to develop policies that will satisfy each segment's industry-wide problems. In general, industry associations do not possess the capital or the expertise to promote their image or views.

9.8.2 Organizations, Associations, and Other Groups

The following organizations have some interest in oyster and shellfish legislation, harvest, and management.

9.8.2.1 National

Interstate Shellfish Sanitation Conference
209-2 Dawson Road
Columbia, SC 29223

9.8.2.2 Regional

Gulf Oyster Industry Council
1039 Toulouse St.
New Orleans, LA 70112

Southeastern Fisheries Association, Inc.
1118 B Thomasville Road
Tallahassee, Florida 32303

9.8.2.3 State and Local

9.8.2.3.1 Florida

Franklin County Oyster & Seafood Task Force
Apalachicola, FL 32329

Apalachicola Bay Oyster Dealers Association, Inc
PO Box 247
East Point, FL 32328

Franklin County Seafood Workers Association, Inc.
PO Box 247
Apalachicola, FL 32329

Wakulla Commercial Fishermen's Association, Inc.
PO Box 672
Panacea, FL 32346

Suwannee Oyster Association, Inc.
PO Box 72
Suwannee, FL 32692

Cedar Key Oystermen's Association, Inc.
1133 Whiddon Ave
Cedar Key, FL 32625

9.8.2.3.2 Alabama

Organized Seafood Association of Alabama
13288 N. Wintzell Ave.
Bayou La Batre, AL 36509
251-824-7942

United Seafood Association
13316 N. Wintzell Ave.
Bayou La Batre, AL 36509
252-824-2394

9.8.2.3.3 Mississippi

Save Our Shellfish (SOS)
Crystal Seas Seafood
Pass Christian, MS 39571
(228) 452-2722

9.8.2.3.4 Louisiana

United Commercial Fishermen's Association
President - George Barisich
3413 Don Redden Court
Baton Rouge, LA 70820

Louisiana Seafood Promotion and Marketing Board
Harlon Pearce
Louisiana Fish
P.O. Box 486
Kenner, LA 70063-0486

Gulf Oyster Industry Council
Contact Person - Mike Voisin
200 Autin Lane
Houma, LA 70360

Louisiana Oyster Dealers and Growers Association
President - Carolyn Falgout
Post Office Box 1597
Covington, LA 70434

Plaquemines Oyster Association
Jakov Jurisich
112 Bayhi St
Belle Chasse, LA 70037

Southwest Pass Oyster Dealers and Growers Association
President - Shane Bagala
396 Alice B. Road
Franklin, LA 70538

Terrebonne Parish Oyster Leaseholders Association
Mike Voisin
P O Box 3916
Houma, LA 70361

Delta Commercial Fishermen's Association
Acy Cooper, Jr.
P.O. Box 186
Venice, LA 70091

Louisana Oyster Association
Byron Encalade
P.O. Box 284
Pointe a la Hache, LA 70082

Calcasieu Lake Oyster Task Force
Contact – David Deere
815 Deere Lane
Sulphur, LA 70665

Louisiana Farm Bureau – Oyster Commodity Committee
Dan Coulon
5310 Privateer Blvd.
Barataria, LA 70036

9.8.2.3.5 Texas

Texas Oyster Growers & Dealers
Association, Inc.
PO Box 5
Dickinson, TX 77539

10.0 SOCIAL AND CULTURAL CHARACTERISTICS OF OYSTER FISHERMEN AND THEIR COMMUNITIES

10.1 Introduction

Fisheries management is ultimately about managing fishermen, not fish stocks. Therefore, it is important to understand the social and cultural characteristics that guide patterns of traditional resource use, the conditions under which these change, and the impact of these changes on fishermen and the communities in which they live. Sometimes change is catastrophic, like Hurricanes Ike and Katrina, which destroyed infrastructure, covered oyster beds in debris and silt, and dispersed coastal communities. Non-catastrophic changes occur over a longer time frame and include stresses such as increased regulation, declining ex-vessel prices in relation to higher prices for inputs, competition from imports, and gentrification.

This chapter will describe the social and cultural characteristics of the oyster fishery, paying special attention to information generated since the last oyster management plan in 1991. Social characteristics pertain to the structure of family, fishing, and work practices. Cultural characteristics pertain to the meanings and values oyster fishermen and their families attach to oysters, fishing, and community life.

A caveat is in order. The oyster industry in the Gulf of Mexico has not been fully characterized socio-culturally. Standard 8 of the Sustainable Fisheries Act, which requires the identification and characterization of fishing dependent communities, focuses on geographic communities that are involved in an array of fishing sectors. Fishing dependent communities are defined by a variety of indicators including fishing's contribution to the local economy, presence of fishing related infrastructure, and presence of cultural icons such as fishing festivals, statues etc. (Hall-Arber et al. 2001, Jacob et al. 2001). These characterizations do not provide detailed information on specific fisheries (e.g. oysters) within each community. Therefore, this chapter relies heavily on the social science literature regarding fishermen and their families. Not all of the literature cited pertains to Gulf of Mexico oyster fishermen because data specific to Gulf of Mexico oyster fishermen is sparse. Although there are undoubtedly some differences among geographic regions and fisheries, the conditions of their work give them certain shared social and cultural characteristics.

10.2 Gulf Oyster Fishermen

There are two general categories of harvesters in the Gulf of Mexico oyster industry, lease holders and non-lease holders. Although the governance of wild harvest and lease management differ, there is overlap in personnel and work practices. Some leaseholders and their employees or agents harvest from public reefs both for direct sale and for transplant to their private leases, leading to some shared work practices. However, with the exception of Louisiana, the majority of oyster fishermen in the Gulf are non-lease fishermen. Although leases are allowed in all of the Gulf States, the relative importance of leases to total production varies widely. See Section 7.2 for more information on state leases. Some families own leases in more than one state and, in some states, leases are passed down through the generations.

10.2.1 Cultural Characteristics of Oyster Fishermen

The Croatian and French history of the Louisiana oyster fishery and its relation to the institution of leases usually foregrounds cultural descriptions of that fishery (e.g. Vujnovich 1974, Riden 2003). Yugoslavian fishermen have contributed important developments to the fishery including transplanting oysters, dredging, and motorized boats (Dugas et al. 1997). While culture is often tied to a person's ethnic background, language, traditions etc., another way to conceptualize it is in terms of a shared way of understanding the world and one's place in it (Paolisso 2002, Paolisso et al. 2006, Paolisso 2008). Conceptualizing culture in terms of how fishermen view nature and society provides managers with a better understanding of fishermen as a community of work, and is hence more immediately relevant to management than a focus on the ethnic composition of the fishery. This is the approach to culture taken in this chapter. Fishermen and their families may be characterized by independence and individualism (Peterson and Smith 1981, Pollnac and Poggie 2006, 2008). Pollnac (1988) presented an analysis of a world-wide sample of 186 societies that indicates that fishing societies place greater emphasis on self-reliance training for males in late boyhood than other social groups.

The tendency toward relative independence in fishing has been theoretically and empirically related to environmental and technological aspects of the occupation. For example, in his analysis of data from southern New England, Poggie (1980) argues that independence helps harvesters psychologically adapt to their occupation. The decisions that they have to make in the face of uncertainty have immediate effects with respect to the safety of the vessel and its crew as well as the success of the fishing trip. These decisions have to be made independently, with little or no time for consultation and deliberation due to the rapidly changing nature of the sea (Pollnac 1976). Poggie (1980) further suggested that an independent personality characteristic is related to, and selected by, the fact that most capture fishermen are physically removed from the help and support of land-based society. The independent nature of oyster fishermen is, therefore, not uncommon among human populations seeking common capture stocks.

In addition to the shared trait of independence, fishermen share a general belief system of how nature 'works' (Paolisso 2002, Paolisso et al. 2006, Paolisso 2008). According to this cultural belief, nature is complex and unpredictable. It is a creation of God which only He can fully comprehend and fishermen trust in God's stewardship of bay resources. They understand unpredictability as part of the divine plan for sustainable harvests in that "the unpredictable nature of the blue crab protects the crab from over harvesting and helps ensure there will always be crabs" (Paolisso 2002). Given this unpredictability, it is impossible for scientists to ever predict population numbers. Similar cultural beliefs were found by Smith (1990) for a variety of New England fishermen and Weeks (1995) and Ward and Weeks (1994) for Gulf Coast oyster fishermen. Fishermen believe in the cyclical nature of fish stocks and believe that fishery scientists' linear graphs depicting stock decline do not capture these cycles. Such beliefs are important to management in that they underpin much of the resistance to regulations based on population models.

10.2.2 Social Characteristics

10.2.2.1 Family Interactions and Family Businesses

Traditionally, the production activity of individual fishermen is embedded in a social network of kin-based responsibilities with the core of this network being the oyster family (Acheson 1981, Acheson 1988, Deseran & Riden, 2000, Riden 2003). Oyster families are traditionally highly cohesive, production-oriented and tradition-limited and highly competitive with each other (Rockwood 1973). Tradition-limited means that perceived options of family members are tightly linked to the expectations and perceptions of fishing as a profession.

According to a survey by Deseran and Riden (2000), over half of Louisiana oyster fishermen have at least one family member serving as crew. This percentage, however, decreases as the vessel size increases. 78% of small vessel operators use family as crew but only 35% of large vessel owners do so. Wives contribute by keeping books, working in sales, helping make repairs, doing routine maintenance, transporting supplies, as well as serving as an occasional deckhand (Deseran and Riden 2000). Children also help in the business as deck hands or in post-harvest activities. Young harvesters are helped by family members through loans, jobs, and social support. Additional opportunities exist for working in other aspects of a broader family business that might include harvesting, owning leases, processing, or wholesale marketing. Riden (2003) describes dense social and financial ties among members of the Croation oyster industry in Louisiana. Formal studies on the oyster fisheries in other Gulf states do not exist but informal questionnaires distributed to Mississippi and Alabama fishermen indicate that approximately 75% of the Mississippi and 66% of the Alabama respondents use some member of their family as crew and when non-family crew was used, they were usually friends.

Lease holding is also kinship based. In both Texas and Louisiana, for example, there are fixed acreage allowances per individual. Therefore, family arrangements are such that several members in a family will hold leases in their individual names and work them either as one lease or in partnership (Weeks 1995, Deseran and Riden 2000). Members of the extended family may operate other aspects of the business. Although kinship ties are evident with oyster lease fishermen and lessees, business operations often involve specialized jobs that are sometimes conducted by persons unfamiliar with fishing itself. Many of these operations are quite large and employ not only fishermen but also biologists, bookkeepers, and sales personnel.

The tradition of a kin-based fishery appears to be changing despite the fact that the most commonly cited reason for entering the fishery is “carrying on the family business” (Deseran and Riden 2000). While over 80% of the interviews state that they personally would become oyster fishermen again if given the choice, fewer than 50% would encourage their children to enter the fishery (Deseran and Riden 2000). The segment of the fishery least likely to encourage children to become fishermen is large vessel owners. This is a social group that controls a lot of ecological and economic resources and has accumulated social capital from long years in their communities and in the fishery. Despite these seeming advantages, this group stresses education and considers oystering a fallback option, making the socialization of the younger generation *vis-à-vis* the fishery quite different from that of their parents. Another indicator that the kin-based fishery structure may be weakening is the increased use of non-kin employees and migrant labor (Riden 2003, McGuire 2006). The use of non-family crew is especially true for leaseholders and processors who depend heavily on migrant labor.

Deseran and Riden (2000) found a range of educational attainment from grade school to post-graduate. Older fishermen tended to have less formal education than younger fishermen, with about half of older fishermen having had completed high school compared to Louisiana’s general population of which 68.3% received high school diplomas. Women participating in the study had higher education levels than men and current fishermen had higher levels of education than their parents. In other words, each generation attained a higher degree of formal education, creating more diverse employment options.

10.2.2.2 Non-Family Business Interactions

There is very little recent sociological work published specifically addressing the oyster industry but earlier work by Rockwood (1973) characterized the relationships between the various fishery participants. Rockwood (1973) noted that self-employed, non-lease oyster fisherman sell their oysters to ‘raw-house’ dealers/processors. Some of these marketers still provide rigs (e.g., fishing boats or vessels set-up or ‘rigged’ for oyster dredging) to oyster fishermen on a contractual basis. Shares are deducted from the oysters gathered depending on the value of the rig, the debt-load of the operator with his patron, and whether or not the rig is being rented (Rockwood 1973). Patron-client relationships between marketers and fishermen restrict to whom fishermen can sell oysters. The majority of independent oystermen can theoretically sell to anyone, but will usually establish socioeconomic ties to one or two buyers. Control of supply and price is maintained, to a degree, by informal agreement between marketers and may restrict from whom they buy. Such agreements may be ignored because of competition for buying oysters during the peak of the season (November through December) (Rockwood 1973).

10.3 Changes in the Fishery

10.3.1 Structure of the Community

Fishing communities can be described in terms of their dependence upon economically important natural resources, i.e. as natural resource communities. This dependence on natural resources structures social relationships in these communities. The organization of natural resource communities is most often traditional and identification as an 'insider' may take several generations to establish (Dyer and Leard 1994).

According to Dyer and Leard (1994), natural resource communities may be open or closed. Closed natural resource communities are defined as being geographically and traditionally isolated from outside influence, and kinship ties are important to gain knowledge and access to the oyster fishery (Rockwood 1973). Tonging is more often associated with closed natural resource communities. Open natural resource communities do not place the same value on having historical roots in the community (Dyer and Leard 1994). In an open natural resource community, it is easier to gain access to the fishery and establishing relationships with buyers and sellers does not require being linked to long-established social networks or kinship. According to Dyer and Leard (1994), dredging is more likely to be promoted and practiced in an open natural resource community where the territorial claims on public reefs more typically associated with tonging are not as strong.

Although natural resource communities may be closed in the sense that outsiders cannot easily gain entrance into local social networks, they are not closed in the sense that they are linked to the outside world through markets, communication and in-migration. Product prices are dependent on outside markets, youth leaving the community for school and work, and newcomers coming to live in the community. Furthermore, given the population increases along the coast in the last 20 years, many closed natural resource communities are no longer geographically isolated. Brennan et al. (2005) found that once-remote rural villages are being discovered by retirees and recreationalists. For example, developers have dubbed Wakulla County Florida the "Forgotten Coast" and its population has grown by 61% from 1990-2000 (Brennan et al. 2005).

Given these financial and social linkages, it makes sense to view natural resource communities as units in a larger economic, political, and social system, i.e. as a natural resource region (Dyer and Poggie 2000, Hall-Arber et al. 2001).

> "Communities are not viewed in isolation, but are defined internally through social, ethnic, and historical ties and externally through networks of regional and extra-regional total capital flow" (Hall-Arber et al. 2001).

These networks are composed of the users (i.e. harvester, processors, marketers, buyers, etc.) of marine resources. The shift in focus from the natural resource community to the natural resource region captures the interplay between geographic scales and between ecological, economic, social, and political processes, thus offering a more realistic view of fishing communities.

10.3.2 Changing Economic Strategies

One traditional economic strategy is to hold several licenses and to switch between fisheries depending on the season and strength of the harvest or prices, switching between shrimp, oysters, crab, and finfish (Riden 2003). As more limited entry programs and/or moratoriums that are based on previous fishing history and landings are imposed as a means of controlling effort, this economic strategy becomes more difficult. The inability to move to other fisheries creates special difficulties after natural disasters such as storms. For example, during Hurricane Ike, an estimated 50-60% of Galveston Bay reefs were silted over and the season was delayed. Those fishermen not holding licenses for other fisheries were unable to switch to another species to offset oyster losses unless licenses were available for sale.

Over half of the fishermen interviewed by Deseran and Riden (2000) had engaged in non-oyster work in the last 12 months and a little less than half of the spouses of fishermen worked outside of fishing. The smaller the vessel, the greater the percent of total income generated from outside jobs. Generally, these outside jobs constituted other forms of self-employment in a craft or trade. Similarly, informal questionnaires reveal that 26% of Alabama fishermen responding and 37% of Mississippi fishermen responding had wives that hold jobs outside of the fishery and that about half of the respondents in each state hold jobs that are not fishery related**.**

10.3.3 Demographic Changes

One overall trend facing commercial fishing in general is an ageing population of fishermen and a younger generation who seek alternative careers outside the fishing industry (e.g., Rhodes et al. 2001, Crosson 2007, GSAFF 2010). If there is no restriction on entry, participants in the fishery wax and wane depending on the general economic climate; entering a fishery when non-fishery employment opportunities are scarce, and leaving the fishery when other opportunities arise. Although fishermen have traditionally employed an economic strategy that mixes fishing and non-fishing activities (Jacob et al. 2002, St. Martin and Hall-Arber 2008), fishing was the primary occupation and identity for older fishermen (Pollnac and Poggie 2006). Fishing has traditionally been a family occupation but with the 'loss' of the next generation to non-fishing jobs, captains and processors have increasingly come to rely on migrant labor (McGuire 2006).

Demographic changes have also occurred in the lease sector of the fishery. Some leaseholders, or their inheritors, are increasingly relying on sub-leasing with oyster harvesters or other leaseholders. Captains and crew may be hired to work their leases using the leaseholder's or their own boats. Boat captains under such arrangements may be paid per sack or might be required to sell back to the lease holder (Lezina pers. comm.)

10.4 Relationships with Management and Others

10.4.1 Science-Based Regulation

As previously described, fishermen bring a particular view of how nature works which guides their understanding of how fish stocks work. They see nature as unmanageable (by humans) and fish stocks as fluctuating with cycles of abundance and scarcity. This perspective is based on fishermen's experience on the water and is thus broadly shared. Such shared understandings are called cultural models. Fishermen's cultural models contrast to the way that scientists portray fish stocks, using linear graphs, as either declining or rising differences between fishermen's and scientists' cognitive models of how nature works can cause tension between fishermen and regulators (Weeks 1995, Weeks 2000, Paolisso 2002).

10.4.2 Cooperative Management and Research

Cooperative management, commonly called co-management, is collaboration between citizens and government in the management of natural resources. It has been used to manage a variety of resources including watersheds, forests, rangelands, and fisheries (Munoz-Erikson et al. 2007). Co-management can be considered as an option to traditional management techniques particularly when a fishery is under stress (Pinkerton 1989). It has the potential: 1) to promote conservation and enhancement of fish stocks; 2) to improve the quality of data and data analysis; 3) to reduce excessive investments by fishermen in competitive gear; 4) to make allocation of fishing opportunities more equitable; 5) to promote community economic development; 6) to increase product quality and reduce health risks; 7) to reduce government versus fishermen and fishermen versus fishermen conflicts; and 8) to increase transparency of the management process (Pinkerton 1989, Pinkerton and Weinstein 1995, Kaplan and McCay 2004, Weber and Iudicello 2005).

Pinkerton and Weinstein (1995) conceptualize cooperative management as a continuum from almost total government control to systems in which community rights to manage fish stocks are encoded in law and cover a wide range of management functions such as setting catch limits, conducting research and harvest monitoring. Their review of the international social science literature on collaborative management regimes in fisheries reveal that successful cooperative management can occur at local, regional, and national levels, at different geographic scales, with varying degrees of institutionalization, and in various types of fisheries (Pinkerton and Weinstein 1995). Despite this variation, all of the successful co-management communities are highly dependent on the fishery and hence vulnerable to non-sustainable use, have a profound sense of place tied to fishing, are committed to equity, are able to assert either formal or informal rights, and are willing to invest their own resources in management (Pinkerton and Weinstein 1995).

Pinkerton and Weinstein (1995) identify four attributes that are common to successful co-management systems; all have mechanisms for accountability, effective management, equitable representation, and adaptiveness. Mechanisms for accountability include access to data, evaluation criteria for management actions, and community input into problem definition. Mechanisms for effective management include the ability to make, monitor, and enforce rules, and promote stewardship. Equitable representation includes the inclusion of different gear groups and the community at large. Adaptive mechanisms include the ability to receive feedback and to change in response to new information. The scale of effort can be an important factor in determining the success of cooperative management programs. Cooperative management operates most favorably where: 1) the area is not too large and benefits can be linked to watersheds or local waters; 2) the number of fishermen or communities is not too large for effective communication, or there are well-organized sub-groups that communicate well with each other or have effective umbrella organizations; and 3) the size of the government bureaucracy is small and its mandate is fairly regional or local (Pinkerton and Weinstein 1995).

Through years of harvesting, fishermen have learned a great deal about oysters and local ecology. This type of knowledge is referred to as local or experiential knowledge. NMFS recognizes the value of fishermen's experience and knowledge through several programs that support collaborative research between fishermen and managers.

> "Using the scientific method, scientists bring precision, modeling capabilities, statistical verification, and hypothesis generation. Fishermen bring experience on the water and repeated observations of fish and their habitat that can be used to generate hypotheses." (NRC 2004a).

Participation by fishermen varies and includes activities such as chartering vessels to research teams, aiding in the conduct of stock assessments, participating in gear selectivity trials, conducting industry based surveys, and contributing to research design (NRC 2004a, Johnson and van Denson 2007). The potential benefits of cooperative research include the ability to increase data collection while reducing costs, broadening the knowledge base on which management decisions are based and getting buy-in from fishermen for research (Johnson and van Denson 2007). Specific examples of cooperative research include gear efficiency experiments (TEDS and BRDS) on the Gulf coast, mesh size experiments on the west coast and scallop surveys on the east coast, stock assessments, and gear selectivity research. Two projects specific to oysters are the Oyster Recovery Partnership and the Gulf Coast Oyster Industry Program (GOIP).

The Oyster Recovery Partnership is a non-profit organization that is comprised of watermen, environmentalists, government agencies, and businesses. The goal of the Partnership and the GOIP is to restore oysters to Chesapeake Bay. This is accomplished through collaborative research and management that includes activities such as a hatchery, the planting of disease free spat, monitoring of reefs, and research on oyster diseases.

The GOIP provides a venue for members of the fishing industry, one processor and one harvester from each Gulf state, to identify areas of research they feel are important to the industry (Supan 2000). The industry members have substantial input into the selection of research priorities and in the review and ranking of proposals.

The Emergency Disaster Recovery Program (EDRP) was authorized in 2006 through an amendment to the 1976 Magnuson-Stevens Act (Hode pers. comm..) It is another avenue through which members of the fishing industry can participate in research, the goal of which is to keep fishermen employed until resources recover and they can begin fishing again. Over a third of EDRP funds have been used for cooperative research projects including resource monitoring, reef restoration, and catch per unit effort studies.

Case studies indicate that research collaboration between scientists, agencies, and fishermen is most successful when: the fishery is under duress; fishermen expect that the research is linked to increased yield; and/or there are gaps in data or current scientific understanding that the research will address (NRC 2004a). Utilizing fishermen’s knowledge as a resource for successful management can facilitate the development of regulations and build stakeholder trust, and is often an important component in collaborative management. The NRC (2004a) recommends that cooperative research between fishermen and scientists be increased as long as other management and core research objectives are still met.

Despite the benefits of cooperative research, implementation can be difficult due to different priorities and work practices between fishermen and scientists (NRC 2004a). Although both parties desire good information, scientists are also driven to publish and fishermen to earn a living. Generally, academic scientists are not rewarded for conducting cooperative research and cooperative research is not always viewed as legitimate by their colleagues (NRC 2004a). Alternately, some cooperative research projects have been driven too much by economic considerations (NRC 2004a). To avoid these pitfalls, the NRC suggests that:

- Cooperative research be used in those cases in which it can significantly enhance management
- A competitive review process be used to allocate funds.
- Scientists and managers participating in cooperative research receive administrative support.

Co-management of natural resources has been criticized for sometimes putting the process of collaboration before the need to manage resources sustainably (e.g. Peterson et al. 2005). The most commonly used criteria for co-management success are related to process: i.e. how do the participants perceive the process, was it transparent, did all viewpoints get expressed, etc. Critics of co-management claim that ecological principles get submerged in favor of the principles of cooperation. In response to such critiques, Munoz-Erikson et al. (2007) and Conley and Moote (2003) suggest incorporating a suite of ecological, social, and process indicators into co-management processes to ensure sound ecological outcomes.

10.5 Fishery Conflicts

Problems are associated with both the regulated open access and leasing aspects of the oyster fishery. Problems with the lease fishery primarily involve the 'taking' of perceived common-property bottoms and limiting access to only a few fishermen, and in some states, the use of dredges on leases while public reefs are tonged. Questions concerning appropriate fees, qualifying criteria, and proper marking of leases are common as are concerns about bag limits and other regulations that impact one group and not the other. Additionally, it is sometimes argued that lease areas are not sufficiently worked and could perhaps produce more.

Problems within the open-access fisheries occur among user groups and between users and regulators. Conflicts between tongers and dredgers primarily occur when reefs reserved for the separate gear are located in close proximity to one another. Problems primarily result from perceptions by tongers of illegal dredging on tonging reefs. Fishermen often have disagreements over preferred areas and harvest practices. Also, conflicts occur between fishermen and dealers/processors regarding culling, adequate measures, and prices received.

A relatively new conflict involves the allocation of resource between in-state harvesters and out of state harvesters (Randall pers. comm.). Fishermen are allowed to harvest in the waters of other states. This is especially the case in years in which harvest is poor in one state and good in another. There have been allegations of intimidation of out of state fishermen and vandalism of their boats in an attempt to dissuade out of state fishermen (Randall pers. comm.). See Section 7.2 for specific state license requirements.

Examples of non-fishery activities that cause conflict are leasing bay bottom for oil and gas production and coastal restoration projects. Canals needed to navigate the marsh have changed the hydrology, impeded silt deposition, and created open water where marsh once was. Salinity patterns have changed and areas suitable for oyster production have shifted. Additionally, production activities and traffic increase turbidity, covering vegetation and oysters (Lester and Gonzalez 2008). See Section 5.2 for detail on many of these issues.

Coastal restoration has been contentious due to water diversions designed to restore a more natural (i.e. historic) salinity regime in areas that were historically marginal for oysters and thus cannot support commercial oyster production if restored. Mississippi River diversions have produced large scale changes in salinity and oyster leaseholders claim that their leases have been damaged (Meitrodt and Kuriloff 2003).

10.6 Stressors

Negative impacts to the oyster fishery can be natural or manmade, acute or chronic. Acute stressors are those which develop over a relatively short period of time. These include environmental stressors such as flooding, oil spills, hurricanes, harmful algal blooms, and drought.

Although they may develop over a matter of days or even hours, acute stressors can have long term impacts.

Chronic stressors are those that occur over a long period of time. Gentrification of the coastline is a key example of a stressor that occurs slowly, over time and has lasting consequences.

10.6.1 Acute Stressors

10.6.1.1 Gulf Hurricanes

From 1950-2008, the NOAA's National Hurricane Center reports that there were 58 hurricane strikes in the Gulf of Mexico, two of which were Category 5. The major impacts of hurricanes to fisheries include coastal gentrification, rising fuel costs, labor shortages, and a shift from commercial to recreational fisheries and rising insurance costs (IAI 2007). Two major hurricanes occurred during the writing of this management plan. Their impacts are briefly described below.

In August of 2005, Hurricane Katrina, a Category 3 storm, hit the Gulf coast, heavily impacting fishing ports in parts of Mississippi, Louisiana, and Alabama. Ninety percent of Mississippi's oyster reefs, 20% of Alabama's reefs, and almost 66% of Louisiana's reefs were damaged (Petterson et al. 2006, IAI 2007) and the reefs that Empire, Louisiana depended upon were severely damaged (McGuire 2006). The economic loss to marine infrastructure was estimated at $330 million (NMFS 2005). Boats, docks, processing establishments, icehouses, and restaurants were damaged or destroyed. In addition to infrastructure damage, labor was in short supply. Louisiana processors lost between 35% and 40% of their laborers and Alabama processors also faced labor shortages because they were forced to compete for labor with the higher paying construction industry (IAI 2007).

Hurricane Ike made landfall September 13, 2008, causing significant damage to the oyster reefs both on the eastern and western shores of Galveston Bay. Initial side-scan sonar data collected following the storm was compared with data collected before the storm and indicated that approximately 50-60% of the oyster reefs in Galveston Bay were lost due to siltation/sedimentation. East Bay (a sub bay of the Galveston Bay system) was the hardest hit, with losses in excess of 80%. The public reef fishery that normally opens November 1, 2008 was delayed for three weeks due to the loss of markers designating the boundary between approved and restricted waters.

Texas Sea Grant conducted a survey of the processing and marketing sectors of the oyster industry to ascertain the extent of the damage caused by Ike (Table 10.1; Haby et al. 2009). Many of their respondents were vertically integrated and also owned leases and were harvesters. Sixty-two percent of all oyster firms responded to the survey. Respondents noted that 54% of vessels sustained minor damage, about 33% of their vessels sustained substantial damage and 8% were destroyed (Haby et al. 2009). Over half of the bulkheading owned by respondents was damaged and no respondent carried insurance on bulkheads. Approximately 44% of processing equipment was damaged from the storm surge. Of that, about half was completely destroyed (Haby et al. 2009).

10.6.1.2 Oil Spills and Pollution

The Gulf of Mexico is an important region for the production, shipping, and refining of petroleum. Petroleum spills come from both industry and shipping. When spilled, the lighter components enter the air while the heavier ones either become floating balls of tar or sink to the bottom where they can damage benthic organisms. Some compounds can last several years in the sediments. The type of damage incurred by the fisheries, therefore, depends not only on the quantity of petroleum spilled, but also on the type of product spilled and the time it takes to respond to the spill (see Section 5.2.2.1).

Table 10.2 summarizes spill data in the Galveston Bay as an example of the number and type of spills occurring in the Gulf.

10.6.1.3 Harmful Algal Blooms (HABs) and Other Biological Toxins

Periodic contamination by biological toxins such as dinoflagelates, viruses, and bacteria in coastal waters negatively impact commercial fisheries by closing areas to fishing in order to protect public health. A common form of contamination requiring the closing of oyster beds is bacterial, i.e. fecal contaminated run-off following heavy rain. Beds are usually reopened fairly soon after the rain event following testing by the Health Department. See Section 6.5 for more discussion.

Harmful algal blooms (HABs) in coastal waters are a source of concern for managers and fishermen due to their perceived increase in frequency and reported illnesses from eating contaminated shellfish (Jewett et al. 2008). Florida, for example, has suffered almost yearly outbreaks of *Karenia brevis* (red tide) for the last 20 years (Alcock 2007). HABs have caused relatively long-term closures and hence cause significant economic disruption to fisheries. For example, it is estimated that the economic impact of an outbreak of *K. brevis* along the Texas Coast in the summer of 2000 was $10 million in Galveston County alone (Evans and Jones 2001). Shellfish beds were closed well into the autumn in most Texas waters and some stayed closed through the winter. Outbreaks in 2002-2003 cost the shellfish industry in Florida $6 million ex-vessel value (NOAA 2004).

Outbreaks of Norovirus, which causes gastro-intestinal problems, fever, and fatigue, have resulted in consumer advisories, closed reefs, and/or recalls in several Gulf Coast bays. HABs and other acute outbreaks can cause economic damage beyond the outbreak zone and in non-impacted fisheries due to consumer fears about eating seafood after reports of potential hazards. See Section 6.4 for further discussion regarding human health concerns related to various contaminants and pathogens.

10.6.2 Chronic Stressors

10.6.2.1 Land Use Changes and the Disappearance of Working Waterfronts

Land use changes in coastal areas typically include loss of docks and fish houses, thereby reducing the capacity of smaller-scale commercial fishing operations (Blount 2006). Areas that are generally oriented toward water related industries (fishing, oil and gas, shipping, etc), are defined as ‘working waterfronts’. In the context of this management plan, we are focusing only on fishing and processing activities and those areas along the coasts that support them. An account of the range and types of changes to coastal areas can be found in recent community profiles, e.g., for Florida (Jacob et al. 2002) and for New England (Hall-Arber et al. 2001).

Over 50% of the U.S. population lives in coastal areas (Crossett et al. 2004). Assuming that this percentage remains constant, the Census Bureau estimates an increase in the coastal population of 4,281 persons per day until 2050 for a total population increase of 37.2 million people (NOAA/CSC 2007). As migration to coastal towns increases, fewer towns retain the socio-cultural and economic structures characteristic of fishing communities. This process of gentrification is driven by three factors: 1) urban sprawl, 2) people attracted to natural amenities,

Table 10.1 Estimated losses and costs to repair or replace fishing infrastructure in Texas from damages caused by Hurricane Ike (from Haby et al. 2009).

Asset Class	Replacement Cost	Contribution to Total Damage
Oyster Leases (1,713 acres)	$31,646,765	83.20%
Vessels	$1,630,000	4.30%
Docks, Piers, Roads and Parking	$1,845,000	4.90%
Fuel Systems	$169,550	0.40%
Plant & Equipment	$2,394,800	6.30%
Inventories	$351,750	0.90%
Total Repair / Replacement Cost	$38,037,865	100.00%

and 3) in-migration of retirees (Yagley et al. 2005). Jepson (2004), in his study of Cortez, Florida documented the occurrence of all three factors in addition to a large influx of tourists. Maine Sea Grant (2007) conducted research on the consequences of uncontrolled coastal development and detailed the following consequences: 1) loss of access for commercial fishermen; 2) recreational fishing access conflicts with commercial fishermen and other users; 3) limited public access; and 4) environmental impacts on important ecosystems.

Thus, community-to-community interactions within a natural resource region change. Fishermen are physically displaced as hotels, shops, expensive homes, and casinos replace the working waterfront that consists of docks, processing facilities, fish houses, and net shops. Many have been economically displaced as property values skyrocket and banks stop giving loans for fishing related activities (Hall-Arber et al. 2001, Maine Sea Grant 2007, Hartley et al. 2008). The result is stress, not only on production activities, but also on social networks as the places fishermen regularly meet decline and are replaced by places designed to satisfy the needs of newcomers. As infrastructure is lost in one community, more strain is placed on fishing infrastructure in nearby fishing communities. Fishermen have to go further to dock, unload catch, and buy supplies. When fishermen and infrastructure are forced to relocate, social networks are dispersed. Displacement happens without suitable relocation of facilities, forcing fishermen to go further to dock, unload catch, etc.

One of the most problematic outcomes of gentrification includes increasing housing costs. This troubles long-term rural residents because it makes it difficult for their children and extended family members to live nearby, as had been the norm in the past. The young in the area get priced out of the home market and have to relocate further away from family. This undermines the traditional family values that have been documented in rural community life (Wilkinson 1999, Jacob et al. 1997).

Hurricanes and other seminal events may accelerate gentrification as fishing infrastructure is altered, devalued, or in some cases, destroyed. Docks and processing facilities compete with casinos, recreational fishing facilities, and condominiums for space. For example, post-Katrina land values in Biloxi, Mississippi, rose sharply (Petterson et al. 2006). Shortly after the hurricane, the number of proposed waterfront condo units in the city tripled while development of affordable housing units, like apartments, had not been proposed (IAI 2007). Similar processes are happening in other parts of the Gulf. The decline of working waterfronts signals a cultural shift away from traditional fishing lifestyle to tourism and other uses. City leaders in Biloxi, for example, want to

Table 10.2 Number and volume of oil spills reported annually in the Lower Galveston Bay watershed (from Lester & Gonzalez 2008).

Year	Number of Spills	Gallons Spilled
1998	284	18,125
1999	387	33,021
2000	390	103,174
2001	397	123,828
2002	338	13,279
2003	315	10,381
2004	266	48,770
2005	246	20,678
2006	267	5,726
2007	306	6,915
2008	321	4,911

transform the region's image from the "seafood capital of the world" to the "Las Vegas of the Gulf" (Petterson et al. 2006).

Despite the potential negative impacts on commercial fishing from gentrification, the extent to which gentrification results in the decline of a particular fishing community varies. Some fishermen and fishing communities are able to adapt to the demographic and economic changes that come with gentrification. Individually, some commercial fishermen are switching to work in the recreational fishing sector (Jacob et al. 2002). On a community level,

> "... while tourism has in some ways led to the decline of commercial fishing, it simultaneously contributed to its preservation. Many participants explained that tourists come to Amelia Island and Fernandina Beach "to eat, breathe, and live" the life of a fishing community. While there is little remaining of the fishing industry that once dominated the local economy, vestiges that do remain are an important component of the tourist experience" (Jacob et al. 2002).

Research conducted in the Northeast found that the three communities that scored highest on a gentrification scale (i.e., were most gentrified) enthusiastically supported local fishing communities and provided adequate fishing infrastructure. Generally, towns with industrial looking docks and infrastructure are seen as unaesthetic. In these cases, fishing is not integrated into the design for the changing community, is not supported, and is pushed further away from the site of tourism or new development (Hall-Arber et al. 2001). Florida has recently passed working waterfront legislation and planners in a small city on the Upper Texas Coast have incorporated the idea into their master plan.

11.0 OYSTER MAPPING AND ASSESSMENT

11.1 Mapping Oyster Reefs

Properly managing oysters in the Gulf of Mexico, including effectively assessing their status and trends and estimating harvest potential, requires that the locations of oyster reefs are known. At present, that is not the case in most estuaries. Instead, complete oyster reef inventories are available for very few Gulf of Mexico estuaries, and even partial inventories are available for only a few of the many estuaries that border the Gulf. According to a recent global assessment of their status (Beck et al. 2009), oyster reefs are one of the most imperiled marine habitats on earth. Data from that assessment indicate that shellfish reefs in > 70% of bays worldwide have declined by at least 90%, and 85% of reefs have been lost, although the timing and magnitude of that destruction has been poorly quantified (Kirby 2004). The situation in the Gulf is better, with many reefs remaining in good or fair condition. However, that conclusion was based upon available data and literature reports, and such information is sparse at best. Thus, accurate assessment of the condition of oyster reefs in the Gulf is compromised by the lack of basic and comparative information on the locations of those reefs. One of the key recommendations advanced by Beck et al. (2009) to better manage for sustainable fisheries and reef rebuilding is to map the distribution of remaining reefs.

Historically, sounding across the bottom by poling or by dragging a chain or pipe behind a survey vessel was the most common method employed to map the distribution of shallow sub-tidal reefs (Haven et al. 1979, Smith et al. 2001a, Allen et al. 2005). These methods could be surprisingly accurate. For example, Smith and Greenhawk (1998) reported that the boundaries of oyster bars surveyed by Yates (1911) in the Maryland portion of Chesapeake Bay exactly matched buried terraces they had detected using chirp sonar. However, poling and dragging of chain or pipe may have misrepresented the details. Within the boundaries described by Yates (1911), much of what had been previously considered to be oyster reef was later found to be soft-bottom features (Smith and Greenhawk 1998). Lack of accurate and precise geographic referencing also resulted in map products that remain difficult to compare with more recent maps (e.g., Smith et al. 2001a). Moreover, subsidence, changes in basic geography and geology, and storm events result in potentially substantial changes to the distribution of oyster reefs through time (Berrigan 1988, Powell et al. 1995, Smith and Greenhawk 1998, Twichell et al. 2010). To capture such spatial and temporal change requires repetitive mapping (Grizzle and Ward 2009), and the periodicity of repetition will depend upon the dynamics of the habitat and the desired resolution of the reef map. Regardless, methods such as poling can provide relatively coarse to high resolution information on the location and physical structure of oyster reefs (see below) and is cheaper but more labor intensive, particularly when coupled with historical information provided by fishers and resource managers (Melancon et al. 1998).

Modern techniques for mapping the location and, to some degree, the characteristics of oyster reefs, primarily utilize photographic, acoustic, or spectral methods. Based upon available literature, acoustic methods have enjoyed the most frequent and widespread application (e.g., Dealteris 1988, Mayer et al. 1998, Allen et al. 2005, Maddox 2005, Twichell et al. 2006), but each approach has its strengths and weaknesses depending upon the setting and the goals of the mapping project (Grizzle et al. 2008a). In some cases, poling and dragging techniques discussed above remain viable, especially within the framework of modern Global Positioning System (GPS) technology that allows for the determination and application of precise location information.

Smith et al. (2001b, 2003, 2005) applied sub-bottom profiling sonar, side-scan sonar, and acoustic seabed classification systems to characterize the foundation for and distribution of oyster reefs in the Maryland portion of Chesapeake Bay. Sub-bottom profiling proved effective in identifying the hard terrace structures upon which successful oyster reefs were dependent (Smith et al. 2003). The authors were able to use those results to provide recommendations regarding opportunities for restoration of Chesapeake Bay reefs. To better characterize the distribution of modern reefs, they compared the sub-bottom profiling methodology with side-scan sonar and acoustic seabed classification (ASBC), concluding that ASBC platforms, such as RoxAnn (Caddell 1998, Wilson 2006) held the greatest promise as 'stand alone' systems for mapping oyster reefs and other complex benthic habitats (Smith et al. 2001b). They then applied ASBC, in combination with underwater videography, to assess oyster habitat in Chesapeake Bay and were able to determine that much of the historically productive oyster bottom has degraded to the point that it was no longer suitable to support oysters (Smith et al. 2005).

The application of acoustic techniques, such as single-beam or multi-beam sonar, generally has been restricted to subtidal targets due to the requirement that the signal path be exclusively aquatic. Moreover, the minimum depth at which these techniques are applied is restricted because as the distance between the target and the sensor decreases, the swath width decreases, eventually to the point that the level of effort becomes impractical (Grizzle et al. 2008a). A notable exception is a portable, shallow draft robotic vehicle employed in Apalachicola Bay, Florida, to map very shallow (0.75-2.0m depth) oyster reefs (Twichell et al. 2006). This vessel, nicknamed Iris, was equipped with interferometric sonar that provided a very wide swath (7-10 times the water depth), thereby overcoming the limitations inherent in other sonar-based systems for which swath width is limited in shallow waters. By coupling their shallow water results with those obtained from the deeper portions of the bay, the researchers were able to develop relatively high-resolution maps of oyster reef distribution in this very shallow bay.

Photography and videography have provided additional enhancements when mapping subtidal oyster reefs. Cutter and Diaz (1998) described a benthic sled mounted with a plow blade and carrying a video camera system that was effective in documenting benthic habitat type over short distances. That system allows real-time continuous viewing of the sediment profile as the plow carves through the substrate. As noted above, video from an integrated camera/RoxAnn system was used to classify the images extracted from the RoxAnn acoustic system when assessing habitat conditions in Chesapeake Bay (Smith et al. 2005). Grizzle and colleagues (Grizzle et al. 2008a, 2008b, Grizzle and Ward 2009) have applied videography alone to map oyster reefs in several New England estuaries with apparent good results. The towed video camera array is relatively inexpensive to build and maintain. Success is dependent upon suitable water clarity, but Grizzle et al. (2008a, 2008b) conclude that towed video is a low-cost and effective tool with which to map the size and shape of reefs, particularly if the sample design employs adequately spaced transects. As is the case with all oyster reef mapping techniques, the utility of the resultant map is directly correlated with the precision and accuracy of the positioning system utilized.

In many estuaries, most if not all of the oyster reefs are found in the intertidal or very shallow (< 0.5m) subtidal zone (e.g. O'Keife et al. 2006). There, sonar-based techniques are impractical, but a variety of other methods have been applied to reef mapping. In southeast Florida, the three-dimensional structure of oyster reefs in four estuaries (Sebastian River, St. Lucie Estuary, Loxahatchee River, and Lake Worth Lagoon) was mapped by capturing longitudinal, latitudinal, and vertical location information at each node of a 1m-scale grid (Gambordella et al. 2007). Three-dimensional location information was obtained using a Real-Time Kinematic GPS which was synchronized to the National Geodetic Survey's Online Positioning User Service (OPUS) for georeferencing. Resultant accuracy in each dimension was estimated a priori at 1-cm. During the winter of 2005/2006, 152 reefs covering 30.51 acres were mapped within the four estuaries. The approach was labor intensive but provided high resolution maps of the horizontal reef boundaries and a somewhat less accurate but extremely valuable, depiction of the oyster reef's vertical contours. High-density (every 1-m grid node) sampling minimized the confidence interval around the mean predicted vertical datum, but lower sampling densities were evaluated to allow for considering trade-offs between cost and accuracy.

However, a desirable goal of emerging oyster reef mapping technologies is to achieve extensive but rapid coverage with maximum accuracy. Remote sensing techniques provide the most direct path to this goal. Aerial photography was used in Mosquito Lagoon, Florida, to map and assess intertidal oyster reefs (Grizzle 1990, Grizzle et al. 2002). This methodology was advanced considerably by staff at the South Carolina Department of Natural Resources (SCDNR) in their attempts to map intertidal oyster reefs in that state (Corbley 2004). There, oyster reefs are extensive along the coast, but due to the highly turbid nature of South Carolina estuaries, there is a need to conduct aerial photography for mapping purposes only at the lowest tides to ensure maximum coverage. The South Carolina solution, developed by SCDNR in cooperation with GeoVantage Inc., was to employ multiple aerial platforms (generally up to ten small fixed-wing aircraft) during each surveying window. In addition to deploying identical externally mounted camera systems on each aircraft, the aircraft were similarly equipped with a coupled GPS/Inertial Measurement Unit (IMU) to display the exact location of the aircraft and its intended flight lines. Resultant photographs were analyzed using feature analysis software and dropped into a GIS format.

In cooperation with NOAA Coastal Services Center staff, SCDNR advanced their oyster reef remote sensing technology by conducting comparisons between standard film photography and digital (i.e., multi-spectral) photography and by comparing six analytical approaches to processing the resultant data/images (NOAA/CSC 2003). Their primary goals included the ability to detect both fringing and patch reefs, to determine the perimeter of oyster habitat, and to identify the type of habitat based upon nine previously developed strata. A major focus of the study was to compare processing methodologies for their ease of use and their accuracy in identifying reefs. Six processing methodologies were compared, including manual, unsupervised, supervised, image processing, feature analysis, and image segmentation. Results indicated that feature analysis was a very promising technique for consistently identifying oyster reef signatures in both film and digital formats, because of its relative ease of use (minimal training required) and effectiveness in describing details. Both manual analysis and image processing were similarly effective in discerning details, but both of these methods required considerable effort. Manual analysis was very labor intensive, and image processing required substantial training. The best approach was considered to be a combination of feature analysis and image processing, with feature analysis effectively identifying boundaries and image processing then categorizing within those boundaries. This contrasts with results from a Louisiana study that compared supervised, unsupervised, mean-based thresholding, and artificial neural network classification techniques (Allen et al. 2005). Comparative outcomes suggested that the accuracy of the classification method generally ranked supervised > unsupervised > artificial neural network > mean-based thresholding. However, this ranking could be altered depending upon the sampling method used to validate the acoustic signatures. Reed et al. (2006) provide a unified framework for creating classified seafloor maps from acoustic imagery that may assist in organizing the analysis of acoustic data.

Oyster reefs in Tampa Bay, Florida, are largely intertidal in nature, so aerial remote sensing techniques are appropriate for mapping those reefs. A comprehensive mapping effort was conducted during the first six months of 2005 (O'Keife et al. 2006). The objectives of the study were to establish baseline maps of the current extent of oysters within Tampa Bay, to assess the accuracy of the mapping effort, and to develop an historic map layer derived from scanned USGS post-1927 topographic maps (T-sheets). A secondary goal was to determine if the oyster reef mapping process could be automated. For the effort, hyperspectral imagery collected by the Galileo Group Inc., and 2004 digital orthophoto quarter quadrangles (DOQQs), were used. Extensive field reconnaissance was performed to provide training sets as well as to identify errors of commission and omission. The resultant images are available in an interactive mode that allows blending and swiping of layered images. Hyperspectral imagery, comprising 128 spectral bands, was collected at low tide from throughout the Tampa Bay nearshore region including the southern portion of Boca Ciega Bay. Ground resolution was 1.5-2.0m. Helicopter overflights of the entire intertidal region of Tampa Bay were flown to provide ground-truthing, with visual and photographic images being combined with GPS georeference information to plot the locations of apparent reefs. Problems with the hyperspectral data included geographic offsets and interference between the apparent oyster reef and sand flat signatures. Feature analysis software was used as a secondary method to test the feasibility of automated reef mapping. Finally, traditional photointerpretation methods were applied to the Galileo low tide imagery to supplement the analyses. Problems with interpretation and analysis included interference from mangroves, especially with respect to fringing reefs around islands, lack of vertical relief of the oyster beds, and interference due to mud and algae on the oysters comprising the reefs. These problems led to mistaken classification of shadow areas and mud flats as oyster reefs in many instances. It was concluded that too little consistency existed in the digital signature of oysters in Tampa Bay for the automated approach to produce high accuracy imagery. The classifications provided by Galileo performed better, but over 50% of the ground-truthed locations where oysters were found were not predicted by the hyperspectral output to be oysters. Only 32% of the locations where oysters did occur were predicted by the hyperspectral output to be oysters. Although these results are less than ideal, this was a pilot study and the hyperspectral approach remains potentially useful due to the capability of this process to cover large areas in a short period of time. However, further refinement of the assignment algorithms will be necessary.

There remains considerable opportunity for improvement of oyster reef mapping methodologies. One intriguing possibility is laser line scanning. A system described by Tracey et al. (1998) was tested in Alaskan waters and the resultant images were remarkable to the point that not only could individual fish be clearly discerned, but even the shadow of the fish was evident. Resolution is on the order of a few millimeters to centimeters, but the distance from sensor to target is influenced by water clarity, with distance limited to approximately 2.5m in turbid waters. Swath width is 1.4 times that distance. At present, the system is restricted to application in at least 2.5m water depth, so its practical application to oyster reef mapping will require additional advances. Nonetheless, laser line scanning holds promise. Similarly, the utility of hyperspectral imagery for mapping intertidal and very shallow oyster reefs may be improved. This will require that the hyperspectral signatures of various types of oyster reefs, as well as other substrate types that may be confused with oyster reefs, be better defined (O'Keife et al. 2006). The great advantage of hyperspectral imagery, and the attribute that makes advancing this technology worthwhile, is its capability to cover large areas in a relatively short period of time. Such expansive coverage is needed in the Gulf, where oyster reefs extend from the Ten Thousand Islands area of southwest Florida to the Texas/Mexico border and beyond. Another approach is Light Detection and Ranging (LIDAR) technology, which uses pulsed lasers to detect changes in elevation as small as 15 cm. Because the system is airplane mounted, this technique also provides expansive coverage. Coupling LIDAR with aerial photography considerably eases the interpretation of the resultant map products. The system also is capable of penetrating water depths up to 25m, further enhancing its application to mapping oyster reefs in all ecological settings. An advanced LIDAR system termed EAARL (Experimental Advanced Airborne Research LIDAR) is being developed (Nayegandhi et al. 2009) and may have applications to mapping oyster reefs because the system is specifically designed to measure submerged topography and adjacent coastal land elevations seamlessly in a single scan of transmitted laser pulses (Wright and Brock 2002).

At present, the options available for mapping oyster reefs in the Gulf of Mexico include aerial imagery for intertidal and very shallow sub-tidal reefs, ASBC for sub-tidal reefs with videography for calibration and verification, and intensive RTK-GPS based surveys of a subset of the available reefs to validate results and to assess the vertical status of the reefs. Statistical methods can be applied (e.g., Gambordella et al. 2007) to expand the results of on-the-ground intensive surveys to the universe of oyster reefs within each estuary. Each method has its strengths and weaknesses depending upon the specific application (Grizzle et al. 2008a). These approaches should be appropriately applied to develop the first baseline map of intertidal and subtidal oyster reefs in the Gulf of Mexico. Future advances in both subsurface and aerial imagery techniques will allow for even more efficient mapping of these reefs in the future. However, the results of the initial survey, using presently available technology, should provide the baseline necessary for comparison with future survey results that will allow evaluation of the status and relative gain (or loss) rate of oysters in the Gulf.

11.2 Estimating Population Parameters for Model Calibration

An effective assessment of oyster populations has four basic requirements. First, an estimate of total population size is needed to convert fishery harvest into an exploitation fraction. If the population is spatially segregated then population size should be estimated independently by region. Population size should also be estimated annually over a reasonably long time period so that trends in population size can also be estimated. The optimal case is for the time series to begin prior to significant fishery exploitation in order to provide an estimate of virgin stock size (Hilborn and Walters 1992). Where this is not possible, a time series is desired that is sufficiently long to allow for the maximum possible variability in annual fishery landings. This typically requires time series at least 5-10 times the species generation time. Second, the recruitment rate to the fishable population should be estimated at the same time scale of the population estimates (e.g., annually). Third, the non-fishing mortality rate needs to be estimated at the same time scale. Optimally, the non-fishing mortality rate will be estimated independently pre- and post-recruitment to the fishable stock. Finally, the harvest rate is needed to estimate mortality due to fishing. More specific data are often collected to allow for a more accurate assessment or to properly measure uncertainty in assessment results and these will be addressed more specifically in the section on Assessment Models.

The first component of an oyster assessment is to conduct a survey of oyster distribution (ideally including spatially-explicit size information) and abundance. If the survey includes a very large number of sample stations, then a fixed-station (i.e., non-stratified) survey approach is suitable. In most cases, however, funding constrains sampling effort so a quantitative stratified random survey will be more appropriate. Stratification requires a basic knowledge of where the oysters are, and in what densities, to properly stratify for the survey. Stratification may be based on abundance or biomass, up-bay/down-bay location, habitat suitability, or other factors that characterize the relative distribution of oysters within a specific system but which are independent of resource distribution. Oyster occurrence is patchy, so a large number of samples are required to obtain an accurate estimate of abundance. If the strata are allocated based on numbers or biomass, the survey will be less expensive because patchiness is reduced in high biomass areas so less sampling is required to achieve a low coefficient of variation (CV). At a minimum, areas of high quality, median quality, and low quality need to be identified and strata allocated accordingly in order to reduce the CV, thereby reducing sample size and associated costs while increasing precision. The more precise the stratification employed, the more efficiently stations can be allocated.

Once the strata are established and an initial survey is completed, the sampling densities of the survey can be adjusted to further minimize the CV. This initial survey should include a high density of sample sites, from which a Monte Carlo model can be applied to establish future sampling densities and thereby achieve a suitable CV. This will ensure that sufficient sampling is conducted in future assessments while minimizing effort. In Delaware Bay, an intensive re-survey program has shown that significant modifications in the allocation of sites to strata may be required over time, particularly in locations heavily fished or manipulated through shell-planting programs. As a consequence, the Delaware Bay program has adopted a 10-year re-survey protocol in which beds are fully re-surveyed and re-stratified at least once every 10 years (HSRL 2010). Note, also, that transplanting oysters will artificially alter the strata by changing the relative density among reefs. Thus, there is a need to maintain detailed records regarding the movement of oysters and shell from or between sampling units.

Caution is advised regarding the interpretation of the CV. There is an apparent dogma in the assessment literature that the quality of a survey is demonstrated by a low CV (Powell personal communication). However, if the sampling density is low and the distribution of oysters is patchy (as it usually is), it is possible to sample the patches with bias, resulting in an increased likelihood that the survey will be biased low and an increased probability of a poor estimate of the real biomass. Proper stratification and adequate sampling will minimize this source of uncertainty. In addition, the initial dense survey can provide a good estimate of the CV target. One cannot expect a survey CV to drop below the CV obtained by dense sampling of the entire population unless sampling is inadequate.

An essential first step in the assessment is for the abundance estimates to be based on a truly quantitative survey method. To seamlessly introduce oyster density data into most models, it is necessary to be able to standardize abundance (or biomass) to a unit area basis (e.g., square meter). It is necessary to quantify the area sampled, whether it's obtained by quadrats, hydraulic patent tongs, a dredge, or other gear. Regardless of how it's done, the gear needs to be calibrated to determine the true area sampled and the sampling efficiency of the employed gear. Quadrat and dredge sampling are commonly used in the Gulf of Mexico region.

Quadrat samples are obtained by hand using a square frame of known area (i.e, quarter, half, or full square meter) positioned on the substrate at a predetermined sampling station. The entire contents of the substrate to a predefined depth within the frame are gathered for subsequent sorting and analysis. Quadrat sampling calibrates the areal extent of collection and is very efficient by completely collecting the designated substrate. In addition, the results can be extrapolated to larger production units (e.g., acres) with reasonable accuracy, if sample size is adequate. Ideally, the number of quadrat samples obtained is determined after estimating initial sample variability, however, time and cost usually limits the number of samples taken.

Oyster dredges are used extensively to conduct population assessments. The area swept by a dredge may be difficult to accurately quantify because of problems with variability in dredge efficiency and in measurements of the distance and width of the tow path. Some studies have employed high tech approaches to quantify swept area by using various sensors on the dredges (Powell et al. 2007). Dredges are calibrated using at least one of several available methods. For example, a depletion study involves repeatedly sampling a predefined area until all of the oyster material has been removed. A published formula and computer model is then available (Rago et al. 2006) that is used by the NMFS to back out the efficiency of the dredge. However, the depletion approach is very labor intensive. An alternative is to employ quadrat sampling along with dredge sampling to directly compare what is on the bottom versus what is in the dredge (Powell et al. 2007). The latter approach is straightforward and relatively easy in the field. It is also highly repeatable. Hydraulic patent tongs can be used rather than diver quadrats. Dredge efficiency can vary widely both within and between studies. Powell et al. (2007) reported from ten years of calibrations that the dredge efficiency in Delaware varied between beds (10-39% overall) and size classes (market size were either more or less efficiently sampled than juvenile or submarket oysters and were more variable between reefs), but the efficiency didn't change substantially from year to year on a specific reef. Dredge efficiency drops considerably if the dredge is allowed to fill, so sampling must be conducted on short paths to avoid misleading estimates. The size of the dredge also may bias results, as smaller dredges tend to fill faster and may bounce over the reef rather than collect consistently. In addition, the construction of the dredge [e.g., tooth number and bar length, bag size, shoes (depth limiters), etc.] and scope (length of rope or chain deployment per water depth) will alter its efficiency. Consistency in approach, when sampling among reefs and when sampling among years, is essential to comparability of results. Dredge efficiency also varies between the collection of live oysters, boxes (articulated shells of dead oysters), and disarticulated shell and the difference is almost always statistically significant (Powell et al. 2007). Dredges are effective sampling devices for live oysters, but are less effective for sampling boxes. The boxes are used for estimating mortality, but the effectiveness of the dredge in sampling boxes is reduced because, while recently dead and live oysters are equally accessible, older boxes may be buried in the bottom and thereby missed by the dredge. Calibration sampling, particularly if conducted by divers, generally includes counting of the buried boxes that the dredge missed, resulting in a relatively lower estimate of dredge efficiency. Dredges are least efficient for sampling relic shell because small and broken shell passes through the dredge or may be embedded more deeply than the dredge teeth can penetrate. However, Ford et al. (2006) have reported on counting boxes for mortality estimates and their results suggest that box counts are reasonably accurate for larger size classes. Box counts typically severely underestimate mortality rate for juveniles. The several studies on box counts (e.g., Ford et al. 2006 and Christmas et al. 1997) suggest, however, that the rate of disarticulation is highly sensitive to local conditions. Therefore, use of boxes to estimate mortality should be accompanied by experimental data documenting the disarticulation rate.

11.3 Overview of the Assessment Process

Effective management of oyster resources requires an understanding of how many oysters occur within each defined management unit, the locations of those resources, and recruitment and mortality rates within each unit. Considering the fundamental importance of effectively modeling population status and suitability for harvest, there remains a surprising dearth of information regarding the stock status of oysters in the Gulf of Mexico. Guidance is available from the mid-Atlantic region of the United States, where modeling of oyster populations for a variety of purposes, including harvest assessments, has a longer history and is therefore more advanced. Oyster populations in Delaware Bay have been particularly well-studied, with specific emphasis on gathering data appropriate to calibrate population models (Powell et al. 2009a, 2009b).

Population assessments of oyster stocks represent a special challenge due to fundamental differences in data availability and population biology between shellfish and other fishery resources. There are three broad modeling approaches that will be discussed here based on a declining level of data-requirements. Optimally, assessment models are based on cohort-specific data for abundance and mortality (Hilborn and Walters 1992). Tracking individual cohorts requires an accurate estimate of individual age and the age distribution of the stock. At present, estimating the age of oysters is possible using growth increments on the animal's umbo; however it is labor intensive and thus receives little practical use (Mann et al. 2009a, Harding et al 2008). Alternative methods involve the use of length data as a surrogate for age but this approach is only reliable for fast growing, short-lived species. Length-based cohorts can rarely be followed in oyster populations (Mann et al. 2009b). When reliable cohort-specific data are not available, biomass or abundance based surplus production models can be used to estimate changes in population size in relation to equilibrium-based thresholds (i.e., population carrying capacity; K) (e.g., Powell et al. 2009b). Biomass-based models often are suboptimal for shellfish, as landings are reported in volumetric units based on shell size and not animal meat weight and conversion to numbers from volumetric reports (e.g., bushels) is more readily accomplished. Thus, most oyster models have been numbers based, rather than biomass based (e.g., Powell et al. 2009a, 2009b). Finally, in cases where data on oyster abundance are not available, a growth-based assessment model has been developed by Soniat et al. (*in prep*), the Sustainable Oyster Shellstock (SOS; Section 11.4.3), that can give site-specific estimates of allowable harvest in a given year based on oyster counts at the beginning of the season, size-specific harvest rates, and a generic growth curve. This model has minimal data requirements beyond an annual count and is, therefore, applicable in small areas where harvest is known. This approach is situational in that it is based on a survey conducted just prior to the harvest season. The model is capable of application to two possible objectives: stable population size or stable shell budget. The issue of a shell budget as a management tool will be addressed in Section 11.3.2.

Current assessment approaches used for oyster stocks in the Delaware Bay are based on a census-based surplus production model that does not require biomass data (Powell et al. 2009a). The Constant Abundance Surplus Production (CASP) model requires a data time series of population abundance, annual recruitment (i.e., spat set), stage-specific mortality rates, fishery harvest, and the impact of fishing on both cultch abundance and the mortality of pre-recruit life stages. The data requirements of this model and the Sustainable Oyster Shellstock (SOS) model are relatively low for an assessment model. The objective of the next section is to explore the applicability of the CASP model and the SOS model to assessment of oyster stocks in the Gulf of Mexico. Section 11.3.1 provides an overview of the Delaware Bay assessment process as a reference. Section 11.3.2 explores the data requirements for both models with respect to two index oyster populations in the Gulf of Mexico, explores the results from the CASP model for one of these index systems, and identifies research and data needs for more general application of the CASP model.

11.3.1 Delaware Bay Assessment Process

The Oyster Industry Science Steering Committee in Delaware meets each fall to identify the Terms of Reference (TOR) and to establish a Stock Assessment Reviewing Committee (SARC). In addition, they host a Stock Assessment Workshop (SAW) to review the data and determine how to achieve the reference points. Reference points are management goals for the stock. At the end of the workshop they draft a report describing the status of the stock and providing management advice. The process is peer reviewed (since 1997) and input from the SARC is incorporated. This allows for rapid progress with the quota setting process conducted by the Mid-Atlantic Fishery Management Council.

The reference point-based oyster assessment of the Delaware Bay has been in place since about 1960. The management approach started as a 40% rule; when the volume of a single dredge haul fell below 40% live oysters, the reef was shut down. As a result of that arbitrary and conservative harvest level, Delaware Bay oysters have not been overfished since the late 1950s. The current assessment approach employs more modern reference points that are based on an exploitation-rate time series and on a surplus production model permitting comparison of stock-wide abundance to carrying capacity. The latter approach provides Abundance at maximum sustainable yield (Amsy). However, setting fishing quotas using Maximum Sustainable Yield (MSY) reference points has proven difficult as the fishing rate goal is more difficult to constrain than the abundance goal. An important impediment is the uncertainty in the mortality rate that can vary widely from one year to the next because of Dermo disease. As a consequence, reference points have been established using the time series of exploitation relative to observed variation in stock abundance. As implemented in Delaware Bay, these result in quotas that are precautionary relative to the surplus production-one year forward prediction model of Klinck et al. (2001) in that allowed landings fall at or below surplus production predictions. This allows for minimizing the possibility of overfishing during an epizootic that otherwise would result in a significant decline in stock abundance. Recent retrospective analyses of the accuracy of the forward-prediction model have proven encouraging, however, suggesting that the surplus production approach will be useful to adjust use of the exploitation rate time series to optimize harvest (Powell pers. comm.) Additionally, the SAW sets area management and transplant goals. The area management program is designed to limit local overfishing by spreading the fleet out over the entire region yielding a marketable product. The transplant program is designed to bring into the fishery regions with oysters not immediately marketable. In this case, the animals are transplanted to improved growing areas. Experience shows, for Delaware Bay, that condition and marketability improve over a 6-week time scale, so that harvest within the season of transplant is routinely achieved.

11.3.2 Gulf of Mexico Assessment Process

In most states an annual survey of oyster abundance is conducted but with high variability in coverage among states and years. The survey results provide the best time series from which to generate abundance estimates. Derivation of abundance estimates, combined with size-specific estimates of wet or dry weight, then allows an estimation of size-specific biomass. However, weight conversions should be reevaluated every year.

In addition to an annual abundance estimate of harvestable oysters, abundance estimates should also be collected for newly settled recruits (i.e., spat) and previously settled but sub-legal sized oysters (i.e., seed). Abundance data for spat and seed oysters can be collected in the same manner and at the same time as adult abundance by counting oysters by groups (seed, spat, and market sized oysters) during annual surveys. Estimates of spat abundance are most sensitive to bias due to their small size but this is an important survey component as spat abundance is needed to estimate annual recruitment and to establish a stock-recruitment relationship for the population. Further the relationship between spat and seed abundance and seed and market abundance are needed to estimate mortality rates prior to recruitment to the fishery.

Adult non-fishing mortality is estimated from box counts and is critical to the model. Mortality is calculated as the proportion of total population (boxes + live oysters) comprised of boxes. This approach assumes that boxes are not missed (i.e. disarticulation prior to sampling) or double counted (i.e., boxes remain in the system for more than one sampling period). Christmas et al. (1997) estimated a 12-18 month half-life for boxes in the Chesapeake Bay, depending on prevailing temperature and salinity. Ford et al. (2006) estimated similar half-lives of 6-12 months for the Delaware Bay. Results from Powell et al. (2009a) indicate that the rate at which boxes break down is the best source of data at the local level for estimating adult mortality. Along the mid-Atlantic coast, box counts appear to work well for estimating adult natural mortality because most adult mortality does not result in the complete destruction of the shell. However, in the Gulf of Mexico, stone crabs will disarticulate and crush some of the oysters, possibly resulting in an underestimate of the box count.

Because models such as CASP (Section 11.4.2) assume constant adult abundance, they require an adult mortality term. Box counts presently are the only way to estimate the adult mortality. Because the half-life of boxes varies between estuaries (and even between reefs within an estuary) based on prevailing currents, salinities, temperatures, and perhaps other activities such as fishing, as seen in both the Chesapeake and Delaware bays (Christmas et al. 1997, Ford et al.

2006), box half-life should be determined for each estuary and with as much spatial resolution as possible within the estuary.

Results from a quantitative time series of adult oyster abundance, annual recruitment, and adult mortality rate then allows for an account ledger approach to calculating a productions balance as follows:

beginning population + recruitment + transplants – fishery removals – non-fishing mortality = next year's starting balance.

A typical management goal would be that the ending population abundance equal or exceed the beginning population abundance. In this case, note that the population is the portion of the total population of legal size and recruitment is the smaller oysters that will grow into market size over the model time step, typically one year. The next year's balance may be lower due to 'other' mortality that is not picked up by the box counts, as mentioned above for shell destruction due to predation by stone crabs. This unknown mortality can be estimated in year t-1 by reversing the starting and ending balances in the equation for year t-1 and comparing the result to observed estimates of market oyster abundance in year t, as follows:

start abundance – end abundance = 'unknown' mortality.

The unknown mortality is most important to the estimate of juvenile mortality as box counts tend to underestimate juvenile M due to box destruction, but the term also includes other components that were missed due to sampling error, redistribution of shell, etc. The two terms (M_{bc} and M_0; *sensu* Powell et al. 2009b) are additive and can be combined to estimate total instantaneous non-fishing mortality by life-stage.

Unfortunately, setting quotas based on the above population dynamics fails to recognize the necessity of maintaining the shell stock. Oysters generate their own substrate and production of that substrate is critical to the stability of annual recruitment. Oyster shell breaks down over time and thus some mortality is necessary to provide replacement of lost shell. The life-span of relic shell in New Jersey is only about 5-10 years (Powell pers. comm.), so shell is not a long-term substrate. A variety of chemical and physical processes (dissolution and breakage) reduce the shell (Carriker 1996), so loss of shell must be incorporated into management of the population (Powell pers. comm.) Shell is generated by natural mortality, but when the oysters are harvested the shell is no longer available to the reef. Shell or other suitable cultch material must be returned to the reef or otherwise replaced to maintain a 'neutral' shell budget.

Recent modeling of shell budgets suggests that removals at MSY are too high to conserve shell; thus an additional level of precaution must be added in establishing allowable landings (Powell, pers. comm.). Thus, a time-series of surface shell quantity is an important survey component and a constant shell term should be added into any assessment model or alternatively estimated separately based on projected removals. In the Delaware Bay assessment, the shell budget is updated yearly and used in status of the stock determinations and management advice (HSRL 2010).

In Delaware Bay, the shell budget is based on a volumetric time series of surficial shell. Powell et al. (2006) determined the volume of shell from their sampling efforts, but the volume estimate was converted to a weight equivalent using derived conversion factors. A better approach may be to determine the weight of planted shell material directly rather than by volume, because it doesn't matter what size the shell particles are and therefore the carbonate estimate is more accurate. The time series of surficial shell combined with the size-dependent box counts permits one to estimate shell addition and shell amount. A simple restrospective calculation permits estimation of the shell loss rate from these two time series.

Powell and Klinck (2007) provide a model that utilizes these half-lives and shell addition rates from box counts to estimate the yearly shell balance. In Delaware Bay, oyster beds appeared to be losing shell and shrinking at a rate of 400-750K bushels of shell per year (HSRL 2010) due to the lowered abundance that is the outcome of the natural balance of Dermo disease and recruitment rate. This information allowed direction of a shell planting program with two goals. One goal of this program is to guide stock enhancement efforts to create more spat, but the more important goal is to put the bay back into shell balance. The bay has become balanced for shell in the last few years and stock abundance has increased substantially, augmented by additional spat recruitment due to focused enhancement. Thus, any assessment program must include a shell budget calculation. In the Gulf of Mexico, oysters grow, live, and die faster but the shell also probably degrades faster. Therefore, shell degradation rates need to be determined for Gulf of Mexico reefs.

A site specific shell budget model should be coupled with one of the population models discussed in Section 11.4 to produce a comprehensive oyster stock assessment. Such an approach has not yet been successfully accomplished for oyster populations in the Gulf of Mexico. However, the Soniat model provides this capability, assuming adequate information to parameterize the model is available.

11.4 Assessment Modeling

Three broad types of fisheries assessment models have been discussed, but all have two goals: 1) estimate fishing mortality rate and abundance of the fishable stock, and/or 2) generation of population reference points (either abundance/biomass based or derived from an index-based proxy) with which to set stock status relative to measures of sustainable harvest. At present, there is not an assessment model that accomplishes both goals for any Gulf of Mexico oyster fishery. Therefore, the primary goal should be to select the best candidate model framework for the Gulf and conduct a data needs assessment. Data requirements are an important consideration when selecting an assessment model framework. Some models require considerably more data than others and this may be a more important issue than model outcomes, particularly in the Gulf where sampling programs have not been designed to generate data suitable for inclusion in the available assessment models.

11.4.1 Stage-Based Assessment Models

Stage- or age-based assessment models exploit the exponential decay of single cohorts to estimate total annual mortality (Z). Annual mortality due to harvest can then be estimated by difference using an external estimate of non-fishing mortality. Exploitation rate can then be estimated based on model estimates of population size, as well as standard reference points such as MSY. This approach is commonly used in fishery stock assessments where age-structured data are available and a good example of this type of model is the Age-Structured Assessment Program (ASAP) model available for use from NMFS (NEFSC 2008). The data requirements are high, and in particular good estimates of age are needed to estimate cohort size. This approach is not feasible for oysters due to the lack of age estimates, but represents the standard for comparison of the other, less data intensive, assessment models.

11.4.2 Surplus Production Models

The Population Dynamics-Surplus Production model estimates reference points based on MSY and can be effective for establishing rebuilding goals in data poor situations. This requires a relatively long time series and knowledge of the stock biomass, annual recruitment, and mortality relationships. Biomass estimates for oysters are not typically recorded due to the dominant influence of the shell. Count data are far more common and harvest is recorded in numeric or volumetric units. For this reason, a biomass-based assessment model is not optimal and abundance-based alternatives have been developed.

The Constant Abundance/Surplus Production (CASP) model does not require age-structured data (although it can be incorporated if available) (Powell et al. 2009a) and places minimal requirements on length structure data in that the population must be divided into market-size animals and animals that will recruit into the fishery over the projection period. Like all surplus production models, CASP assumes a maximum population growth rate which allows for excess production that can be sustainably harvested. Information on growth rate is essential, and this often represents the limiting factor in prediction accuracy. The implicit assumptions regarding population stability tend to apply well to healthy oyster populations and this model is effective for establishing biological reference points such as the population abundance associated with maximum surplus production, as well as short-term forward predictions of optimal harvest. The CASP model can also incorporate estimates of compensatory mortality, due to fishing or epizooitics (e.g., Dermo), which allows more efficient allocation of harvest.

To populate the CASP models requires dividing the population into three components; those animals that won't achieve market size this year, those that will, and those that are already at market size. The quota is then set based upon those that will grow to market size minus those that are predicted to die. The goal is to have at the end of the year the same number of adult, marketable oysters with which the year began. Under data limited conditions this is an effective model. For example, this model was used to assess oyster populations in New Jersey until adequate data were obtained to populate a more sophisticated assessment model. Recent retrospective analyses of CASP model predictions are encouraging in that this approach can provide a good estimate of potential yield, given reasonable expectations of growth rate and mortality rate for the period of the prediction (Powell pers. comm.)

11.4.3 Sustainable Oyster Shellstock (SOS) Model

In cases where a sufficient time series of abundance and mortality is not available or available for only a portion of the stock, the growth-based Sustainable Oyster Shellstock (SOS) model may be an effective alternative approach for assessment. The SOS model requires that a survey of the resource be conducted prior to the harvest season and that stage-based mortality rates and growth rates are independently estimated. These rates can be estimated generally for the region based on a von Bertalanffy growth model (Hilborn and Walters 1992), rather than being measured separately for each stock. Allowable harvest, based on the goal of a stable population size, is then estimated for the time period of interest (e.g., 12 months) based on population inputs due to growth and removals due to harvest and natural mortality. Stability is defined based on a constant population biomass over the time period. Alternatively, management can be based on a stable shell budget, in which biomass of new boxes on the reef is balanced against shell loss due to harvest, dissolution, and advection. This model is similar to a surplus-production approach, but is not dependent on monitoring-derived estimates of population growth, mortality, or recruitment. An approach like this does not give any estimate of current biomass relative to the maximum sustainable biomass under the current shell budget conditions.

11.5 Implications for the Gulf of Mexico

Although most of the models described above have been developed for application to mid-Atlantic oyster populations, those models could be used to model Gulf of Mexico oyster populations, if properly modified to account for differences in biology and ecology between regions. The software and models, the size stratification, and the outputs would be the same. However, generation time of Gulf oysters is much shorter, spawning is more protracted, and Dermo has a much lower impact in the Gulf than it does in the Delaware Bay. For these reasons, interpretation of model results may be very different.

The magnitude and importance of differences in oyster ecology between estuaries is also not well documented, so region or local scale model parameterizations may be necessary. For all models, choosing the spatial scale at which to conduct the analyses (e.g., individual reef, reef complex, bay, etc.) is essential and should provide a balance between assessment generality and accuracy. That scale should correspond to the management unit. It is possible to analyze at levels above that of the management unit, for example, to ensure regional consistency of management plans to achieve a metapopulation level analysis. However, results from the Delaware Bay, with only four management areas, suggest that it's better to apply the assessment at the level of the management unit. Results can be combined in summary, but effective management ultimately will occur at the level of the management unit. During the initial development of the modeling effort, when data may be limited, it is best to focus field sampling and modeling efforts on representative data-rich management units. Effort and analysis can then be expanded to other areas as the model matures and essential data needs are identified.

At present, the data needed to parameterize any assessment model are only available for a few areas. A primary goal for Gulf of Mexico oyster reef modeling is to demonstrate an assessment method for estimating adult population size by management area, as well as, to have enough of a time series to generate an estimate of sustainable exploitation rates. The CASP model is best suited to achieve these goals for Gulf oyster populations because it is a relatively simple model with low data requirements: harvest, adult abundance, recruitment rate, and mortality rate. These data can be obtained from quantitative samples, either collected on a meter square basis or suitable for extrapolation to that unit of area. From these data, it is possible to estimate abundance of pre-recruits (spat), recruits (juveniles), and adults (at or above legal size limit) per unit area. If these data are collected comprehensively across a management unit, they provide a direct estimate for that management unit. If these data are collected from fixed stations or only a subset of the management unit, then they represent an index of abundance that must be converted into an estimate of total abundance for the entire management unit.

In either case, it is also possible to generate natural mortality estimates from the box counts and knowledge of the life span of boxes (e.g., Ford et al. 2006). A key component of this estimate is an estimate of the disarticulation rate of boxes by oyster size. As stated above, these data need to be collected independently for each management unit because local conditions such as reef structure, hydrodynamics, and predator abundance and type all influence this value.

Sampling gear and approach used to collect these data need to be carefully considered, the goal being to sample quantitatively and efficiently. As an example, oyster survey data collected by the TPWD could be expanded, employing the same number of samples, to develop a truly quantitative time series. The TPWD has already mapped areas that do not require sampling because of low oyster abundances. The next step would be to establish abundance related strata and randomly sample those strata, thereby considerably reducing the total area to survey and the number of survey stations within those strata. The TPWD also has dredge calibrations, enabling quantitative dredge hauls (TPWD unpublished data). In particular, data from Matagorda Bay is sufficient for populating a CASP model, and with a slight redesign to the sampling regime, will support a fully quantitative analysis. Assuming that all of the component bays have the same type of data and those data are already in an electronic format, it is a simple matter to arrange the data in accordance with a random stratified design and minimize the resultant CV.

Effective assessment depends upon feedback from management. In the Delaware Bay, the recommendations made by the SAW are addressed and an attempt is made to implement them each year to improve the assessment. A Science Committee (separate from the SAW) prioritizes the SAW recommendations and identifies those that can be placed into a funded research program. The constraint on the research program is that the data must be able to be included in the next year's assessment, which means it must be entered, proofed, and analyzed within about six months. The data are included in the assessment for evaluation, in order to review the research prior to commitment. If the provisional assessment is reviewed favorably by the SARC, the additional data collection methods are incorporated into the routine assessment. If the review is not favorable, the research protocol is either modified or eliminated and new recommendations may be provided.

An assessment is essentially bookkeeping of numbers of animals. Good survey data will provide knowledge of recruitment, mortality, and available shell, for each size class. This information is fed into the population dynamics model, but to complete the equation requires information on the location and size distribution of harvest. In the Delaware Bay, a dockside monitoring program is utilized that involves samplers randomly boarding the boats, taking a bushel of oysters, counting and sizing the animals, and identifying where the oysters were harvested. This high-density sampling design is based on 25-acre grids over the bay's 21 beds, so the resultant assessment is based on bed units and the landings are reported by individual bed. The Delaware Bay beds range in size from 500-3,000 acres, and fishing effort and removals are identified within these beds. The GPS coordinates for all the bed boundaries are reissued each year so the fishermen know exactly which beds they are in, although the bed boundaries haven't changed much during the duration of monitoring. So far, harvesters in the Delaware Bay have been very cooperative with the dockside sampling and reporting. Harvesters initially reported in bushels, but the conversions to suitable areal and volumetric units proved inadequate. However, when the fishermen realized that the conversion could over- or under-estimate their contribution to the total quota, and that they could be shorted in a year due to inaccurate conversions, they began to participate willingly to get the best conversion each year.

11.6 Assessment Modeling Using Available Gulf of Mexico Data

As an introductory effort, the use of the CASP model as an assessment tool was explored for two index oyster populations in the Gulf of Mexico. This is a proof of concept approach that is intended to provide information on the applicability of this model to Gulf of Mexico oyster populations and a data and research needs inventory to guide future efforts. Two index sites were chosen for exploration of the CASP model. They will be referred to as index sites A and B. A generic site label was chosen to avoid the use of this preliminary exploration as a more formal stock assessment of a particular oyster population.

The two index sites are each comprised of all of the known harvestable oyster bottom in two different estuaries along the Gulf coast. Index site A is in Louisiana and is comprised entirely of public oyster reef that has been actively harvested since 1963 and surveyed since 1984 (Figure 11.1). Surveys at Site A include a trawl-based annual estimate of abundance for spat seed and market oysters, as well as box counts and total fishery landings reported as number of sacks. Index site B is in Florida and is comprised of both harvested and non-harvested reef. Site B also includes some restored oyster reef that has been intensely monitored for short periods of time post-restoration (1988-1989). Broader transect-based monitoring of oyster abundance and size has occurred on certain reefs since 1982 resulting in an index of abundance but not an annual estimate of abundance as in Site A.

11.6.1 Site A Assessment

Based on the annual estimates of population abundance, the population size of market-sized oysters has been highly variable but generally increasing with a positive linear trend in the data since 1990 (Figure 11.1). While data have been collected on abundance of both spat and seed oysters annually, the data for spat is likely an underestimate as spat abundance has consistently been lower than seed abundance in the preceding year. The trend in the abundance of seed oysters tracks that of market oysters but is also highly variable through time.

Fishing mortality rate was estimated based on exploitation rate, which is calculated as:

u(t) = total estimated harvest in year t/total population abundance in year t.

Fishing exploitation rates have been low (< 10% yr^{-1}) in most years with the exception of the period from 1997-2000 and in 2007 (Figure 11.3). These ‘peak’ periods do not associate well with peaks in effort suggesting the increase in annual landings, particularly in 1998 and 1999 where related to an increase in catchability possibly associated with an observed increase in abundance in 1997 (Figure 11.2).

Natural mortality (M) in each year was estimated using the ‘box count + other’ formula described in Section 11.3. Natural morality rate has also been generally low and comparable in

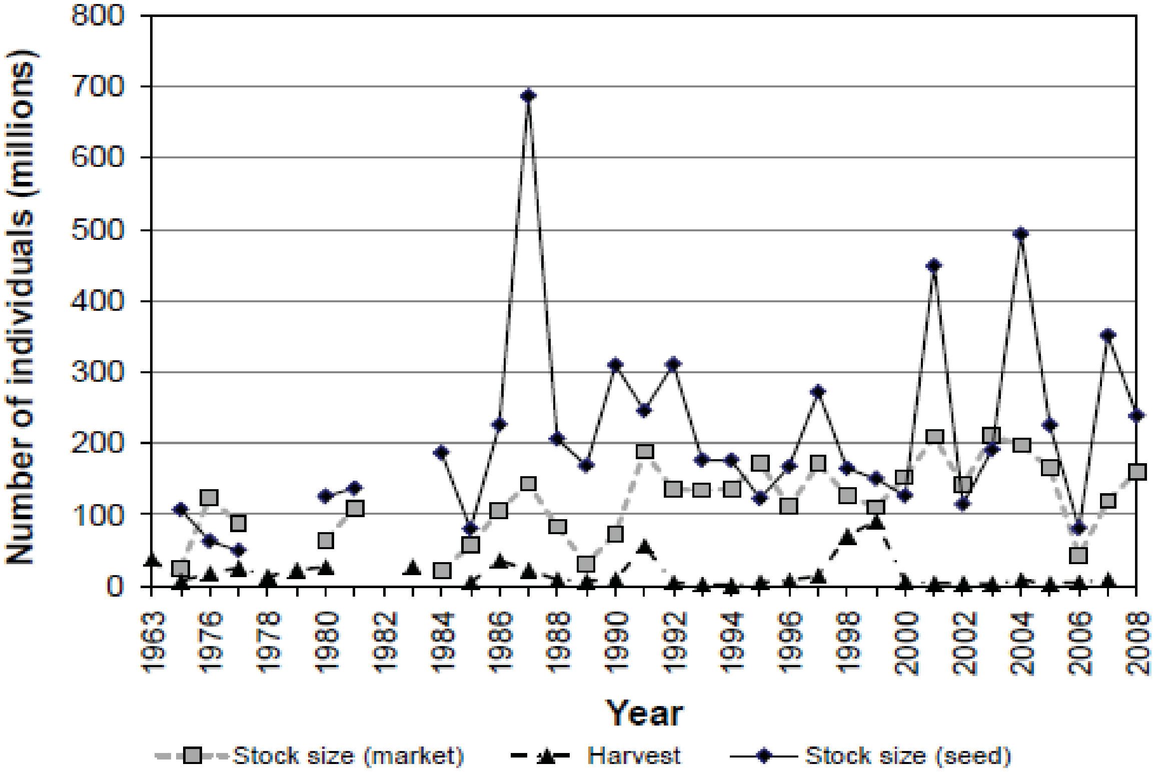


Figure 11.1 Time series (1963-2008) of harvest and stock size of market and seed oysters at Index Site A. Harvest is a tally for the entire harvest season based on mandatory reporting. Stock size is estimated once per year in June-July based on a trawl survey.

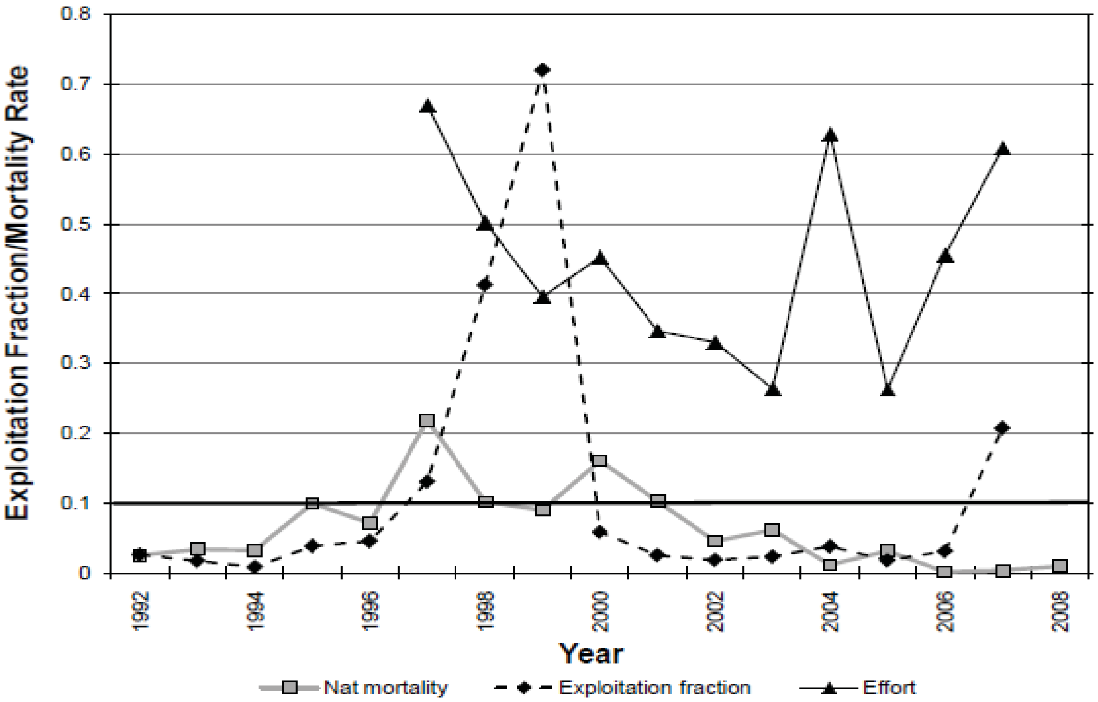


Figure 11.2 Timeseries (1992-2009) of exploitation fraction (μ), non-harvest mortality rate (M), and effort for Index Site A. A reference line at an exploitation/mortality rate of 0.1 is indicated with a solid black line.

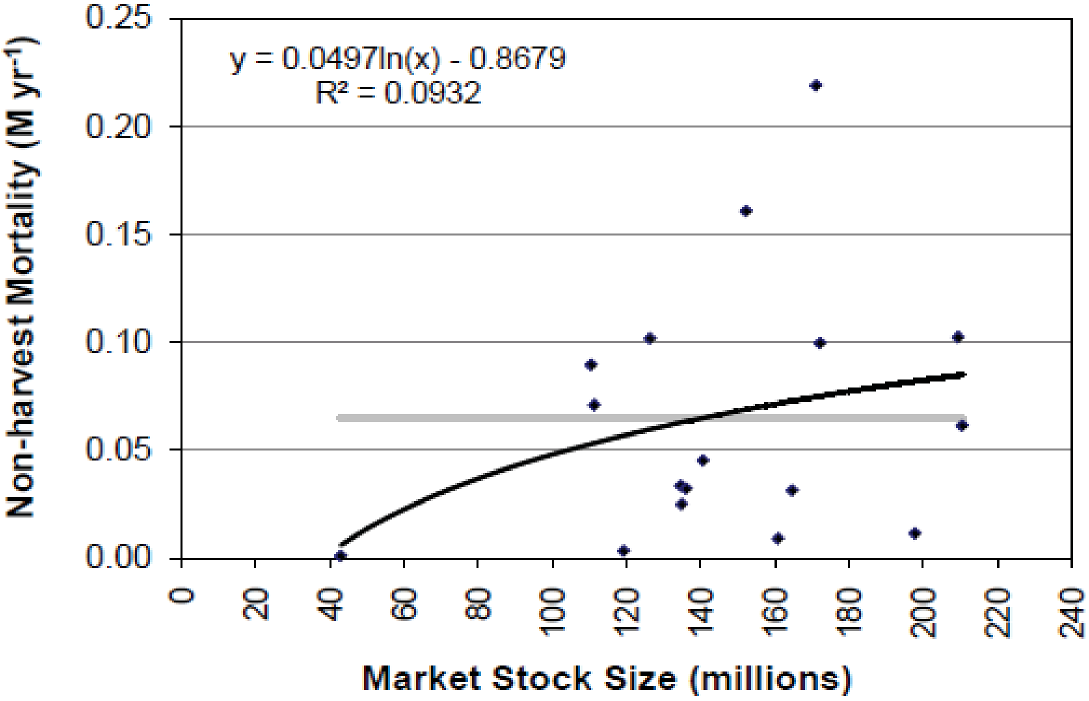


Figure 11.3 Scatter plot of stock size of market-sized oysters against annual instantaneous non-harvest mortality rate. The two trends used in CASP model simulations (log-linear-black line; constant M – gray line) are shown.

scale to exploitation rates (Figure 11.2). Natural mortality only exceeded 10% yr^{-1} in 1997, 1998, and 2000. One important aspect of the CASP model is to identify any trend between fishery harvest and natural mortality rates. There is little evidence for either a density-dependent trend in natural mortality or a trend in M with harvest effort (Figure 11.4). These data suggest an environmental influence on M but there are insufficient data to establish if this is the case.

Annual recruitment was estimated based on annual abundance of seed oysters (Figure 11.1). The seed oyster data were used because of the underestimation bias in the spat data already mentioned. The use of seed data to estimate annual recruitment condenses the calculation into a single value, rather than the approach used in the Delaware Bay model that included a density-dependent stock recruitment function combined with an independent post-settlement mortality term (Powell et al. 2009b). Combining these two together prevents a separation of variability in annual spat settlement and variability in post-settlement mortality. These two processes are impacted by different factors, in particular harvest effort and disease, and combining them for the Gulf of Mexico oyster stock minimizes our ability to distinguish specific influences. A stock recruitment function is needed to parameterize the CASP model. Two relationships were fit to the abundance of market sized oysters (stock) in year t and the abundance of seed oysters (recruits) in year t+1: a Ricker-type curve and a power curve (Figure 11.4). The power curve fit the data better but this is largely due to the lack of an observable trend. Both alternatives were evaluated in the CASP model.

The CASP model defines maximum allowable harvest (numbers) based on the preservation of constant population size and assumptions regarding population stability. Four scenarios were

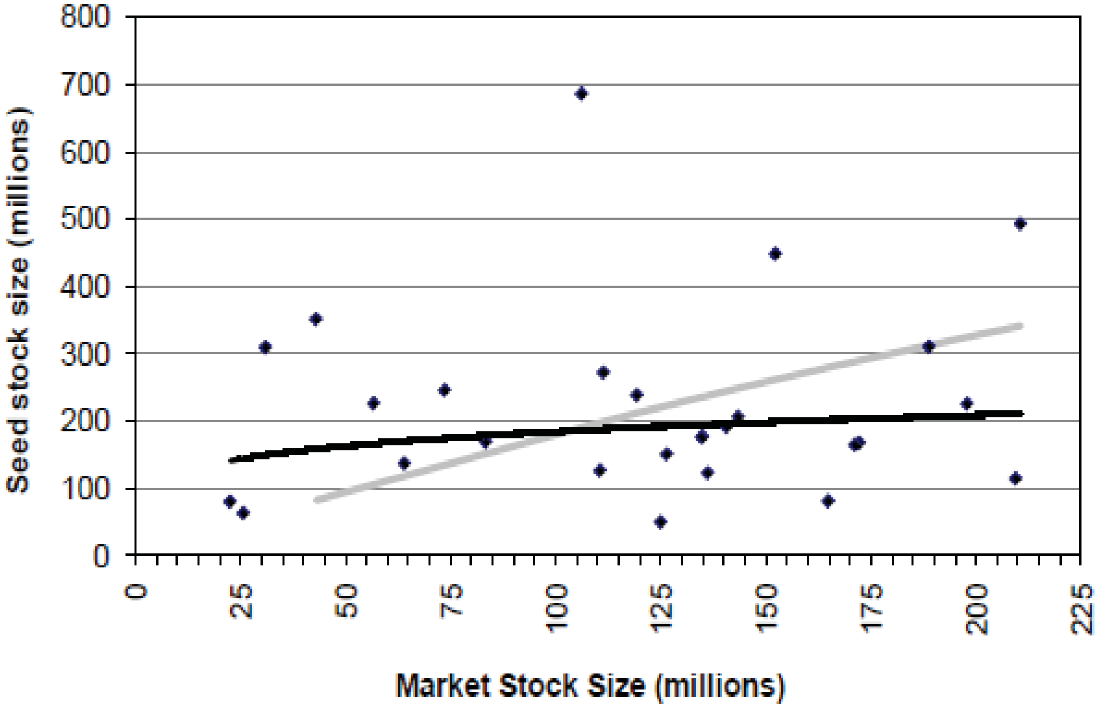


Figure 11.4 Scatter plot of stock size of market-sized oysters against stock size of seed oysters in the preceding year for data from 1963 to 2008. The two trends used in CASP model simulations (Ricker-black line; Power function-gray line) are shown.

Table 11.1 Summary of output of the Constant Abundance Surplus Production (CASP) model applied to Index Site A. Information for 'Recruitment' and "Mortality' gives the function type used to relate the variables to stock size. Data are given for population size (N, x10^8), estimated surplus production (SP, x10^8), and exploitation rate (μ). Lnlin indicates log-linear.

	Scenario	Recruitment	Mortality	N @ max SP	Max SP	μ(SP)	N(2008)	μ (2008)	μ(2008) @ SP
Seed M=0	1	Ricker	Lnlin	8	6.07	0.76	1.61	0.06	1.61
	2	Power	Lnlin	3	2.06	0.69	1.61	0.06	1.24
	3	Ricker	0.064	9	6.76	0.75	1.61	0.06	1.62
	4	Power	0.064	7.5	2.31	0.31	1.61	0.06	1.25
Seed M=10* market M	1	Ricker	Lnlin	2.38	1.3	0.55	1.61	0.06	0.76
	2	Power	Lnlin	0.4	1.58	3.96	1.61	0.06	0.57
	3	Ricker	0.064	3.18	2.23	0.7	1.61	0.06	0.82
	4	Power	0.064	2.68	1.05	0.39	1.61	0.06	0.63

examined for Site A using the CASP model. The first scenario involved a Ricker type surplus production term and a log-linear relationship between market-sized oyster mortality and stock size. The second scenario combined the Ricker curve with a constant value for market-sized M based on the mean of observed data (1992-2008). The third scenario applied a stock recruitment function based on a power relationship (Figure 11.5) combined with a log-linear relationship for mortality. The final scenario combined the power recruitment function with a constant value of market-sized M. Finally, each of the four scenarios was examined both without a mortality term for seed oysters equal to market M and with seed M =10 times market M in each year. The use of a Seed mortality rate equal to 10 times market M is based on estimates of seed mortality rates used in Powell et al. (2009a). In all scenarios, examined seed oysters in year (*t*) were assumed to reach market size by year *t*+1.

Surplus abundance (i.e., available for harvest each year) rose rapidly and peaked at a stock size close to $2\cdot10^8$ for scenario 2 or close to $8\cdot10^8$ for scenarios 1, 3, and 4 (Table 11.1). The maximum exploitation rate at these stock sizes was estimated to be 0.31 for scenario 4 and between 0.69 and 0.76 for the other three scenarios. The largest absolute amount of maximum surplus production ($6.76\cdot10^8$ oysters) occurred in scenario 3 that combined a Ricker stock recruitment function with a mean constant value for market sized M. In general, the use of the Ricker model resulted in the steepest relationship between stock size and surplus production at small stock sizes, while the use of a power relationship between recruitment and stock size was fairly flat. On the other end of the stock size spectrum, scenarios employing a log-linear mortality term drop more rapidly at higher stock sizes due to the increased influence of stock size on M.

Rerunning the CASP model scenarios with seed M set equal to 10 times market M resulted in a different general pattern in that scenarios employing a constant value of M (scenarios 3 and 4) resulted in the highest (Ricker) and the lowest (Power) surplus production values. The influence of M, and whether M increased with stock size, was more important in this second set of runs than calculations of recruitment. The model predicted a reduction in the estimate of maximum surplus production of between 23 and 79% (Table 11.1). At current estimates of stock size (2008), the exploitation fraction based on the four scenarios of surplus production range from 1.24-1.61 with

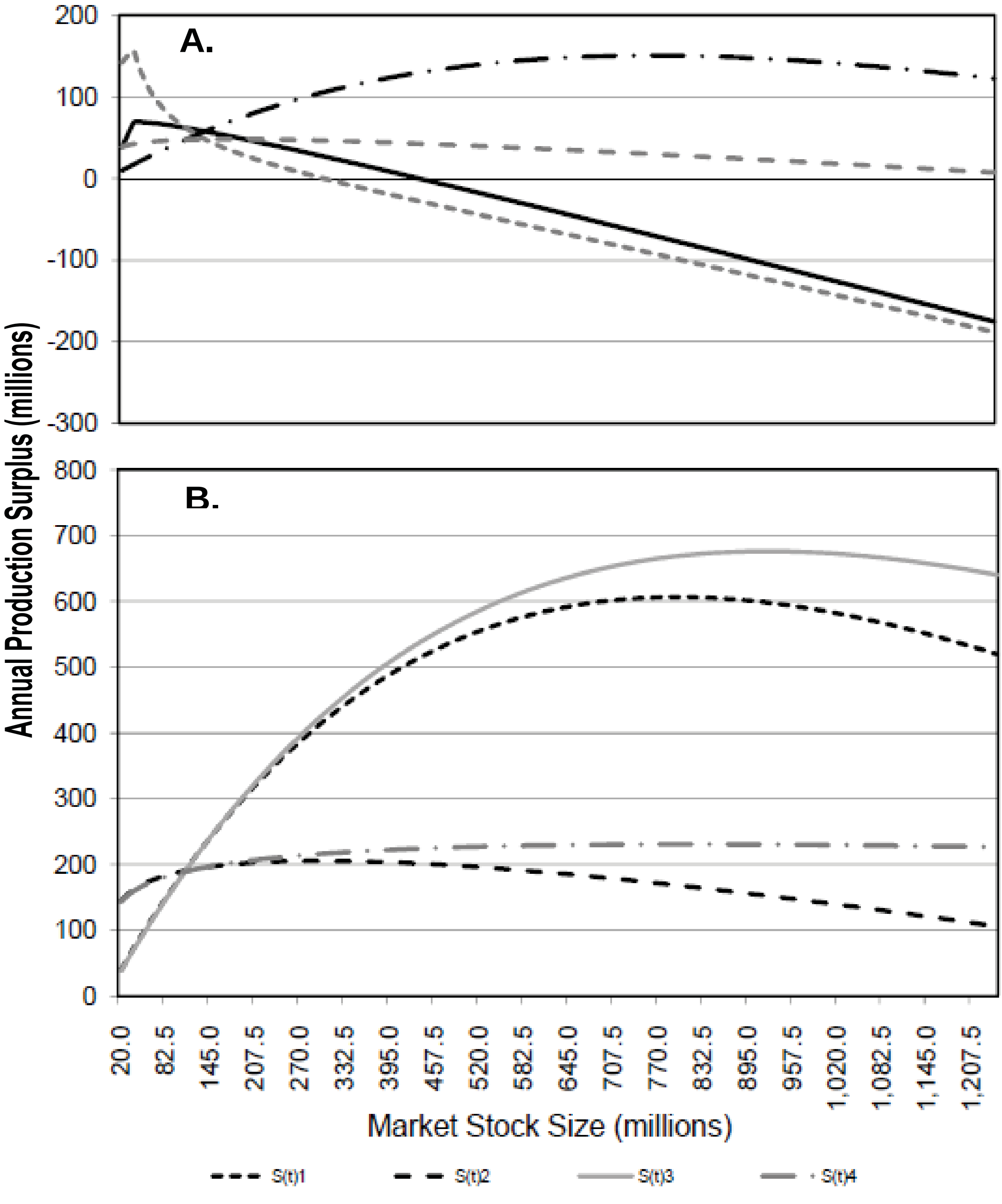


Figure 11.5 Trend in surplus production of market sized oysters as a function of Market stock size for Index Site A based on estimates from the CASP model. Four model-based scenarios are shown: S(1)-Ricker typed recruitment, log-linear M; S(2) – Ricker typed recruitment, constant M; S(3) – Power typed recruitment, log-linear M; S(4) – Power typed recruitment, constant M. See section 11.7.1 for details. Results are provided with A. Seed oyster mortality set to 10*Market mortality and B. with Seed oyster mortality set equal to Market non-harvest mortality.

no seed M and 0.57 to 0.82 with seed M set to 10 times market M (Table 11.1).

The most realistic model scenarios are those incorporating a seed M substantially higher than market M. The exact value for mortality rate of seed oysters is not known and would be an important value to estimate for the CASP model. The incorporation of seed M into the model calculations makes the trend in M with stock size the most important component of the model for estimating surplus production. Recruitment is less influential particularly at stock sizes in the observed range for Site A (Figure 11.1). The most stable scenarios were those with nearly constant rates of recruitment and natural mortality (scenario 3) or counter balancing stock size-recruitment and stock size-mortality relationships (scenario 1). Both box count data and recruitment data for Site A show minimal evidence for stock recruitment relationship in the observed range, which suggests that a variant of scenario 3 may be the most realistic for this system. Additional data are needed to verify this conclusion.

Current harvest at Site A is far below that suggested by the CASP model for any of the scenarios tested (Table 11.1). The exploitation rate was estimated to be 0.06 in 2008 and has exceeded 0.1 in only one year since 2000. In contrast, the CASP model provided an estimate of surplus production ranging from 0.57-1.62 at 2008 stock levels. An exploitation rate exceeding one is inherently dangerous to population stability, as it incorporates the harvest of oysters recruiting to the management unit and reaching market size within one year and does not account for effects of harvest on pre-recruit mortality. Nonetheless, all of the estimates of maximum exploitation rate are much larger than current harvest rate.

Site A was chosen as the primary index site for this analysis because of the large amount of data available. There is a relatively long time series (1975-2008) of annual abundance available that includes estimates for annual harvest, as well as abundance of both market and seed oysters. Box count and spat count data have been collected since 1992. The abundance data are collected each year in June and July, and the harvest data are collected from oyster buyers throughout the season. This time series of both fishery-dependent and fishery independent data forms the core dataset for use of surplus production models.

There are also some important gaps in the available data for Site A that need to be filled to properly apply the CASP model. The spat data appear to be an underestimate as spat counts are consistently lower than seed counts for the preceding year. This makes it hard to use these data to form a stock recruitment relationship or estimate spat to seed mortality rates. In addition, the abundance data are based on dredge surveys and dredge efficiency changes both between life stages of oysters and through time (Powell et al. 2007). Estimates of dredge efficiency need to be made to improve the data and the resultant model outputs. In addition, the use of box count data to estimate the natural mortality rate is based on assumptions regarding the disarticulation rate of boxes, which have yet to be verified for Gulf of Mexico oysters. A study of box disarticulation rates for both market and seed oysters would greatly improve the available data for estimating mortality rates. Finally, recruitment of oysters in most Gulf of Mexico populations is thought to be very high and non-limiting to population stability. However, the influence of harvest on available settlement habitat has been found to be important in Atlantic populations (Powell et al. 2009b) and it may be important to estimate the effects of harvest rate on spat settlement success with a shell budget model in order to account for changes associated with fishery regulations.

11.6.2 Site B Assessment

Site B is a marine dominated embayment in the north-central Gulf of Mexico that contains approximately 4,300 ha of oyster reef. Oyster harvest has occurred at Site B continuously since the 1880s and monitoring data is available back to 1990. Surveys have consisted of transect counts of oysters per square meter along with estimates of individual oyster size. Unlike Site A, the survey is not conducted uniformly across the site and survey data are available for different individual reefs in different years. Thus the survey is more like an index of abundance through time rather than an annual census as at Site A. In addition, several restoration projects have been conducted on specific reef sites within Site B and these were associated with more intense post-restoration sampling at these sites. Because the data are collected using quadrats rather than dredges (in contrast to Site A), the data are an unbiased estimate of abundance for individual reefs and do not require additional data on gear efficiency by size.

The CASP model applied to Site A requires a consistent time series of both landings and oyster abundance, which is not available for Site B. Trends in oyster abundance are available but the length of the time series varies greatly by reef. In addition, no time series exists for mortality rates or recruitment rates as spat count and box count data are not collected as a part of the survey. This means that the CASP model cannot be applied to this Site to estimate sustainable harvest rates.

The data available for Site B are better suited to the SOS model (Section 11.4.3) in that survey data can be used to parameterize mortality and growth functions that can be used to assess sustainable harvest on a reef-specific basis. This model requires harvest by size and total biomass by size for the site which is estimable on some reefs from the existing survey. Constant mortality and growth rates for this system can be estimated from the data as well based on the more intense survey work associated with restoration. In fact, restoration projects for reef bottom impacted by storm events or other disturbance events is a useful tool for estimating oyster growth rates for a particular system. It is less clear whether a shell budget can be established within Site B as data are needed on shell disarticulation and dissolution rates. If these data are available then simple shell density estimates collected along with the survey of the oyster population would provide the necessary input for a simple shell budget model. Application of the SOS model to this system was not completed due to time constraints and the availability of the model itself, but this is the recommended approach for systems such as Site B where survey data are high quality, but sample coverage and frequency are intermittent. In such cases, data on shell loss, oyster growth, and oyster mortality can be estimated independently and then applied on an annual basis in the SOS model to those sub-areas with an annual survey.

11.7 Data Needs for Population Models

Assessment models vary widely in their basic data requirements, as well as types of output they provide. In general, the more detailed the input data, the more detailed the output and the subsequent management advice. Three broad approaches to assessment modeling have been presented (Table 11.2) and the recommendation for any given management unit will be based on what data are available. Nonetheless, the management objectives of the unit must be considered in structuring future data-gathering activities. For instance, the need for an unbiased estimate of non-harvest mortality is ubiquitous and the dependence of such an estimate on box counts requires an estimate of size-specific disarticulation rates in order to properly convert box counts to annual mortality. There are also inherent qualities in assessment of bivalve fisheries. For instance, the ability to accurately age bivalves is limited, so cohort-specific assessment models, such as ASAP, will not be as effective. In contrast, the sessile nature of bivalves means that an unbiased estimate of abundance is simply a matter of time and effort. This is highly advantageous in that any estimate of harvest mortality can immediately be converted to an estimate of exploitation fraction and/or optimal yield. Appropriate decision-making regarding oyster assessment will be based on existing data, but have an eye towards what can be done to realistically meet management objectives for the stock. To that end, we have summarized data needs and output in Table 11.2.

Table 11.2 Summary of data needs for three assessment model types. Examples in parentheses refer to examples of each model type discussed in Section 11.3.

Model type	Data requirements	Model output
Age-structured model (ASAP)	Survey index time series by cohort Harvest time series by cohort Estimates of market M Estimates of Seed M Estimates of Spat M	Estimates of annual exploitation fraction Estimates of maximum sustainable yield Projections possible based on management options Estimate of current fishery status
Abundance-based surplus production model (CASP)	Abundance time series Harvest time series Time series of market M Time series of Seed M Time series of Spat M	Estimates of surplus production (SP) by stock size SP can be converted to recommended exploitation fraction as a function of stock size Estimate of current fishery status by proxy (F)
Sustainable Oyster Shellstock model (SOS; Soniat et al.)	Annual abundance estimate (pre-harvest) Estimates of market M Estimates of Seed M Estimates of Spat M Estimate of individual growth parameters Wt-shell ht relationship Volume to shell ht relationship Shell dissolution rate (shell budget) Box disarticulation rate (shell budget)	Annual harvest rate associated with a biomass-neutral OR shell density neutral management target. Assessment repeated each year based on new survey of abundance.

12.0 MANAGEMENT ISSUES, MEASURES, CONSIDERATIONS, AND RECOMMENDATIONS

12.1 Management Unit

The management unit is comprised of oyster populations on the natural and artificially propagated oyster habitat (reefs) occurring in the coastal waters of the Gulf of Mexico, including Florida, Alabama, Mississippi, Louisiana, and Texas. The management unit can be subdivided into oyster habitat in individual states, estuarine systems, shellfish harvesting areas, and reef complexes.

12.2 Management Goal

The goal of this plan is to provide management strategies that ensure the maintenance and health of oyster stocks and oyster habitat, and ensure the sustainability of the fishery. An additional management goal is the maintenance of ecosystem services provided by healthy oyster reef within the management unit. Ecosystem management must include oysters as habitat, a biological resource, a fishery resource, and an essential part of the environmental process.

12.3 Management Objectives

The objectives of the oyster fishery management plan are:

- Determine the status of oyster resources using comprehensive assessment techniques: resource data can be used to predict production trends, develop economic indices, establish harvest benchmarks for sustainability, regulate harvesting, and direct management practices.

- Ameliorate and reverse oyster habitat losses caused by human alterations and natural erosion, including but not limited to: (1) changes to salinity and water flow on reefs, (2) destruction of reefs, (3) removal and fouling of cultch, and (4) pollution of shellfish growing areas.

- Develop easily understandable regulatory and management strategies for oyster populations within the management unit that provide for optimum benefits from the resource while: (1) managing for harvest efficiency, (2) encouraging compatibility and standardization, (3) facilitating enforcement, (4) supporting management strategies with the highest benefit/cost relationship, and (5) reducing management conflicts.

- Recognize that oysters are a keystone species in healthy estuarine systems and incorporate oysters as habitat, a biological resource, and a fishery resource in any ecosystem management.

- Maintain public health standards for the harvest and handling of oysters to ensure that consumers receive a safe and wholesome product.

- Implement research and development programs to increase production, increase utilization, and expand the overall oyster knowledge base.

- Develop collaborative efforts to involve all the stakeholder agencies and entities that directly or indirectly affect oyster resources in the estuarine and marine environment.

- Establish communication links between the various groups to develop interagency or interstate management protocols and activities involving freshwater discharges and diversions that alter downstream water quantity, quality, and periodicity.

- Develop outreach programs and materials to educate the public and other stakeholders on the issues related to oyster resource management including seafood safety, fishery stewardship, marketing, ecosystem services, and general management activities.

12.4 Specific Management Measures to Attain Management Objectives

The following is a discussion of management measures and strategies that may potentially resolve specific management challenges and achieve management goals. This section includes various management strategies that can be applied within a state's jurisdiction, depending on numerous variables, conditions, and constraints.

12.4.1 Resource Monitoring and Assessment

Monitoring oyster resources (population parameters, reef conditions, landings) is a desirable management strategy to determine ongoing status of the oyster stock(s). Knowledge of oyster size frequency distributions, abundance, cultch availability, yields, catch per unit of effort, reef locations, area of reefs, and other factors are important elements in managing oyster resources. Resource data may also be used to regulate harvesting, direct cultch planting activities and restoration projects, predict production trends, and develop economic indices. Resource monitoring strategies include collecting data which is representative of the resource and data that is representative of the fishery. In addition, the calculation of an annual shell budget on harvested reefs would be critical to the implementation of a 'shell-neutral' management strategy as discussed in Section 11.2.

Fishery-independent monitoring involves sampling oyster populations present on oyster reefs or reef areas based on applied scientific and statistical protocol. Fishery independent monitoring is standardized and replicated over relevant spatial and temporal scales and therefore gives a better picture of the source population, unbiased by size-selective harvest. This may involve sampling larvae, juveniles and/or adults to develop data to estimate (predict) production parameters, such as setting potential, recruitment, growth and survival, natural mortality, and standing stocks and yields.

Sampling larval abundance and distribution can be very important to determining the optimal times and locations for cultch planting and reef habitat restoration. Sampling juveniles and adults provides data for predicting future harvest, based on assessing numbers of 'spat,' 'seed,' and 'market' oysters, assessing the condition of reefs, and forecasting production trends. Additionally, monitoring data may be used to manage harvesting and prevent overharvesting. Harvesting areas and/or individual reefs can be opened or closed, based on indices developed from the data that show when populations are sufficient to support commercial and recreational harvests or become too depleted to support harvesting.

Fishery-independent monitoring provides an essential component in making science-based management decisions, and analyses and results should be critical elements in all adaptive management strategies.

Fishery-dependent monitoring involves collecting and analyzing harvest and landings data. Fishery-dependent monitoring is intended to sample both the resource and the fishery and will generate a much larger sample than fishery-independent monitoring at a much lower cost. Landings data are often used by fisheries managers to monitor oyster productivity and assess the impacts of fishing regulations. This type of data can be collected for individual reefs, specific harvesting areas, or statewide. Monitoring strategies are effective in determining potential landings and revenues, analyzing trends in catch and effort, and evaluating management practices. Monitoring data can include size structure and biomass of landings, the number of fishermen, the amount of effective fishing effort, fishing locations, and other parameters that represent actual fisheries activities.

Long-term, fishery-dependent monitoring provides an essential component in making science-based management decisions, and analyses and results are critical elements in all adaptive management strategies. Dependent monitoring reports generally have a longer and more consistent history than other independent monitoring reports; however, there are some considerations when utilizing this type of data. The skill of each individual fisherman will affect CPUE, different reporting requirements among states can affect the amount of non-reporting and thus affect the estimates of relative abundance based on reported landings (Green and Thompson 1981), deficiencies in reporting requirements and enforcement may affect the utility of commercial landings.

Management Considerations

- Independent sampling protocols may not be consistent among states: as resource managers employ different sampling protocols to measure various population metrics; sampling protocols can be affected by using various types of sampling gear (dredges, grabs, quadrats, SCUBA) at various times (before and after fishing seasons, spawning peaks). Resource managers may apply sampling protocols that have been used over an extended period, and changing protocols may be challenging in many respects, including consistency among data collection and reporting, program funding levels, staff time and experience, and other factors.

- Because the size, shape, and productivity of oyster reefs can be highly variable, sampling protocol may not always be adequate to identify the levels of variability. For example, the locations of sampling stations, the number of samples collected, and the size of the samples collected may not be representative of the entire reef complex, and may result in statistically invalid conclusions. For data to be useful and representative for an oyster population or reef, data collection and analyses must be conducted over a long term; ideally, the data should represent at least 5-10 times the generation time of the resource. For example, a minimum time series of ten years would be optimal for surplus production modeling.

- Collecting data can be burdensome and expensive and will generally require a regulatory mandate (statutory reporting requirement). However, the relative cost of collecting fishery-dependent data may be less than independent data collection, once a mechanism for collecting the data is established (trip tickets and electronic reporting). Fishery-independent data collection, requiring on-site surveys, may be more expensive when fishery stocks are spread over wide areas.

- Landings data (fishery-dependent) alone may not provide an accurate assessment of resource abundance or status, since reporting by fishery participants is often incomplete and inaccurate, and the fishery targets a subset of the total population as a function of size and location of harvest. Additionally, without effort data, landings alone have little value in terms of understanding changes in the stock.

- Fishery-dependent data may be skewed by associated influences, such as prevailing market prices, fuel costs, seasonal closures, duration of seasons, environmental factors, and regulatory changes.

Management Recommendations

1. Resource managers should develop and evaluate fishery and resource monitoring programs to access the biological condition of oyster resources, population dynamics, fishing pressure, and other parameters required to optimize benefits from the fishery, while protecting and sustaining the resource. Resource managers should construct assessment models to include: 1) estimated reproductive potential; 2) spat fall (abundance and seasonality); 3) growth and survival rates for all life stages; 4) estimated natural mortality (determine the disarticulation rates of boxes under various conditions, locations, and harvesting pressures); 5) the effects of harvesting on mortality rates; and 6) other metrics which will provide more accurate assessments of population dynamics.
2. States should collaborate in the development of standardized scientifically and statistically defensible methods to accurately assess oyster populations and reef habitat. Additionally, states should work cooperatively toward converting existing information into a data inventory that can be used system- and Gulf-wide.
3. Resource managers should evaluate their current fishery-independent sampling protocols to determine if they provide valid and accurate data to assess the abundance and condition of oyster stocks. The assessment models provided in Section 11.2 should be used to evaluate existing, and establish future, sampling protocols. Sampling protocols should be calibrated to identify potential changes that a new sampling method might produce and the data should be compared between methods to determine possible deviations prior to adding or replacing current fishery-independent sampling protocols
4. Resource managers should delineate all reef areas (harvested and non-harvested) so that population models can be used to accurately estimate standing stocks, and to predict the effects of catastrophic mortality events, success of restoration projects, and fishery trends.
5. States should revisit the NMFS conversions and provide accurate conversions to standardize production and product units. NMFS historically reports oyster shucking activities in gallons and converts to pounds of meats using a conversion ratio of 8.75 lbs of meats to a gallon which was estimated based on the weight of a gallon of water, not actual oyster meats. A better estimate of shucked meat weights needs to be developed, validated, and used by NMFS (see Section 9.5.1).
6. States use various measurements for ‘standard’ sacks of oysters. The NMFS should begin to utilize the sack conversions provided by the states in this FMP to reduce confusion when comparing production and landings data across states (see Table 8.3).

12.4.2 Protecting Oyster Habitat

Loss of oyster reef habitat (human-caused or natural) is perhaps the most serious and chronic problem facing the Gulf coast oyster fishery and oyster resource management (see Section 5.0). Over decades, oyster reefs have been lost or damaged through shell removal (fishing, mining, dredging), sedimentation (coastal development, navigation, fresh water diversion), and contamination (pollution, manufacturing), especially when adequate safeguards to protect oyster habitat have been lacking. The most destructive activities have occurred in regions of intense coastal development. Numerous laws have been passed to minimize or prevent the destruction of estuarine habitat, and oyster resource managers must now incorporate a broad suite of environmental regulations into regional approaches to ecosystem management.

12.4.2.1 Sustaining and Protecting Freshwater Sources

The importance of freshwater to oyster setting, growth, and survival is well-known (see Sections 4.5.2.3 and 5.2.2.4). Maintaining optimal salinity regimes and water quality is equally important to oyster survival, growth, and production, and are inextricably linked to high quality freshwater sources. Growing reliance on freshwater diversion projects to control flooding, create reservoirs, enhance development opportunities, and ensure drinking and irrigation water supplies threatens the ecological stability of estuarine systems that depend upon short-term and long-term variations in river stages and flow rates. This is especially problematic for managers in estuaries that receive fresh water from a single drainage basin.

Typically, short-term changes in river stages, volumes, and flow rates are part of the ecology of coastal estuaries, and estuarine organisms can cope or even thrive under the changing conditions. However, when freshwater input is disrupted for prolonged periods, serious adverse impacts to estuarine ecology may result.

12.4.2.2 Water Management Projects

Water control projects that disrupt the flow of fresh water for prolonged periods may result in serious adverse impacts to oyster ecology. Some major freshwater control projects are underway in the Gulf States, and others are planned (see Sections 4.6.3 and 5.2.2.4.2). For example, the states of Alabama, Florida, and Georgia are currently involved in negotiations and litigation over activities which affect the amount of fresh water reaching Apalachicola Bay from the Apalachicola, Choctawhatchee, and Flint Rivers. Interstate agreements which affect water usage in large river drainage basins should consider the positive and adverse effects of water use practices on estuarine ecology.

Management Considerations

- Properly planned and implemented freshwater control projects may have long-term positive ecological and economic impacts.
- Water management for alternative objectives can be contrary to biological management objectives in estuarine systems.
- Freshwater diversion may biologically change both the area from which water is diverted and the area receiving diverted fresh water. Production of some species (e.g., oysters) may be enhanced at the expense of other species (e.g., shrimp). Thus, biological, social and economic value disputes are possible, while the cumulative environmental impacts and benefits are difficult to determine.
- Depending on the freshwater source and the drainage basin, diversion projects may decrease water quality and increase sedimentation in a given oyster growing area. Any increased production, in such a case, may be negated if harvesting is restricted as a result of increased contamination. Also, increased sedimentation or erosion may result in the loss of productive oyster habitat.
- Diversion projects and reservoirs can impact the nature of high flow events and result in declines in important nutrient and sediment loads.
- Water management can simulate natural water cycle events in drainage basins and improve conditions for various life stages of oysters and other estuarine organisms. For example, manipulating river stages and flow rates may be beneficial in managing Dermo disease, marine predators, and summer stress disease in oysters.

Management Recommendations

1. Water allocations should be considered in any water projects which affect levels and flows in rivers and downstream biological communities. Water policies should be directed toward providing water flows that mimic the frequency, duration, magnitude, and seasonal periodicity of historic inflows and contribute to a sound ecological environment.
2. Resource managers should review and evaluate all available information relating to freshwater control projects, water use policies and practices before implementation. Such review includes an assessment of the biological, hydrological, ecological, geomorphological, social, and economic impacts that are likely to result from a project or practice in order to provide accurate projections of a project's impacts on oyster resources. The project design, objectives, and implementation should include collaborative links with all stakeholders.
3. States should assess the condition of reefs that have been affected by altered freshwater discharge. Adverse impacts to reef habitat and oyster populations should be monitored to determine the source of the problem. Efforts should be initiated to correct the problem and improve hydrologic conditions (salinity regimes, flow rates, circulation pattern) by managing freshwater inflows when practical.
4. Surface water diversion is the most logical choice for restoring flows. However, and where applicable, states should consider groundwater sources, particularly shallow, quick-recharge aquifers should also be evaluated, as a source for restoring inflows to estuaries.
5. Strategies for restoring freshwater inflows should include conservation, reuse, or the dedication of flows for the environment through the retirement of water rights or use of water trusts where appropriate.

12.4.2.3 Planning Coastal Development

The expansion of development to accommodate an ever-increasing population that desires to live and work on the coast has created problems for all levels of public administration and resource management. Adverse impacts to oyster reefs and oyster reef ecology may result from coastal development, including: loss of reef structure due to dredging and construction (channelization, bridges, causeways); shoreline erosion and stabilization (bulkheads, sea walls, docks and piers), oil and natural gas exploration and utilization; and point and non-point pollution sources. Additionally other alterations that result in substantial changes in hydrology, circulation patterns, currents, tidal impacts, sedimentation, and topography, adversely affect oyster reefs. A detailed discussion of these issues and challenges is presented in Section 5.2.2.3.

Management Considerations

- In many instances, fisheries resource managers have little influence on the processes that shape coastal development, but it remains important that fisheries resource issues are included in regional and local comprehensive planning.

Management Recommendations

1. Coastal permitting and management agencies should develop collaborative efforts to involve all stakeholders who, through their actions, could directly or indirectly impact

oyster resources in the estuarine and marine environment. The fisheries management agencies should review and evaluate available information relating to coastal development projects in order to provide accurate projections of a project's impacts on oyster resources and make recommendations to avoid or minimize those impacts.

12.4.2.4 Preventing Destruction of Oyster Habitat and Reefs

Oyster reefs should be viewed as necessary and vital components of the estuarine community along the Gulf of Mexico. As acknowledged throughout this plan, oysters are a keystone species in most Gulf estuaries which provide ecological services to these ecosystems (see Section 4.7.2 and 9.6). Direct and indirect destruction of oyster reefs has resulted from numerous activities, including dredging projects for navigation, bridge construction to meet growing transportation demands, oil and mineral exploration, easements for pipelines and power lines, water control projects, sedimentation, urban and coastal development, and other activities that disturb or remove oyster reef habitat.

Management Considerations

- Despite its importance to Gulf estuaries, oyster habitat conservation and protection has not received notable attention as it relates to ecosystem management. Recognizing the importance of oyster habitat, similarly to sea grasses, marshes, mangroves, and coral reefs, may result in greater protection and management. It is necessary that resource managers inform all stakeholders, including the general public, that protecting and restoring oyster reef habitat not only supports an important fishery, but that oyster reefs are also essential for providing a suite of ecological services which sustains entire ecosystems and a full array of valued uses.

- Replacing lost habitat is difficult and expensive, and funding to restore lost habitat is a fiscal constraint for resource management. For example, state and federal funding to support in-water restoration of the native oyster population and recovery of the fishery in the Chesapeake Bay totaled approximately $58 million from 1994 through 2006 (USACE 2009). Clearly, the most cost-effective management objectives should be to prevent the loss of existing oyster habitat, and to restore depleted or damaged habitat before the loss becomes a more serious ecological problem.

Management Recommendations

1. Resource managers should determine the rate of oyster habitat loss and recognize the consequences of losing it.

2. Resource managers should identify oyster resources and make recommendations to protect and conserve oyster habitat. Management plans should identify the value of all oyster resources, not just those that are managed for commercial fisheries.

3. Activities not directly associated with the oyster fishery should be evaluated to determine whether they contribute to the destruction of reef habitat, alter reef structural integrity, or remove shell and substrate. In cases where activities damage oyster reef structure or substrate, mitigation should require refurbishing impaired oyster reef habitat.

12.4.2.5 Preventing Shell Removal

The excessive removal of substrate, cultch, or shell from reefs affects the structure, functionality, and long-term viability of living oyster reefs (see Section 5.2.2.2.2).

Management Considerations

- A core component of a shell-neutral management strategy (see Section 11.2) is the development of a shell budget for the management unit.

Management Recommendations

1. States should enforce regulations that protect oyster reef habitat and prevent the direct or incidental loss of substrate and shell from public reefs.
2. Oyster reef habitat should be evaluated and monitored to determine a shell budget with a strategy of no net loss.
3. All harvesting activities should be evaluated to determine whether they contribute to the destruction of oyster reef habitat or alter reef structural integrity. In cases where activities damage oyster reef structure or substrate, mitigation should require refurbishing impaired oyster reef habitat.

12.4.3 Regulatory Measures to Manage and Sustain Oyster Resources

There are a number of harvest oriented regulatory measures which can be taken to manage oyster resources and sustain habitat. These include: size restrictions, gear requirements, harvesting seasons and areas, limited access, quotas and bag limits, licenses, user fees, and taxes. Harvesting can be controlled and is generally not as devastating as damage resulting from extreme environmental and climatic fluctuations (Section 5.0). Successful management strategies and effective regulations can provide safeguards against both short- and long-term depletions, as well as, habitat loss resulting from harvest.

12.4.3.1 Size Restrictions

Currently, the market size limit of three inches is accepted by all of the Gulf states for oysters harvested from public reefs (Section 8.2.3). Applying size restrictions to harvested oysters is a practicable management and enforcement measure to control harvests, and provide a desirable market-size product. A standard size facilitates intrastate and interstate law enforcement, and is expected to provide a more uniform and consistent product in the marketplace. Regulating harvest size also contributes to the conservation and sustainability of public reefs by controlling direct harvesting toward larger oysters while restricting the harvest of small rapidly growing oysters.

Management Considerations

- Size limits may be inconsistent with management objectives to maximize landings and economic returns. There are valid economic arguments for eliminating size regulations, but few sectors of the industry and resource managers agree that de-regulation is a practicable option.
- Enforcing a size limit contributes to the conservation and sustainability of public oyster reefs by controlling harvesting practices.
- Size exemptions may lead to disparity in oyster size limits between leases and public grounds and present an enforcement challenge.
- Size exemptions for oysters grown on private leases or by certified aquaculture producers would allow leaseholders to take advantage of market opportunities.

- Size exemptions may provide an incentive for fishermen to harvest undersized oysters from public reefs to meet market demands.

- Co-mingling aquaculture products with wild fishery products can be problematic for tracking as well as for the consumers.

- Enforcing multiple size limits requires additional management costs.

- Enforcing any size limit requires substantial cost.

Management Recommendations

1. From a law enforcement perspective, states should maintain a uniform Gulf-wide size limit (via cooperative or reciprocal agreements) for oysters harvested from public reefs to facilitate enforcement of size regulations, provide a consistent market standard, and reduce the regulatory conflicts for fishermen when reef areas and/or harvested product cross state lines.

2. States should establish uniform tolerances for undersize and unculled oysters.

3. States should evaluate emergency closure options when harvesting indicates an overabundance of undersized oysters on the reefs if there is no change to the current size limits.

4. States should evaluate the existing three-inch size limit and determine if a reduced minimum size would accomplish management objectives and still provide a marketable product or new markets for Gulf oysters.

12.4.3.2 Bag Limits (Quotas)

Establishing daily or seasonal bag limits is an effective measure for controlling harvesting levels, and bag limits are generally applied to reduce the threat of overharvesting. Bag limits can be applied statewide, to an individual harvesting area, or to a specific reef to facilitate resource management. Bag limits and/or quotas may be applied to enhance recovery efforts following resource depletions, to extend harvest seasons, or to spread potential landings and revenues over a longer period.

Management Considerations

- Conflicts regarding actual limits may develop when the data used for establishing such limits are inadequate or not well understood. Often bag limits are based on economic criteria and social acceptance, rather than on biological parameters and accurate assessment of standing stocks.

- Applying bag limits may affect harvesting efficiency and effort, and the resource may not be fully utilized.

- Adaptive management strategies may be used to take advantage of short-term oyster abundance and availability to optimize landings and values based on oyster population dynamics.

Management Recommendations

1. Evaluate the effectiveness of quotas to constrain total harvest and bag limits to constrain daily harvest to determine benefits to the fishery, resources, and economy.

12.4.3.3 Harvesting Gear

Requiring or restricting specific harvesting equipment is a practicable measure to control harvesting and manage habitat. Misuse of specific fishing gear, primarily bottom dredges, has been reported to alter the physical structure of oyster reefs and remove essential shell material (Beck et al. 2009). However, proper management of fishing gear and techniques provides fisheries managers with opportunities to increase harvesting effectiveness, landings, and values, while protecting oyster reef habitat. Restricting gear in response to specific conditions can prevent excessive damage to reef habitat from aggressive fishing practices (see Section 5.2.2.2.1).

Management Considerations

- In some instances, gear restrictions may act as an exclusionary practice. For example, oystermen without the wherewithal to own and operate the most effective fishing gear may be at an economic disadvantage and may have to leave the fishery.
- Gear restrictions may be inconsistent with efforts to maximize harvesting efficiency, landings, and economic returns.
- Gear restrictions offer a practical alternative for managing oyster resources and oyster reef habitat, and may be beneficial during oyster restoration projects to enhance recovery.
- The use of specific fishing gear may be established based on socio-economic issues or fisheries-driven preferences and to reduce gear conflict (e.g., tonging only on public reefs).
- Reef construction practices may differ when harvesting will be performed with a dredge or with hand tongs. Oyster managers in Louisiana have a long history of managing reefs for dredging; seed grounds are continually renewed to provide seed stocks for private leaseholders. Alabama is currently building a reef where dredging will be allowed.

Management Recommendations

1. Develop gear requirements to prevent excessive damage to reefs.
2. Develop uniform gear requirements to facilitate law enforcement and reduce regulatory conflicts when the gear may be used in more than one state or when fishing grounds cross state boundaries.
3. Consider adaptive gear management strategies to engineer and/or recover reefs for maximum economic value while balancing with ecological value.
4. Develop and build specific reefs for dredging (low profile) to establish and maintain public oyster reefs for harvests using specific gears.

12.4.3.4 Harvesting Seasons and Harvesting Areas

Harvesting seasons and harvesting areas represent effective control measures for managing public oyster reefs. Opening and closing growing areas based on calendar dates, production parameters, and/or public health protection act to control harvesting in specific shellfish areas. For example, closures may be used to prevent harvesting from a given reef when population data indicate declines in availability of market-sized oysters, contamination, or other problems.

Closures may also be used to restrict harvest from areas where restoration activities are underway, for refuges or specially managed areas, and for adaptive management strategies.

Shellfish harvesting areas may be closed to harvesting to increase spawning and setting success, by protecting spawning stocks, fragile spat, and vulnerable juveniles. Closures may also be based on environmental conditions. For example, during the warmer summer months, high water temperatures can adversely affect oyster condition and oyster populations. Closures during periods of environmental stress (summer stress syndrome) may significantly reduce total mortality (exacerbated by harvesting stress) because highest natural mortality can occur during these times. Oyster quality and marketability may also be enhanced by closing areas during the warmer months, since the overall condition and appearance of oyster meats are improved during cooler months.

Management Considerations

- Opening or closing shellfish harvesting areas, based on seasons or other management criteria, provides a practical method to control harvesting in specific areas. Unfortunately, there are a number of management criteria that affect fisheries management, making it impractical to standardize harvesting seasons and/or harvesting area closures on an interstate or intrastate basis.
- Short-term closing of areas to harvesting will affect landings and values in the fishery and may have an adverse economic impact in local areas.
- Adaptive management strategies may act to reduce landings and values in the fishery, since closures may reduce localized harvesting effort. Also, stocks that could have been harvested if areas were opened may be lost during some subsequent event, such as hurricanes, floods, and natural mortality. Long-term closing of areas to harvesting reduces landings but may drive values in the fishery up if demand remains high and supply is limited. Adaptive management strategies may be used to take advantage of short- and long-term oyster abundance and availability to optimize landings and values based on oyster population dynamics and the condition of reef habitat.
- Increasing the number of harvesting seasons and/or harvesting areas necessitates increased management and enforcement if one wishes to achieve the stated purpose of the seasonal closures/harvesting areas.
- Close proximity of designated closed and opened harvest areas make enforcement difficult.
- Harvesting seasons and harvesting areas provide a practical alternative for managing oyster resources and oyster reef habitat, and reduce public health risk.
- Specific high productivity reefs could be evaluated for their capacity as larval contributors and may benefit from added protection. Designation of sanctuaries or refuge areas is not a commonly-used tool for management among the Gulf states, but the sanctuary concept could be utilized in the future to create and protect donor sites for seed and brood stocks for restoration projects, as natural reservoirs for oyster populations to repopulate wider areas, and as research sites.

Management Recommendations

1. Develop uniform harvesting seasons to facilitate law enforcement and reduce regulatory

conflicts, particularly when shellfish harvesting areas are adjacent to or extend across state boundaries.

2. Boundaries between areas designated as opened or closed should be clearly and accurately described and/or delineated with enforceable lines to assist fishermen, law enforcement, and resource managers.
3. States should evaluate the use of vessel monitoring systems (VMS) on board oyster boats to aid in the enforcement of closed harvest areas especially in situations with close proximity of designated closed and opened harvest areas, as well as to privately-held lease boundaries. The VMS provide numerous other benefits to law enforcement, safety, productivity, navigation, business management, and effort monitoring.

12.4.4 Regulatory Measures to Manage the Oyster Fishery

There are a number of regulatory measures which can be applied to managing the oyster fishery, including limited access, licenses, user fees, or taxes.

12.4.4.1 Limited Access

Limiting access to a fishery is most often used to manage effort in fisheries that are subject to overharvesting or other types of depletion. However, it is uncertain whether open access causes or contributes to overfishing in the Gulf oyster fishery. Evidence suggests that limited access contributes to a more stable fishery and results in higher production per fisherman (Lansford and Howorth 1994).

12.4.4.1.1 Leases

Producing oysters on private leases is common practice and may compete with public access for the most favorable oyster growing areas in situations where leases are located on hard bottom areas. Leasing state-owned submerged lands promotes privatization of the industry by increasing private investments of time and capital, and in many instances, may result in increased production and revenues, while reducing management costs. Criteria, qualifications, size, and location are just some of the factors to be considered in managing a leasing program. In Louisiana, private lease landings have outpaced landings from public grounds in all but three years since 1961 and have accounted for greater than 70% of annual landings 33 times during the 1961 – 2009 time series.

12.4.4.1.2 Licenses

The manner in which fishing licenses are issued may be used as an effective measure to manage the number of participants in the fishery. Changing the criteria for license eligibility, changing the cost of a license, and capping the total number of licenses sold during a specific period are means to achieve a desired output via influencing the number of licenses sold and, hence, participation in the fishery. Likewise, these factors can influence harvesting effort, landings, and revenues with the extent of the influence being dependent upon the severity of restriction criteria. Many different methods exist to issue licenses (permits, endorsements) and qualify participants. Texas has established a moratorium, capping the number of licenses to harvest oysters; no new licenses are being sold (Section 7.2.5.1.3). Florida requires oyster fishers to purchase an Apalachicola Bay Oyster Harvesting License during a specific period (Section 7.2.1.1.2.2), and licensees must participate in a training program in order to harvest oysters from Apalachicola Bay. Louisiana has implemented a vessel permit for limiting access to the fishery as well (Section 7.2.4.3.2).

Management Considerations

- Limited access is generally adopted to accomplish specific commercial, economic, and management objectives by reducing participation, increasing product quality and value, and/or increasing catch per unit effort. Limiting the number of license holders facilitates law enforcement, resource management, data collection, and administration. Limited access may also ameliorate some product quality and public health problems by focusing responsibility, inspection, and enforcement on fewer participants. Limited entry also promotes the feeling of ownership of the fishery by license holders, which may contribute to resource management objectives.

- Limited entry programs typically offer a narrow window of opportunity for applying for the licenses and require specific qualifications to obtain the license. All the Gulf states apply some level of limited entry in their oyster fisheries (see Section 7.2 for details).

- Limited access is almost always controversial, since it can provide exclusive use of a public resource to a select group and make it difficult for new entrants to the fishery. Limited access is generally sponsored and supported by fishermen who are currently in the fishery, but in many cases, some groups will feel that they have been unfairly prevented from using a common resource.

- Cost and education requirements to obtain and maintain endorsements can discourage fishermen from participating in a fishery.

- The tradition of switching fisheries during 'times of woe' may be curtailed under strict limited access programs. Typically, fishermen who hold multiple gear endorsements maintain flexibility compared to those who do not, and they can move from one fishery to another.

- The value of the license increases with limited access and becomes a commodity when it can be sold and transferred by the fisherman.

Management Recommendations

1. States should evaluate the feasibility of additional or alternative limited access strategies to determine social acceptance and impacts, public trust implications, fishery benefits, the potential for increased fishery production and values, and the regulatory costs compared to potential revenues for the state.

12.4.4.2 Revenue Sources (Licenses, User Fees, and/or Taxes)

Revenue sources to support state management programs may include severance fees, oyster harvesting licenses and/or endorsements, special gear fees, tags, and other fishery-related fees. The goal of revenue generating initiatives is to provide sufficient funds (and reliable funding sources) to support the states' management programs. Most state resource management programs face continuing mandates (direction) to have specific user groups financially support programs that manage their fishery. As resource management programs become more dependent upon industry-related revenue sources, they are pushed to become less reliant on general revenue sources. These fees provide a dedicated revenue source to finance fishery and resource management. They are especially important in the face of ever tightening restraints on using general revenue to pay for management of specific fisheries. Often, these revenue sources are deposited (secured) in trust funds that must be used to fund fishery-related programs.

Management Considerations

- Establishing uniformity of licenses and license fees for all Gulf states could eliminate confusion and provide for greater public acceptance**.**
- All of the Gulf states employ either user fee or gear fees in addition to regular harvesting licenses to generate additional income for management purposes. For example, Mississippi and Texas have a bag or sack tax; and Louisiana and Alabama have gear fees in addition to their regular commercial fishing licenses.
- A lack of flexibility to expand or contract the number of licenses, participants, and fees can complicate program administration. Using licenses and fees as a primary funding source can be problematic when a fishery declines, resulting in funding shortfalls for management activities. The source of the funds can also lead to potential conflicts of interest.
- Fees and taxes may lead to higher costs to consumers, and social and political conflicts.

Management Recommendations

1. States should investigate the practicality, appropriateness, and cost-effectiveness of establishing or maintaining licenses, user fees, taxes, or other revenue sources which are used to support state management programs. Economic impact should be applied fairly across all user groups that benefit from the fishery.
2. States should evaluate social acceptance and impacts, public trusts implications, fishery benefits, the potential for increased fishery production and values, and the regulatory costs compared to potential revenues for the state of user fees and licenses.

12.4.4.3 Shell Retention Fees

Shell retention fees (or severance tax) are established to cover the value of the shell and the costs associated with collecting and returning the shell to the reefs. Ideally, shell retention fees should be assessed to the user segment which is responsible for the loss of the shell or ultimately benefits from the unreturned shell. In many cases, processed oyster shell is placed in commerce for alternative use at the expense of restoring oyster reef habitat. The fees can be especially important in the face of ever tightening restraints on using general revenue to pay for management of specific fisheries. Some states are already implementing shell fees [see Section 7.2.3.1.7.1 (Mississippi) and Section 7.2.2.1.1 (Alabama)].

Management Considerations

- Establishing shell retention fees places responsibility on the fishing industry to finance fishery and resource management, provides an alternative revenue source, and reduces the cost to the public.
- Establishing shell retention fees could help the states offset the cost of cultch planting programs designed to maintain a neutral or positive shell budget.
- Program costs associated with collecting shell retention fees may offset benefits.
- Shell retention fees may lead to higher costs to consumers.

Management Recommendations

1. Resource managers should identify, evaluate, and implement strategies which improve their capacity to retain processed oyster shell and return the shell to rehabilitate oyster reef habitat.
2. Resource managers should investigate the practicality, appropriateness, and cost effectiveness of establishing shell retention fees to compensate for shell which is removed from public oyster reefs.
3. States should investigate different fee levels for shellstock that stays in the state as opposed to shellstock that is exported or processed outside the state to help finance cultch planting on public reefs.

12.4.4.4 Laws and Regulations

Sound regulations and diligent enforcement are essential to effective oyster resource management and compliance by participants in the fishery. Effective law enforcement remains the primary measure to enforce fishery regulations, reduce illegal fishing activity, increase resource conservation, increase boating safety, reduce health risks from consumption of illegally harvested oysters, and improve compliance with the NSSP. Additionally, effective enforcement identifies habitual offenders, who can be removed from the fishery.

The current enforcement system is database driven. Violations are tracked and shared with other agencies identifying repeat offenders and applying progressive/enhanced penalties. The system also identifies times and areas of increased violations for additional enforcement coverage.

Management Considerations

- Effective enforcement capabilities continue to be a high cost operation, which is generally supported from general revenue funds.
- Enhanced enforcement on the water results in increased feedback from the industry to scientists and managers through enforcement officers who provide education to participants regarding regulations and gear requirements. The presence of officers on the water also promotes a positive enforcement image among most lawful fishery participants and other user groups (recreational boaters, waterfront homeowners, etc).
- There are challenges from a law enforcement perspective, including: 1) distrust of enforcement officers by commercial fishermen and 2) local judicial systems which may not always support enforcement of fisheries violations.
- Enforcement is consistently effective by updating officers to new regulations, enforcement techniques and the role of the oyster industry.
- The Gulf states have common borders and often oyster fishermen are licensed to harvest in multiple states requiring the sharing of violation information of habitual violators to enhance enforcement effectiveness.
- State agencies are expected to provide without compensation, financial resources, logistics, and manpower to transport and accompany FDA staff on inspections related to enforcement and patrol efforts for oyster harvesting as required by the National Shellfish

Sanitation Program Model Ordinance and adopted by the states as a requirement for shipping oysters in interstate commerce.

Management Recommendation

1. States should increase funding, personnel, and/or equipment to improve enforcement capabilities, facilitate resource management, improve safety, and protect the public.
2. States should evaluate the use of new technology, such as VMS, for monitoring fisheries activities and enhancing enforcement.
3. States should create in-service training modules directly targeting oyster fishery enforcement that provide new regulation updates, enhanced enforcement techniques and insight into industry's role in the regulatory process.
4. States should develop requests for information avenues to violator databases from other Gulf states, to provide information about habitual violators of oyster fisheries regulations. Officers would have access to shared information from state to state.
5. States should require that the FDA provide a funding mechanism to cover the costs of their inspections within the states related to shellfish enforcement and monitoring efforts addressing FDA mandates. This could be similar to Joint Enforcement Agreements that exist between the states and other federal agencies.

12.4.5 Measures to Increase Production

12.4.5.1 Shell/Cultch Planting

Cultch planting is perhaps the most commonly used management strategy to maintain or increase production (Section 16.5). The type of cultch material is perhaps a less important factor in planting, although it is a consideration during the planning phase of cultch planting projects. Historically, oyster shells were the most widely used material, primarily because of their availability, low cost, ease to plant and success rates (Dugas et al. 1997). The availability of processed oyster shell has become a problem, as competition for this material for other uses has increased. Since there is a continuous need to restore and refurbish oyster reef habitat, particularly following devastating catastrophic events such as hurricanes and floods, resource managers are relying on alternative cultch materials. Resource managers and private leaseholders in most states are expanding their efforts to identify, use, and evaluate affordable, alternative cultch materials, and focus largely on the use of limestone and crushed concrete.

Management Considerations

- Costs associated with reef construction and restoration have increased, making it more difficult for states to appropriate funds to continue oyster resource development programs.
- Suitable material is not always available, as competition for processed shell for other uses has increased and shellstock is oftentimes shipped out-of-state making shell recovery difficult. Increasing demand and declining supply have led to substantial increases in the cost of processed shell.
- Ownership of the shell is complicated with interstate shipments of shellstock. When

businesses purchase shellstock from other states, they claim ownership, often in conflict with state laws to the contrary.

- Fewer sites are available for reef development, and conflicts may occur with other uses of submerged lands (e.g., shrimping, trawling, oil and gas drilling, pipelines, dredge material disposal, etc.)
- Depositing cultch to create and restore oyster reef habitat is the most proven, practical, and relied upon method to increase oyster production that is available to oyster resource managers. This method is successfully applied in all of the Gulf states and should remain one of the primary components for managing oyster resources.
- Site planning for oyster habitat restoration and cultch planting activities should take into consideration the proximity to restricted waters or unapproved harvest areas. Though the creation and restoration of oyster habitat in unapproved harvest areas can provide significant ecosystem services, abundant oyster resources in these areas could lead to illegal harvest that could pose additional risks to public health.

Management Recommendations

1. Continue to create and restore oyster reef habitat by depositing cultch materials at appropriate times and places. States should implement programs to increase cultch planting on public reefs and encourage similar practices on privately-held leases. These programs should establish the goal of restoring, at a minimum, the same amount of reef habitat that is damaged or lost because of adverse environmental conditions, or poor harvesting and maintenance practices, competing uses, and coastal development. States should implement oyster reef development programs that:
    a. sustain functional reef habitat (no net loss of reef acreage);
    b. increase harvests that result in revenues and economic benefit to the fishing community and the states;
    c. provide ecological services that benefit a wide spectrum of users;
    d. rely on science and fishery-based planning;
    e. include monitoring to evaluate success (efficiency, cost/benefit ratios, yields);
    f. resolve issues associated with use and ownership of submerged lands;
    g. resolve issues associated with ownership of processed shell; and
    h. incorporate incentives to encourage partnerships with private leaseholders, fishery organizations, environmental groups (NGOs).
2. Continue to utilize processed oyster shell, when and where it is available, and use and evaluate alternative cultch materials, such as graded limestone, crushed concrete, and fossil shell.
3. Continue to seek state and federal funding to support reef restoration activities.
4. Permitting procedures need to be simplified and standardized. Issues related to ACOE permitting and the Nationwide Permit process should be resolved so that oyster reef development programs and shellfish aquaculture operations are not burdened by complicated regulatory processes.
5. It will become a greater challenge for states to develop and maintain programs to retain processed shell. States should develop cooperative programs that will encourage processors to contribute shell to oyster management programs. It is unlikely that these

programs can survive based solely on voluntary participation, so it will become more important to establish funding mechanisms to support the programs. Various forms of funding have been tried in the past, including severance fees, retention fees, users fees, bag taxes, etc.

6. States should include oyster reef development into regulatory permitting processes that encourage the construction and maintenance of oyster habitat as a form of project mitigation.
7. States should encourage the building of non-harvest reefs by individuals outside the oyster industry, fishery organizations, environmental groups (NGOs), and academia as it provides reef habitat (and associated ecosystem benefits) at little or no expense to the states. Such efforts can provide indirect benefit to oyster fisheries.
8. States should evaluate and establish larval-source or sanctuary reefs to provide ecological services and reproductive materials (genetics, spat, and broodstock). As freshwater inflows change in some estuaries and shift the optimal water quality conditions away from historical oyster producing areas, these source and sanctuary reefs may become more important in sustaining oyster fisheries.

12.4.5.2 Aquaculture

Aquaculture differs from natural fisheries in several critical aspects and, as such, may require a different approach to its regulation and management. Shellfish or oyster aquaculture is treated differently among the states as it relates to fisheries regulations and enforcement (see Section 8.4) since not all the states consider leasing as aquaculture.

The oysters' biological characteristics make them desirable candidates for aquaculture operations, and they are farmed extensively and intensively around the world. Numerous techniques are currently employed in the U.S. for both on- and off-bottom culture. There is potential to increase oyster production in the Gulf states by incorporating various extensive and intensive aquaculture techniques. Applying aquaculture components to innovative management strategies will lead to a more comprehensive approach to managing oyster populations and production. Improvements in hatchery, nursery, and grow out techniques could lead to increased production, and offset the potential of production declines caused by habitat degradation or loss. A more detailed discussion of aquaculture techniques is presented in Section 16.2.

Management Considerations

- There are potential detrimental ecosystem level genetic issues associated with selective breeding.
- There are potential positive aquaculture-related genetic issues associated with selective breeding.
- Aquaculture may displace traditional commercial fishermen.
- Aquaculture may augment traditional commercial fishing practices.
- Aquaculture may complicate enforcement.
- Creation of aquaculture-based enterprise zones may facilitate enforcement of this component of oyster-harvesting activities.

- To the extent that it increases production, prices are likely to decline at an advantage to consumers.
- Aquaculture can reduce harvest pressure on wild stocks via a reduction in price of the wild product and a commensurate reduction in harvest effort.
- Aquaculture can provide an alternative economic opportunity.
- There are concerns with the introduction of non-native species into culture settings. There are potential, detrimental impacts to local native species if there is escapement or release of the non-native species into the wild from competition or predation. Escaped, non-natives may also serve as vectors for parasites or pathogens of native species resulting in reduced condition or mortality.
- There may be economic and/or non-economic benefits to allowing non-native species to be introduced into culture settings.

Management Recommendations

1. The use of non-native species in aquaculture has regional implications. All Gulf states should evaluate and develop specific policies related to the use of non-native species for aquaculture in ambient waters using a rigorous scientific review process. Decisions regarding introductions should be made on a regional basis because the implications will be regional.
2. States should examine whether aquaculture is desirable in that state and, if so, foster the regulatory changes that would allow for and promote successful aquaculture practices.
3. States should develop more precise reporting requirements such that annual harvest information may be obtained for specific leases and aquaculture endeavors.
4. States that allow aquaculture development should consider and evaluate implementation of marine spatial planning to help eliminate user conflicts concerning the deployment of aquaculture gear in the coastal zone.

12.4.6 Measures to Increase Utilization

Throughout the Gulf, numerous populations of oysters exist in areas where harvest is restricted due to pollution. A wide variety of contaminants and their effects on oysters has previously been discussed. Methods to purge these oysters of pathogens or render the pathogens harmless would increase utilization of this otherwise underutilized resource, and provide increased revenues from added landings (see Section 9.5.4).

12.4.6.1 Summer Harvesting

Summer is traditionally not a time when oyster harvest is allowed due to increased public health concerns (see Section 6.0). Generally, there are several parameters that determine the public health risks of a shellfish harvesting area, and these factors are significantly different during the warmest months compared to the coolest months. During the summer, lower river and stream discharges result in lower freshwater flow rates, which also result in less transport of indicator bacteria into estuaries. Additionally, higher water temperatures result in lower survival of indicator bacteria. The combination of these factors may, on occasion, result in bacteriological water quality parameters that meet public health standards for a specific shellfish harvesting area for a limited period of time, even during the summer months. Allowing occasional summer oyster harvest during periods when the human health risk is reduced offers an opportunity for using resources that would normally not be available.

Management Considerations

- Summer harvest could interfere with the reproductive success by removing spawning adults and impeding spat settlement by disturbing or damaging the substrate.
- Summer oysters tend to be in poorer condition resulting in lower yields and poorer product quality.
- Consumer demand is lower in the summer due to concern over human health risks in general.
- During the summer months, spat, juvenile, and adult oysters may be more vulnerable to indirect mortality due to harvesting activities.
- The presence of pathogens, inclusive of Vibrio bacteria, increases with the higher temperatures and increased difficulty for harvesters to comply with time and temperature standards.
- Summer harvesting would provide an alternative source of oysters to meet specific market demands.

Management Recommendations

1. Resource managers, law enforcement, and public health officials should evaluate alternative approaches to improve oyster resource utilization, while maintaining stringent standards to reduce public health risks.

12.4.6.2 Harvest from Restricted Areas

Regulations presently allow very limited harvest of oysters from waters classified as ‘restricted’. In most cases, these waters are classified as ‘restricted’ because of potential contamination from various pathogens which represent a human health concern, if oysters from these waters are consumed raw or are improperly prepared. Harvesting from restricted areas is dependent upon the oyster’s natural ability to cleanse itself of contaminants.

12.4.6.2.1 Relaying

This technique involves removal of oysters from ‘restricted’ areas and transfer to ‘approved’ areas. Relaying may be accomplished by replanting affected oysters on existing oyster reefs, on private leases, or suspending them in various types of containers in approved shellfish harvesting areas. Relaying is sometimes referred to as ‘field depuration’ (Dunning and Adams 1995), where oysters can be placed on the sea floor or in containers. Relaying can also be used as a resource management practice when relayed oysters are placed on public reefs and become a public property resource or they can be placed on privately-held leaseholds where they become the exclusive property of the leaseholder. The oysters must not be harvested until bacteriological analyses show that pathogens have been purged. Relaying offers the opportunity to increase harvests from an otherwise unutilized resource.

Management Considerations

- Relaying requires additional handling, is more costly, and more labor intensive than direct harvest.

- Current analytical testing may be inadequate to identify all potential public health threats.
- The success of the treatment process in removing viruses and Vibrio spp. is not completely understood and it has not been proven to be 100% effective in the elimination of certain pathogens and may be inadequate to ensure safety.
- Increased regulatory controls and manpower are necessary to ensure product safety.
- Developing leases to receive relayed oysters often requires the use of state-owned submerged lands, and thus excludes these areas from other public use, while relocating a potential fishery resource onto a private lease presents certain ownership and public interest issues.
- Removing oysters from areas where they cannot be harvested may negatively affect population dynamics when otherwise protected (not fished) populations are exposed to extensive harvesting. Relaying from otherwise protected areas may be inconsistent with the 'refugia' concept as these areas may serve as a larval source.
- The removal of live oysters and oyster habitat (clusters of live oysters), even under appropriate management guidelines, may be perceived as damaging to the local ecology. For example, recreational anglers may view the removal of live oysters as detrimental to essential fish habitat.
- Extensive and prolonged harvesting of live oysters and substrate may actually damage the reef habitat.
- There is a belief by some recreational anglers that removal from closed areas negatively impacts associated species, creating a reef 'ownership' issue.
- Increased use of an under-utilized resource provides increased revenues from added landings.
- Relaying allows oysters to be harvested from restricted growing areas which are closed to direct-to-market sales.
- Relaying removes a potentially harmful product that may be targeted for illegal harvesting.

Management Recommendations

1. Relaying oysters from closed areas to open areas provides a practical management alternative for using an otherwise unavailable resource.
2. Resource managers, law enforcement, and public health officials should evaluate alternative approaches to relaying to improve oyster resource utilization, while maintaining oyster reef habitat and applying stringent standards to reduce public health risks.
3. The public interest issues and implications of relaying should be evaluated as part of the management strategy.

4. States should consider container relaying as a more practical method of utilizing oysters from restricted areas than on-bottom relaying. Container relaying provides a complete second harvest, more stringent public health controls, facilitated enforcement, and increased efficiency.

12.4.6.2.2 Depuration

Depuration of contaminated oysters involves removing the oysters from contaminated areas, placing them in land-based treatment systems, and allowing the oyster to eliminate the contaminants through natural biological processes. The treatment systems involve providing oysters with clean uncontaminated water so that active self-cleansing can be accomplished. The process may involve flow through systems when the source of the water is acceptable or require recirculation when the water is treated. Depuration is most often accomplished by a controlled purification process, where oysters placed in clean waters purge themselves of pathogens and contaminants. The process involves the elimination of microorganisms from contaminated mollusks by placing the bivalve in a treated seawater system. During the process, purged contaminants are killed by irradiation, oxidation, and even chemical treatment. Guidelines for depuration are provided in the NSSP.

Because depuration has the potential to reduce the levels of some illness-causing organisms, it has been identified as a practical mechanism to increase public confidence in treated shellfish. This technique has been employed in other shellfish industries for many years, but it has received less attention in processing oysters from the Gulf of Mexico. Techniques and operations could be developed to increase depuration efforts in the region.

Management Considerations

- Depuration is much more costly and labor intensive than direct harvest.
- Depuration requires stringent regulations and enforcement.
- Depuration requires process verification.
- The success of the treatment process in removing viruses and Vibrio spp. is not completely understood and it has not been proven to be 100% effective in the elimination of certain pathogens, and may be inadequate to ensure safety.
- The lack of standards and knowledge of the process for removing physical and chemical contaminants (heavy metals) is problematic.
- Depuration provides a practical management alternative for using an unutilized resource by allowing oysters to be harvested from restricted growing areas which are closed to direct-to-market sales.
- Increased public confidence in oyster products could translate to increased markets and sales.
- Depuration sites may create user conflict issues with other commercial and recreational activities.

Management Recommendations

1. Resource managers, law enforcement, and public health officials should evaluate alternative approaches to improve oyster resource utilization, while maintaining stringent standards to reduce public health risks.

12.4.6.2.3 Harvest with Analysis for Pathogens

Classification of growing waters is based principally on fecal coliform contamination, not on the presence of actual pathogens. There is a potential for some oysters to contain high levels of fecal coliform without harboring pathogens. Analyzing oyster meats and/or waters for pathogens would allow an accurate determination of disease potential at any given time or reef area. If pathogens were not present, waters could be opened for harvest.

Management Considerations

- Comprehensive analyses for many pathogens are expensive, time-consuming, and in some cases inconclusive; thus, safety for consumption could not be completely assured.
- Post-harvest Processing is unlikely to receive ISSC approval at this point from waters which do not meet the approved or conditionally approved growing area classification and would not be allowed to be marketed directly even if testing shows them to be free of pathogens.
- Pathogen analyses provide a management alternative for using unutilized resources.

Management Recommendations

1. Resource managers, law enforcement, and public health officials should evaluate alternative approaches to improve oyster resource utilization, while maintaining stringent standards to reduce public health risks.

12.4.6.3 Cooking, Canning, and Other Heat Processing Methods

Potential exists to increase utilization of oysters by directing harvests to specific processing methods, primarily cooking, to eliminate bacteriological content.

Management Considerations

- Increased regulatory controls and manpower would be needed.
- There is strong competition from canned imports.
- If a conditionally approved but closed area is found to be free of chemical contaminants then heat processed and canned oysters might be a viable alternative use for the resource.
- These processing options are unlikely to receive ISSC approval at this point from waters which do not meet the approved or conditionally approved growing area classification and would not be allowed to be marketed directly even if testing shows them to be free of pathogens.
- There is the potential for niche markets; however, domestically grown canned oysters would be competing with imported Asian products which currently dominate the canned market.

Management Recommendations

1. Resource managers, law enforcement, and public health officials should evaluate alternative approaches to improve oyster resource utilization, while maintaining stringent standards to reduce public health risks.

2. States should consider amending existing laws and regulations that prohibit development of alternative processing of oysters from restricted growing areas.

12.4.6.4 Post-harvest Processing (PHP)

Post-harvest Processing (PHP) of oysters can be accomplished by commercial processors to reduce specific target microbial pathogens to non-detectable levels for added food safety. Post harvest processing requires specified validation and verification procedures in addition to specific provisions of a Hazard Analysis Critical Control Point Plan (HACCP Plan) and the National Shellfish Sanitation Program (NSSP) (see Section 9.5.4 for detail).

Presently, there are four post-harvest processes used in commercial operations: 1) freezing with frozen storage; 2) cool pasteurization; 3) hydrostatic high pressure; and, 4) irradiation. Freezing has a two-stage kill step: initial freezing and a specified frozen storage period. Depending on the initial freezing rate, the product must be retained in frozen storage for a specified period ranging from 7-56 days. Cool pasteurization, hydrostatic high pressure, and irradiation have a single kill step. In cool pasteurization, the product is placed in a warm-water bath and then chilled rapidly in a cold water bath. In hydrostatic high pressure, the product is placed into a stainless steel cylinder filled with water and exposed to high pressure. In treating with radiation, the product is placed in an irradiation chamber and exposed to gamma radiation for about 240 seconds to achieve an absorbed dose of between 0.75 to 1.5 KGy.

Management Considerations

- PHP increases the cost of processing both in start up and routine operations.
- PHP methods can be considered as a value-added process and the costs can be absorbed by commerce.
- Final processed product is not quite the same as the fresh raw product. Organoleptic and physical changes can result during processing.
- Seasonal variation in oyster condition can affect the quality of oysters exposed to PHP processes and consumer acceptance.
- Consumer perception of product quality may be attributed to the PHP process when seasonal variation is the proximal cause.
- Post-harvest processing provides alternative products for consumers seeking raw-like product with greatly reduced to non-existent risk of illness.
- Post-harvest processing could result in increasing the availability of product lines.
- The concept of post-harvest processing can open alternative market channels by increasing the awareness of ‘product safety’.

Management Recommendations

1. States should foster PHP development to maximize resource utilization and enhance product safety.
2. Regulatory policy should be developed to review the PHP verification and enforce proper labeling and product tracking.

12.4.7 Controlling and Preventing Pollution in Shellfish Growing Areas

12.4.7.1 Vessel Sewage Discharges and No Discharge Zones

Without proper management, commercial and recreational activities can contribute to water quality degradation by the discharge of untreated or partially treated human wastes, contributing to high bacteria counts and subsequent increased human health risks, especially in oyster harvesting areas (Section 6.7). Under the Clean Water Act (Section 312) a state can have all or portions of their waters designated as a 'no-discharge zone' (NDZ) for vessel sewage to protect human health and the aquatic environment from disease-causing microorganisms.

Currently, seven states have all (or nearly all) of their surface waters designated as NDZs; including: Michigan, Missouri, New Hampshire, New Mexico, Rhode Island, and Wisconsin. In addition, 14 other States have segments of their surface waters designated as NDZs; including Arizona, California, Connecticut, Florida, Georgia, Maryland, Massachusetts, Minnesota, New Jersey, Nevada, New York, North Carolina, South Carolina, Texas, and Utah. Approximately 50% of the NDZs are in fresh water and the other 50% are in salt or estuarine waters.

Management Considerations

- Substantial costs are associated with equipping and operating pump-out stations.
- Substantial costs are associated with regulating and enforcing NDZs.
- Implementing NDZs may provide an opportunity to protect estuaries from the standpoint of human health, fisheries management, recreation, and environmental protection.
- NDZs may prove to be the most cost effective alternative to protecting environmental quality in the face of costs to clean up contamination or treat public health incidents.
- Clean Water Act enforcement requires substantial multi-agency coordination and communication.

Management Recommendations

1. Resource managers should develop a comprehensive approach to managing vessel sewage, including designating NDZs.
2. Oyster harvesting areas should be designated NDZs regardless of the availability of pump-out facilities.
3. Section 312 of the Clean Water Act should be expanded to include oyster harvesting areas as areas to be covered as NDZs.
4. The ISSC should serve as the clearinghouse for the list of areas that should be designated as NDZs.

12.4.7.2 Pollution

Pollution represents a serious threat to oyster communities at the local level, but the cumulative impacts of all types of pollution threaten oysters on a regional level (Section 5.2.2.1). Pollutants include a wide variety of substances that are introduced into the environment, including solid wastes, nutrients, chemicals (petrochemicals), toxic substances (pesticides, herbicides), and other harmful and deleterious substances. Pollutants degrade water quality and habitat, and expose oyster populations to serious threats, since oysters are sedentary and cannot move to more favorable environments. Pollutants and contaminants can stress and ultimately kill oysters directly or in combination with other factors, may impair oyster reproduction, and adversely affect survival of all life stages. In some instances, pollutants may act indirectly to degrade the environment; for example eutrophication can adversely affect oyster populations by reducing water quality, disrupting the food web, altering species diversity, and supporting harmful algal blooms (Section 5.2.2.1.1.1).

Management Recommendations

1. States should encourage improved multi-jurisdictional coordination of identifying, permitting, and monitoring pollution.
2. Resource managers must continue to work toward a more comprehensive approach to managing shellfish waters amidst a growing threat from pollution, including engaging in comprehensive planning for coastal development.

12.4.8 Establishing Cooperative Management

Cooperative management, or co-management (Section 10.4.2) can be considered as an option to traditional management techniques. Co-management is collaboration between citizens and government in the management of natural resources and has the potential to: (1) promote conservation and enhancement of fish stocks; (2) improve the quality of data and data analysis; (3) reduce excessive investments by fishermen in competitive gear; (4) make allocation of fishing opportunities more equitable; (5) promote community economic development; (6) increase product quality and reduce health risks, and (7) reduce government versus fishermen and fishermen versus fishermen conflicts. The complexity and variability in oyster resources and the local communities that depend on these resources must also be considered when establishing the framework for effective cooperative management strategies.

Management Considerations

- The process of establishing co-management programs is challenging and requires cooperation and coordination on many levels. It is important that the fishing community is well informed and a part of the planning and implementation processes. When a culture of cooperation is established, implementing fisheries and resource management programs is often facilitated, especially when the co-management programs are clearly understood by the fishermen. Cooperative interaction may ultimately build mutual trust and respect, which are crucial to the acceptance of management needs and recognition of common interests between users and regulators.
- Scale of effort can be an important factor in determining the success of co-management programs. Co-management operates most favorably where: 1) the area is not too large and benefits can be linked to watersheds or local waters; 2) the number of fishermen or communities is not too large for effective communication, or where there are well-organized subgroupings (villages, kin groups, organizations) that communicate well with each other or have effective umbrella organizations; and 3) the size of the government bureaucracy is small and its mandate is fairly regional or local.
- Co-management programs may offer a perception of ‘fox guarding hen house’, when there are issues related to conflict of interest, privatization of public resources, special interests being served, and other issues associated with selective benefits and advantages.

Management Recommendations

1. States implementing co-management need to integrate social science data into cooperative programs which would include:
    a. regional user populations,
    b. utilization strategies,
    c. demographics and socio-political constituencies,
    d. traditions and attitudes of fishers,
    e. industry-oriented and local fishery advisory groups, and
    f. fishery management infrastructure.
2. Management councils and state and federal agencies could be linked with user groups through direct representation by those groups, as well as through special extension offices.

13.0 RESEARCH AND DATA NEEDS

Research and data collection on the Gulf oyster fishery is needed to address a wide range of biological, social, economic, environmental, and health related issues. Biologically, the Eastern oyster has been one of the most studied marine species in the Gulf; however, many factors involving spawning, setting, growth, and survival, particularly in regard to environmental influences on these factors, are only partially understood.

The high degree of human involvement in the fishery creates opportunities to better understand the social and economic problems of the fishery. Information is also needed from harvesters regarding catch and effort in order to properly manage reefs.

Research is needed to address habitat deterioration resulting from substrate loss and pollution. An assessment of oyster contamination from chemicals/pathogens and disease is necessary to protect public health. Additionally, studies to determine the potential for aquaculture, depuration and genetic alteration are needed.

The following is a list of some of the more important research and data collection needs. These are not listed in order of priority, and there are perhaps others that are not listed.

13.1 Biological

Develop a greater understanding of oyster population dynamics, reproduction, recruitment, growth, natural mortality, connectivity between populations, and source/sink dynamics.

- Develop ageing techniques that are easy to use and highly resolved for *C. virginica*
  - Determine stage specific mortality
  - Determine stage specific reproduction
- Identify larval transport pathways and factors influencing those pathways
- Reveal source/sink dynamics for oyster metapopulations
- Determine effects of global climate change, ocean acidification, and sea level change on oyster production
- Determine factors contributing to MSX and Dermo infection
- Assess impacts of predators and determine methods of predator control
- Quantify carbon sequestration by Gulf oysters
- Assess pollution effects on oysters
  - Pharmaceuticals
  - HABs
  - Ballast water issues

13.2 Habitat

- Map distribution of all oyster reef habitats (including ecological and non-production areas) and develop a Gulf-wide distribution atlas using available GIS technology
- Mapping and reef classification throughout the bay systems of the Gulf states (United States and Mexico)
- Examine the long term implications to ecosystem services due to degraded oyster habitat.
- Predict future oyster habitat losses, restoration, and implications to ecosystem services due to loss/degraded of this habitat.
- Determine disarticulation rates of boxes and dissolution rates of shells under various conditions, locations, and harvesting pressures

- Develop shell budgets
- Develop and implement a shell recovery program for each Gulf state
- Assess impact of range changes by other molluscan species. Determine if there has been or if there is a potential for shift/expansion in ranges of other molluscan species and if so, what are the potential impacts to the Eastern Oyster
- Assess impact of invasive/non-native species, including competition for available habitat, to the Eastern Oyster

13.3 Public Health

- Determine dosage thresholds for *V.v.* to cause disease for at-risk consumers
- Study the feasibility of Vibrio depuration
- Develop criteria for assessing health risks from eating oysters
- Evaluate indicators of pathogen contamination
- Evaluate the potential impacts of invasive/non-native species as vectors for introduction of pathogens or disease
- Evaluate impacts of pollution on human health including the following pollution sources: pharmaceuticals, point and nonpoint source pollution, ballast water issues

13.4 Resource Management

- Cultch
    - Evaluate feasibility of stock piling and replanting oyster shells
    - Assess alternative cultch use and availability
    - Assess performance of alternative cultch materials
- Evaluate the impacts of water control projects on downstream oyster communities
- Assess pollution sources impacting oyster reefs
    - Nature of pollution and severity
    - Relative impacts of point and non-point sources
    - Feasibility for reduction, mitigation, and/or clean-up
- Evaluate feasibility for leasing prime oyster production areas (public and natural reefs) and other privatization in the industry
- Evaluate feasibility of classifying harvesting areas for specific processing methodologies
- Establish uniform volume measurements for oyster shellstock
- Assess the relative value of closed access areas to serve as MPAs or ecological and genetic refuges
- Determine the ecological and economic value of oyster habitat in the estuarine community and its value as a keystone species

13.5 Enforcement

- Study impacts, feasibility, and costs of establishing uniform enforcement procedures and standardized processes
- Develop effective coordination of data streams for VMS in the oyster industry and identify an industry accepted standard Gulf-wide
- Investigate the possibility of entering JEAs for oyster enforcement
- Study impacts, feasibility, and tradeoffs of establishing higher and progressive penalty schedules for regulation violations to improve compliance

13.6 Industrial/Technological

- Develop shucking procedures and practices to reduce contamination

- Identify practical and cost effective alternatives to “burlap sacks” for holding shellstock
- Develop time and temperature standards for holding shellstock and shucked raw oysters
- Develop uniform packaging and labeling standards
- Establish uniform criteria for water content in oyster meats
- Assess post-harvest processing options
- Assess feasibility or methods for meat pasteurization

13.7 Education, Outreach, and Marketing

- Develop public relations materials
- Develop methodologies for niche market development
- Investigate sustainable product endorsement/certification
- Investigate market branding and gourmet/boutique-type products to add value

13.8 Economic

- Determine impact of more targeted harvest closures on economics
- Study economic feasibility of all aspects of aquaculture, depuration, and relaying
- Determine costs and benefits of cultch planting programs including stocking of oyster shells for cultch
- Assess economic effects of mandatory seafood inspection
- Investigate post-harvest processing benefit-cost analysis
- Examine the extent to which variation in production affects industry revenues
- Determine the direct and indirect ecological (non-market) economic value of oyster habitat in the estuarine community and its value as a keystone species
- Evaluate the impact of imported shellfish (oyster and non-oyster) on the market share of domestic oysters

13.9 Social

- Evaluate consumer attitude toward health risks from oyster consumption
- Determine size preference and propensity for eating cooked and uncooked oysters
- Determine attitudes of fishermen toward dredges versus tongs
- Evaluate feasibility for, and social impacts of, leasing prime oyster production areas (public and natural reefs) and other privatization in the industry
- Develop social indicators to assess impacts of management actions on oyster-dependent families and communities
- Assess the social impacts of moving traditional oyster harvesters into aquaculture
- Determine the changing social structure of the oyster industry today
- Evaluate potential user conflicts in siting aquaculture operations
- Evaluate the impact of loss of market demand on domestic product due to imports

13.10 Stock Assessment

- Determine the relationship between mortality rates and box counts for spat, seed, and adults
- Determine the disarticulation rates of boxes under various conditions, locations, and harvesting pressures
- Determine the impact of harvest on spat survival and settlement
- Develop shell budgets
- Evaluate calibration of potential changes to sampling methods prior to adding or replacing current fishery-independent sampling protocols
- Develop remote sensing techniques to map subtidal and intertidal reefs (e.g. hyperspectral,

sidescan, etc)
- Create a Gulf-wide reef distribution atlas
- Ground truth/validate assessment model outcomes

13.11 Aquaculture

- Evaluate feasibility of off-bottom grow-out techniques
- Evaluate remote setting for cultched and cultchless seed production
- Genetically identify and select strains of disease-resistant oysters for the Gulf region
- Develop a tetraploid broodstock line for the Gulf of Mexico for commercial production of triploid oysters
- Evaluate commercial triploid oyster production
- Define parameters for integrating oyster aquaculture within a marine spatial planning context

13.12 Ecosystem-Based Fisheries Management (EBFM)

- Evaluate existing ecological and socioeconomic data collected to manage oyster fisheries and identify gaps in data needed to manage oysters using an EBFM approach
- Identify and evaluate the institutional changes necessary for effective ecosystem based management of oyster fisheries
- Identify and weigh the importance of all relevant stakeholders involved in the development and implementation of the ecosystem-based management of oyster fisheries
- Analyze the various economic costs and returns of implementation of an EBFM approach
- Evaluate the potential impacts of invasive/non-native species (oysters and nonoysters)
- Develop an oyster reef centric model for an EBFM approach
- Integrate the ecosystem services provided by oysters and oyster reefs into the EBFM approach

14.0 REVIEW AND MONITORING OF THE MANAGEMENT PLAN

14.1 Review

The State-Federal Fisheries Management Committee (SFFMC) of the GSMFC will review, as needed, the status of the stock, condition of the fishery and habitat, effectiveness of management regulations, and research efforts. Results of the review will be presented to the Technical Coordinating Committee (TCC) and the SFFMC for approval and recommendation to the GSMFC and the appropriate management authorities in the Gulf states. The SFFMC may also make recommendations to revise the FMP as needed.

14.2 Monitoring

The GSMFC, the NMFS, states, and universities should document their efforts at management measure implementation for this species and review these with the SFFMC. The SFFMC will monitor each state's progress with regard to implementing recommendations in this regional management plan on a semi-annual basis.

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16.0 APPENDICES

16.1 Glossary

(Modified from Wallace, R.K., W. Hosking, and S.T. Sxedlmayer. 1994, ISSC Model Ordinance, and the Maryland SeaGrant Website.)

A

A - See annual mortality.

ABC - See allowable biological catch.

Abiotic - All non-living factors within an environment, including physical, chemical, and temporal (time) components. Also see biotic.

Absolute Abundance - The total number of kind of fish in the population. This is rarely known, but usually estimated from relative abundance, although other methods may be used.

Abundance - See relative abundance and absolute abundance.

Adductor Muscle - A prominent organ situated in the posterior region of the oyster body, consisting of an anterior translucent part and a smaller, white crescent-shaped region. It functions to close the oyster shells (relaxation of the adductor muscle allows the shells to gape open).

Adverse Pollution Condition - A state or situation caused by meteorological, hydrological or seasonal events or point source discharges that have historically resulted in elevated fecal coliform levels in a particular growing area. [In States using total coliform standard, insert “total coliform” for “fecal coliform”.]

Age Frequency or Age Structure - A breakdown of the different age groups or individuals.

Allocation - Distribution of the opportunity to fish among user groups or individuals. The share a user group gets is sometimes based on historic harvest amounts.

Allowable Biological Catch (ABC) - A term used by a management agency which refers to the range of allowable catch for a species or species group. It is set each year by a scientific group created by the management agency. The agency then takes the ABC estimate and sets the annual total allowable catch (TAC).

Annual Mortality (A) - The percentage of fish dying in one year due to both fishing and natural causes.

Anus - The opening of the rectum into the cloacal chamber.

Approved - A classification used to identify a growing area where harvest for direct marketing is allowed.

Aquaculture - The cultivation of seed in natural or artificial growing areas, or the cultivation of shellstock other than seed in growing areas. Ponds, pens, tanks, or other containers may be used. Feed is often used. A hatchery is also aquaculture, but the fish are released before harvest size is reached.

Artisanal Fishery - Commercial fishing using traditional or small scale gear and boats.

Authority - The State or local shellfish control authority or authorities or its designated agents, which are responsible for the enforcement of this Code.

Availability - Describes whether a certain kind of fish of a certain size can be caught by a type of gear in an area.

B

Bacteria - Diverse group of organisms composed of a single prokaryotic cell without a nucleus or membrane bound organelles whose most important biological roles are decomposition, nitrogen fixation, and disease agents.

Bag Limit - The number and/or size of a species that a person can legally take in a day or trip. This may or may not be the same as a possession limit.

Bed - The bank, reef, or deposit of oysters in the water, either growing naturally or artificially, original or transplanted.

Bedding - Transplanting oysters of any size to prepared beds.

Benthic - Refers to animals and fish that live on or in the water bottom.

Biomass - The total weight or volume of a species in a given area.

Biotic - All living factors within an environment. Also see abiotic.

Bivalve - Marine or freshwater mollusk that has two shells.

Box – 1) A unit of measure for oysters, but may vary by state, and 2) the articulated shell of a recently dead oyster.

Bycatch - The harvest of fish or shellfish other than the species for which the fishing gear was set. Examples are blue crabs caught in shrimp trawls or sharks caught on a tuna longline. Bycatch is also often called incidental catch. Some bycatch is kept for sale.

C

CPUE - See catch per unit of effort.

Catch - The total number or poundage of fish captured from an area over some period of time. This includes fish that are caught but released or discarded instead of being landed. The catch may take place in an area different from where the fish are landed. Note: Catch, harvest, and landings are different terms with different definitions.

Catch Curve - A breakdown of different age groups of fish, showing the decrease in numbers of fish caught as the fish become older and less numerous or less available. Catch curves are often used to estimate total mortality.

Catch Per Unit of Effort (CPUE) - The number of fish caught by an amount of effort. Typically, effort is a combination of gear type, gear size, and length of time gear is used. Catch per unit of effort is often used as a measurement of relative abundance for a particular fish.

Certification or Certify - The issuance of a numbered certificate to a person for a particular activity or group of activities that indicates permission from the Authority to conduct the activity and compliance with the requirements of this Code.

Certification Number - The unique identification number, issued by the Authority to each dealer for each location, consisting of a one to five digit Arabic number preceded by the two letter State abbreviation and followed by a two letter abbreviation for the type of activity or activities the dealer is qualified to perform in accordance with this Ordinance using the following terms:

1. shellstock shipper (SS);
2. shucker-packer (SP);
3. repacker (RP);
4. reshipper (RS); and
5. depuration processor (DP).

Cilia - Hair-like structures used for motility in some protozoans and for the movement of particles or fluids in certain cells of more advanced organisms.

Cloacal Chamber - A chamber which passes excess water and waste from the oyster into the environment. In addition, it houses the adductor muscle and rectum.

Closure – The act of temporarily preventing harvest from a reef or harvest area for management or public health reasons.

Cohort - A group of fish spawned during a given period, usually within a year.

Cohort Analysis - See virtual population analysis.

Coliform Group - All of the aerobic and facultative anaerobic, gram negative, nonspore forming, rod shaped bacilli which ferment lactose broth with gas formation within 48 hours at 95 Fahrenheit (35 + 0.5°Centigrade).

Commensal Organisms - Organisms that rely on a host for a benefit but do not harm or benefit the host (i.e., an oyster bar provides protection for crabs and a hard substrate for barnacle settlement).

Commercial Fishery - A term related to the whole process of catching and marketing fish and shellfish for sale. *It refers to and includes fisheries resources, fishermen, and related businesses directly or indirectly involved in harvesting, processing, or sales.

Common Property Resource - A term that indicates a resource owned by the public. It can be fish in public waters, trees on public land, and the air. The government regulates the use of a common property resource to ensure its future benefits.

Compensatory Growth - An increase in growth rate shown by fish when their populations fall below certain levels. This may be caused by less competition for food and living space.

Compensatory Survival - A decrease in the rate of natural mortality (natural deaths) that some fish show when their populations fall below a certain level. This may be caused by less competition for food and living space.

Condition - A mathematical measurement of the degree of plumpness or general health of a fish or group of fish.

Conditionally Approved - A classification used to identify a growing area which meets the criteria for the approved classification except under certain conditions described in a management plan.

Conditionally Restricted - A classification used to identify a growing area that meets the criteria for the restricted classification except under certain conditions described in a management plan.

Confidence Interval - The probability, based on statistics, that a number will be between an upper and lower limit.

Controlled Access - See limited entry.

Controlled Purification- Controlled elimination of microorganisms and contaminates in treatment systems.

Critical Control Point (CCP) - A point, step or procedure in a food process at which control can be applied, and a food safety hazard can as a result be prevented, eliminated, or reduced to acceptable levels.

Culling – The act of picking over harvested oysters for the better quality animals by knocking and prying apart a cluster of oysters, removing sublegal oysters, or removing the non-living reef material included in the dredge haul.

Culls - Culled-out oysters; the next to the poorest grade or sublegal oysters that are required to be returned to the water.

Cultch - The shells, gravel, rocks, fragments of brick, or any other material placed in the water to catch the spawn of the oyster.

Cultivate - To raise oysters artificially from spawn, or from transplanted young. See plant.

Cumulative Frequency Distribution - A chart showing the number of animals that fall into certain categories, for example, the number of fish caught that are less than one pound, less than three pounds, and more than three pounds. A cumulative frequency distribution shows the number in a category, plus the number in previous categories.

D

Dealer -A person to whom certification is issued for the activities of shellstock shipper, shucker-packer, repacker, reshipper, or depuration processor.

Demersal - Describes fish and animals that live near water bottoms. Examples are flounder and croaker.

Depletion - The removal, under the direct control of the Authority, of shellstock from a growing area classified as prohibited.

Depuration or Depurate - The process of reducing the pathogenic organisms that may be present in shellstock by using a controlled aquatic environment as the treatment process.

Depuration Processor - A person who harvests or receives shellstock from growing areas in the approved or conditionally approved, restricted, or conditionally restricted classification and submits such shellstock to an approved depuration process.

Diatoms - Major phytoplankton group whose organisms are enclosed within a secreted shell of silicon.

Digestive Gland - The gland responsible for the production of digestive enzymes.

Direct Marketing - The sale for human consumption of shellfish which does not require depuration or relaying prior to sale or has been subjected to depuration or relaying activities.

Directed Fishery - Fishing that is directed at a certain species or group of species. This applies to both sport fishing and commercial fishing.

Disappearance (Z') - Measures the rate of decline in numbers of fish caught as fish become less numerous or less available. Disappearance is most often calculated from catch curves.

Dissolution – The process by which oyster shell is dissolved over time into solution by acidic environmental conditions, from the water, or substrate that erodes the shells' calcium.

Dredge – A harvest implement for scraping the top layer of a reef consisting of a heavy, rectangular iron frame for scraping the sea-bottom.

Drill – A marine gastropod or sea snail which bores a hole in the shell of bivalves and consumes the animal inside. There are a number of species in the family Muricidae.

Dry Storage - The storage of shellstock out of water.

E

EEZ - See exclusive economic zone.

EIS - See environmental impact statement.

ESO - See economics and statistics office.

Economic Efficiency - In commercial fishing, the point at which the added cost of producing a unit of fish is equal to what buyers pay. Producing fewer fish brings the cost lower than what buyers are paying. Producing more fish would raise the cost higher than what buyers are paying. Harvesting at the point of economic efficiency produces the maximum economic yield. See maximum economic rent.

Economic Overfishing - A level of fish harvesting that is higher than that of economic efficiency, harvesting more fish than necessary to have maximum profits for the fishery.

Economic Rent - The total amount of profit that could be earned from a fishery owned by an individual. Individual ownership maximizes profit, but an open entry policy usually results in so many fishermen that profit higher than opportunity cost is zero. See maximum economic yield.

Economics and Statistics Office (ESO) - A unit of the National Marine Fisheries Service (NMFS) found in the regional director's office. This unit does some of the analysis required for developing fishery policy and management plans.

Effort - The amount of time and fishing power used to harvest fish. Fishing power includes gear size, boatsize, and horsepower.

Eggs - Haploid gametes produced by females. Also see sperm.

Electrophoresis - A method of determining the genetic differences or similarities between individual fish or groups of fish by using tissue samples.

Environmental Impact Statement (EIS) - An analysis of the expected impacts of a fisheries management plan (or some other proposed action) on the environment.

Epibranchial Chambers - A chamber that is formed by the fusion of the mantle and visceral mass and the base of the gills and houses the gills, mouth, and labial palps.

Escapement - The percentage of fish in a particular fishery that escape from an inshore habitat and move offshore, where they eventually spawn.

Esophagus - Tube that connects the mouth with the stomach

Euryhaline - Fish that live in a wide range of salinities.

Exclusive Economic Zone (EEZ) - All waters from the seaward boundary of coastal states out to 200 natural miles. This was formerly called the Fishery Conservation Zone.

Exvessel - Refers to activities that occur when a commercial fishing boat lands or unloads a catch. For example, the price received by a captain for the catch is an exvessel price.

F

F - See fishing mortality

Fmax - The level of fishing mortality (rate of removal by fishing) that produces the greatest yield from the fishery.

FMP - See fishery management plan.

Fecal Coliform - The portion of the coliform group which will produce gas from lactose in an EC or A-1 multiple tube procedure liquid medium within 24 (+ 2) hours in a water bath maintained at 112 ° Fahrenheit (44.5 ± 0.2 °Centigrade).

Fecundity - A measurement of the egg-producing ability of a fish. Fecundity may change with the age and size of the fish.

Fishery - All the activities involved in catching a species of fish or group of species.

Fishery Dependent Data - Data collected on a fish or fishery from sport fishermen, commercial fishermen, and seafood dealers.

Fishery Independent Data - Data collected on a fish by scientists who catch the fish themselves, rather than depending on fishermen and seafood dealers.

Fishery Management Plan (FMP) - A plan to achieve specified management goals for a fishery. It includes data, analyses, and management measures for a fishery.

Fishing Effort - See effort.

Fishing Mortality (F) - A measurement of the rate of removal of fish from a population by fishing. Fishing mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is the percentage of fish dying at any one time. The acceptable rates of fishing mortality may vary from species to species.

Food Safety Hazard - Any biological, chemical, or physical property that may cause a food to be unsafe for human consumption.

Fork Length (FL) - The length of a fish as measured from the tip of its snout to the fork in the tail.

G

GSI - See gonosomatic index.

Gardening (oysters) – The recreational culture of oyster seedstock to adult by non-professional entities or individuals for oyster population recovery efforts and fish habitat. The ‘oyster gardener’ typically obtains seed and places it in homemade or commercially available containers on their personal piers or docks for the purpose of increasing the filtration capacity of ambient waters and to provide adult oysters for subsequent reef reclamation projects.

Gills - The gills are the largest organ in the oysters body and consists of four folds of tissue. Along with the mantle it is the chief organ of respiration. They create water currents, collect food particles, and move food particles to the labial palps for further sorting. Also serve to separate masses of eggs released from the ovary during spawning into individual ova for efficient fertilization.

Gonochoristic - Fish that maintain the same sex throughout their entire lifespan.

Gonosomatic Index (GSI) - The ratio of the weight of a fish’s eggs or sperm to its body weight. This is used to determine the spawning time of species of fish.

Granulocyte - A type of hemocyte that aides in the defense of an organism from foreign bodies and other materials.

Groundfish - A species or group of fish that lives most of its life on or near the sea bottom.

Growing Area - Any site which supports or could support the propagation of shellstock by natural or artificial means.

Growth - Usually an individual fish’s increase in length or weight with time. Also may refer to the increase in numbers of fish in a population with time.

Growth Model - A mathematical formula that describes the increase in length or weight of an individual fish with time.

Growth Overfishing - When fishing pressure on smaller fish is too heavy to allow the fishery to produce its maximum poundage. Growth overfishing, by itself, does not affect the ability of a fish population to replace itself.

H

HACCP (Hazard Analysis Critical Control Point) - A systematic, science-based approach used in food production as a means to assure food safety.

HACCP Plan - The written document that delineates the formal procedures that a dealer follows to implement the HACCP requirements set forth in 21 CFR 123.6 as adopted by the Interstate Shellfish Sanitation Conference.

Harvest - The act of removing shellstock from growing areas and its placement on or in a man-made conveyance or other means of transport. The total number or poundage of fish caught and kept from an area over a period of time [Note that landings, catch, and harvest are different].

Harvest Area - Any area that contains commercial quantities of shellstock and may include aquaculture sites and facilities.

Harvester - The person who takes shellstock by any means from a growing area.

Heat Shock - The process of subjecting shellstock to any form of heat treatment prior to shucking, including steam, hot water or dry heat, to facilitate removal of the meat from the shell without substantially altering the physical or organoleptic characteristics of the shellfish.

Hemocyte - Blood cell found in the hemolymph. There are different types that perform a wide variety of functions from defense to nutrient transport.

Hemolymph - Circulatory fluid found in all mollusks and many other invertebrates.

Hermaphroditic - Possessing physiologically functioning male and female reproductive organs.

Hinge - The area formed by the joined valves at the anterior of the oyster.

I

ITQ - See individual transferable quota.

Incidental Catch - See bycatch.

Individual Transferable Quota (ITQ) - A form of limited entry that gives private property rights to fishermen by assigning a fixed share of the catch to each fishermen.

Instantaneous Mortality - See fishing mortality, natural mortality, and total mortality.

Interstate Certified Shellfish Shippers List (ICSSL) - The FDA publication of shellfish dealers, domestic and foreign, who have been certified by a state or foreign Authority as meeting the public health control measures specified in this Ordinance.

Interstate Shellfish Sanitation Conference (ISSC) - The organization which consists of multiple state and federal agencies from shellfish producing and receiving states which provides the formal structure wherein state regulatory authorities, with FDA concurrence, can establish updated guidelines and procedures for sanitary control of the shellfish industry.

Intestine - Organ used for the transport of undigested material and transport of nutrients.

Intrinsic Rate of Increase (z) - The change in the amount of harvestable stock. It is estimated by recruitment increases plus growth minus natural mortality.

Isopleth - A method of showing data on a graph which is commonly used in determining yield-per-recruit.

J

Juvenile - A young fish or animal that has not reached sexual maturity.

L

Labial Palps - Consist of two pairs of large, soft flaps that have a roughly triangular shape and have a smooth surface and a rough surface. These specialized organs are known to control the total amount of food ingested, but may also sort food before ingestion, perhaps on the basis of particle size or chemical composition.

Landings - The number or poundage of fish unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen for personal use. Landings are reported at the points at which fish are brought to shore. Note that landings, catch, and harvest define different things.

Latent Species - A species of fish that has the potential to support a directed fishery.

Length Frequency - A breakdown of the different lengths of a kind of fish in a population or sample.

Length-Weight Relationship - Mathematical formula for the weight of a fish in terms of its length. When only one is known, the scientist can use this formula to determine the other.

License - The document issued by the Authority to a person to harvest or transport shellstock for commercial sale. [In those States issuing permits as opposed to licenses, the term license would be replaced with the term "permit" which would be defined the same as "license".

Limited Entry - A program that changes a common property resource like fish into private property for individual fishermen. License limitation and the ITQ are two forms of limited entry.

Lot [of shellstock] - A type of bulk shellstock or containers of shellstock of no more than one day's harvest from a single defined growing area gathered by one or more harvesters.

Lot [of shellstock for depuration] - Any shellstock harvested from a particular area during a single day's harvest and delivered to one depuration plant.

Lot [of shucked shellfish] - A collection of containers of no more than one day's shucked shellfish product produced under conditions as nearly uniform as possible, and designated by a common container code or marking.

M

M - See natural mortality.

MSY - See maximum sustainable yield.

Mantle - Two fleshy folds of tissue that cover the internal organs of the oyster and are always in contact with the shells but not attached to them. Its principal role is the formation of the shells and the secretion of the ligament as well as playing a part in other biological functions (i.e., sensory reception, egg dispersal, respiration, reserve stores, and excretion).

Mariculture - The raising of marine finfish or shellfish under some controls. Ponds, pens, tanks, or other containers may be used, and feed is often used. A hatchery is also mariculture but the fish are released before harvest size is reached.

Marina - Any water area with a structure (docks, basin, floating docks, etc.) which is used for docking or otherwise mooring vessels and constructed to provide temporary or permanent docking space for more than ten boats.

Marine Biotoxin - Any poisonous compound produced by marine microorganisms and accumulated by shellstock such as *Alexandrium spp*. (*Protogonyaulax* species), and *Karenia brevis*.

Mark-Recapture - The tagging and releasing of fish to be recaptured later in their life cycles. These studies are used to study fish movement, migration, mortality, growth, and to estimate population size.

Maximum Sustainable Yield (MSY) - The largest average catch that can be taken continuously (sustained) from a stock under average environmental conditions. This is often used as a management goal.

Mean - Another word for the average of a set of numbers. Simply add up the individual numbers and then divide by the number of items.

Meristics - A series of measurements on a fish, such as scale counts, spine counts, or fin ray counts which are used to separate different populations or races of fish.

Model - In fisheries science, a description of something that cannot be directly observed. Often a set of equations and data used to make estimates.

Mollusk - Organisms in the phylum Mollusca - invertebrate animals with soft unsegmented bodies usually enclosed in a calcareous shell.

Monoculture - The culture of a single bivalve species.

Morphometrics - The physical features of fish, for example, coloration. Morphometric differences are sometimes used to identify separate fish populations.

Most Probable Number (MPN) - A statistical estimate of the number of bacteria per unit volume and is determined from the number of positive results in a series of fermentation tubes.

Mouth – In oysters, the inverted U-shaped slit located between the inner and outer labial palps.

Multiplier - A number used to multiply a dollar amount to get an estimate of economic impact. It is a way of identifying impacts beyond the original expenditure. It can also be used with respect to income and employment.

N

National Shellfish Sanitation Program (NSSP) - The cooperative state-FDA-Industry program for the sanitary control of shellfish that is adequate to ensure that the shellfish produced in accordance with these guidelines will be safe and sanitary.

National Standards - The Fishery Conservation and Management Act requires that a fishery management plan and its regulations meet seven standards. The seven standards were developed to identify the nation's interest in fish management.

Natural Mortality (M) - A measurement of the rate of removal of fish from a population from natural causes. Natural mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is the percentage of fish dying at any one time. The rates of natural mortality may vary from species to species.

O

Omnivorous - Organisms that consume a variety of plant and animal materials.

Open Access Fishery - A fishery in which any person can participate at any time.

Open Water Aquaculture - The cultivation of bivalve shellfish in natural shellfish growing areas.

Opportunity Cost - An amount a fisherman could earn for his time and investment in another business or occupation.

Optimum Yield (OY) - The harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. Optimum yield is different from maximum sustainable yield in that MSY considers only the biology of the species. The term includes both commercial and sport yields.

Overfishing - Harvesting at a rate greater than which will meet the management goal.

P

Parasitic Organisms - Organisms that rely on a host for resources and as a result are harmful.

Pelagic - Refers to fish and animals that live in the open sea, away from the sea bottom.

Pericardial Cavity - Cavity containing the heart.

Phytoplankton - Diverse group of minute plants that drift freely within the water column.

Plant – The act of placing oysters on beds, reefs, and bottoms intending for them to survive, attain full size, and spawn. Also, an oyster, which has been "bedded". See seed.

Point Source - Any discernible, confined, and discrete conveyance including any pipe, ditch, channel, tunnel, or conduit that carries pollution.

Poisonous or Deleterious Substance - A toxic substance occurring naturally or added to the environment for which a regulatory tolerance limit or action level has been established in shellfish to protect public health.

Polyculture - The cultivation of two or more species of shellfish or shellfish with other species in a common environment.

Polyploidy – The condition whereby an organism contains more than two paired sets of chromosomes. Polyploid organisms are usually unable to reproduce.

Population - Fish of the same species inhabiting a specified area.

Population Dynamics - The study of fish populations and how fishing mortality, growth, recruitment, and natural mortality affect them.

Possession Limit - The number and/or size of a species that a person can legally have at any one time. Refers to commercial and recreational fishermen. A possession limit generally does not apply to the wholesale market level and beyond.

Post Harvest Processing – The processing of shellfish for the purpose of added safety or quality that involve hazards not addressed by controls in NSSP Model Ordinance Chapters XI. through XIV.

Predator - A species that feeds on another species. The species being eaten is the prey.

Predator-Prey Relationship - The interaction between a species (predator) that eats another species (prey). The stage of each species' life cycle and the degree of interaction are important factors.

Prey - A species being fed upon by other species. The species eating the other is the predator.

Primary Productivity - A measurement of plant production that is the start of the food chain. Much primary productivity in marine or aquatic systems is made up of phytoplankton which are tiny one-celled algae that float freely in the water.

Process Batch - A quantity of shellstock used to fill each separate tank or a series of tanks supplied by a single process water system for a specified depuration cycle in a depuration activity.

Process Water - The water used in the scheduled depuration process.

Prohibited - A classification used to identify a growing area where the harvest of shellstock for any purpose, except depletion or gathering of seed for aquaculture, is not permitted.

Protandrous Hermaphrodites - The development of maleness before the female phase with the ability to change sex throughout their life cycle.

Protozoans - Single celled eukaryotic organisms belonging to the kingdom Protista.

Psuedofeces - Particles which are not sorted as food and are rejected through the ventral free edge of the mantle adjacent to the labial palps.

Pseudopodia - "False feet" that extend from the hemocyte that enable mobility and capture of foreign bodies and other materials.

Pulse Fishing - Harvesting a stock of fish, then moving on to other stocks or waiting until the original stock recovers.

Q

Quota - The maximum number of fish that can be legally landed in a time period. It can apply to the total fishery or an individual fisherman's share under an ITQ system. Could also include reference to size of fish.

R

Raw - Any shellfish that have not been thermally processed to an internal temperature of 145° or greater for 15 seconds (or equivalent) or do not have altered organoleptic characteristics.

Recreational Fishery - Harvesting fish for personal use, fun, and challenge. Recreational fishing does not include sale of catch. *The term refers to and includes the fishery resources, fishermen, and businesses providing needed goods and services.

Recruit - An individual fish that has moved into a certain class, such as the spawning class or fishing-size class.

Recruitment - A measure of the number of fish that enter a class during some time period, such as the spawning class or fishing-size class.

Recruitment Overfishing - When fishing pressure is too heavy to allow a fish population to replace itself.

Rectum - Organ that is the continuation of the intestine; it runs dorsally over the adductor muscle and ends in the anus, and aborts water while consolidating feces.

Regression Analysis - A statistical method to estimate any trend that might exist among important factors. An example in fisheries management is the link between catch and other factors like fishing effort and natural mortality.

Relative Abundance - An index of fish population abundance used to compare fish population from year to year. This does not measure the actual numbers of fish but shows changes in the population over time.

Relay - The activity of transferring shellstock from a growing area classified as restricted or conditionally restricted to a growing area classified as approved or conditionally approved for the purpose of reducing pathogens as measured by the coliform indicator group or poisonous or deleterious substances that may be present in the shellstock by using the ambient environment as the treatment process.

Remote Status - A designation applied to a shellfish growing area that has no human habitation and is not impacted by any actual or potential pollution sources.

Rent - See economic rent.

Repacker - Any person, other than the original certified shucker-packer, who repackages shucked shellfish into other containers.

Repacking - The practice of removing shellstock from containers and placing it into other containers.

Reshipper - A person who purchases shucked shellfish or shellstock from dealers and sells the product without repacking or relabeling to other dealers, wholesalers, or retailers.

Restricted - A classification used to identify a growing area where harvesting shall be by special license and the shellstock, following harvest, is subjected to a suitable and effective treatment process through relaying or depuration.

S

s - See survival rate.

SPR - See spawning potential ratio.

SSBR - See spawning stock biomass per recruit.

Sack – A unit of measure for oyster harvest that varies from state to state. The term originates from the 'sack' in which oysters are placed following harvest.

Sack Oysters - A production term indicating marketable sized oysters.

Safe Materials - Any articles manufactured from or composed of materials that may not reasonably be expected to, directly or indirectly, become a component of or otherwise adversely affect the characteristics of any food.

Sanitary Survey - The written evaluation report of all environmental factors, including actual and potential pollution sources, which have a bearing on the water quality in a shellfish growing area.

Sanitize - The act of adequately treating food contact surfaces by a process that is effective in: destroying vegetative cells of microorganisms of public health significance; substantially reducing the numbers of other undesirable microorganisms; and not adversely affecting the product or its safety for the consumer.

Seed - Any shellstock which is less than market size.

Selectivity - The ability of a type of gear to catch a certain size or kind of fish, compared with its ability to catch other sizes or kinds.

Shellfish - All species of:

1. Oysters, clams or mussels, whether:
   (i.) shucked or in the shell;
   (ii.) raw, including post harvest processed;
   (iii.) frozen or unfrozen;
   (iv.) whole or in part; and
2. Scallops in any form, except when the final product form is the adductor muscle only.

Shellstock - A live molluscan shellfish in the shell.

Shellstock Packing - The process of placing shellstock into containers for introduction into commerce.

Shellstock Shipper - A dealer who grows, harvests, buys, or repacks and sells shellstock. They are not authorized to shuck shellfish nor to repack shucked shellfish. A shellstock shipper may also ship shucked shellfish.

Shuck - To open oysters and remove the meat.

Shucker - A person who opens oysters.

Shucker-Packer - A person who shucks and packs shellfish. A shucker-packer may act as a shellstock shipper or reshipper or may repack shellfish originating from other certified dealers.

Shucking – The physical act of opening an oyster either mechanically or by hand with a knife.

Simulation - An analysis that shows the production and harvest of fish using a group of equations to represent the fishery. It can be used to predict events in the fishery if certain factors changed.

Size Distribution - A breakdown of the number of fish of various sizes in a sample or catch. The sizes can be in length or weight. This is most often shown on a chart.

Slot Limit - A limit on the size of fish that may be kept. Allows a harvester to keep fish under a minimum size and over a maximum size but not those in between the minimum and maximum. *Can also refer to size limits that allow a harvester to keep only fish that fall between a minimum and maximum size.

Social Impacts - The changes in people, families, and communities resulting from a fishery management decision.

Socioeconomics - A word used to identify the importance of factors other than biology in fishery management decisions. For example, if management results in more fishing income, it is important to know how the income is distributed between small and large boats or part-time and full-time fishermen.

Spat - Used to signify the "set" or oysters immediately after they have become attached to some support. Young oysters typically less than one inch in length.

Spawn - The eggs of the oyster (or any other sea-animal) in their floating condition; but sometimes the "set" or infant oysters.

Spawner-Recruit Relationship - The concept that the number of young fish (recruits) entering a population is related to the number of parent fish (spawners).

Spawning Potential Ratio (SPR) - *The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. SPR can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.

Spawning Stock Biomass - The total weight of the fish in a stock that are old enough to spawn.

Spawning Stock Biomass Per Recruit (SSBR) - *The spawning stock biomass divided by the number of recruits to the stock or how much spawning biomass an average recruit would be expected to produce.

Species - A group of similar fish that can freely interbreed.

Sperm - Haploid gametes produced by males. Also see eggs.

Sport Fishery - See recreational fishery.

Stales – The long wooden handles of a tong. See tongs.

Standardization - The process in which applicable staffs from the FDA and the Authority conduct evaluations using standard criteria in a uniform manner.

Standing Stock - See biomass.

Stock - A grouping of fish usually based on genetic relationship, geographic distribution, and movementpatterns. *Also a managed unit of fish.

Stock-Recruit Relationship - See spawner-recruit relationship.

Stomach - A large sac-like organ that is divided into two chambers used in the digestion and sorting of food particles.

Stressed Area - An area in which there is special concern regarding harvest, perhaps because the fish are small or because harvesters are in conflict.

Surplus Production Model - A model that estimates the catch in a given year and the change in stock size. The stock size could increase or decrease depending on new recruits and natural mortality. A surplus production model estimates the natural increase in fish weight or the sustainable yield.

Survival Rate(s) - The number of fish alive after a specified time, divided by the number alive at the beginning of the period.

Sustainability – The management concept indicating that recruitment and survival of new individuals into the population are at such levels as to offset that portion of the population removed via harvest extraction and/or natural mortality.

T

t – Time Period

TAC - See total allowable catch.

TIP - See trip interview program.

Tentacles - Small sensory organs attached to the edge of the mantle used for the detection of environmental stimuli.

Territorial Sea - The area from average low-water mark on the shore out to three miles for the states of Louisiana, Alabama, and Mississippi and out to nine miles for Texas and the west coast of Florida. The shore is not always the baseline from which the three miles are measured. In such cases, the outer limit can extend further than three miles from the shore.

Tetraploid – An organism bred to have four sets of chromosomes. Tetrapoloids are crossed with diploid organisms to generate sterile triploids for culture operations.

Tonger - One who procures oysters by the use of tongs.

Tongs – A long handled tool used in gathering oysters from the bottom. A tool akin to two opposing yet interconnected garden-rakes so that by operating the extreme ends of the handles the whole contrivance shall scissor together to capture oysters. See stales.

Total Allowable Catch (TAC) - The annual recommended catch for a species for species group. The regional council sets the TAC from the range of the allowable biological catch.

Total Mortality (Z) - A measurement of the rate of removal of fish from a population by both fishing and natural causes. Total mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous mortality is that percentage of fish dying at any one time. The rate of total mortality may vary from species to species.

Trip Interview Program (TIP) - *A cooperative state-federal commercial fishery dependent sampling activity conducted in the Southeast region of NMFS, concentrating on size and age information for stock assessments of federal, interstate, and state managed species. TIP also provides information on the species composition, quantity, and price for market categories, and catch-per-unit effort for individual trips that are sampled.

Triploid– An organism bred to have three sets of chromosomes instead of two, thereby rendering them sterile.

U

Umbo - The anterior end of the oyster. It is pointed and the oldest part of the oyster.

Underutilized Species - A species of fish that has potential for large additional harvest.

Unit Stock - A population of fish grouped together for assessment purposes which may or may not include all the fish in a stock.

V

VPA - See virtual population analysis.

Valves - The two shells of the oyster.

Virgin Stock - A stock of fish with no commercial or recreational harvest. A virgin stock changes only in relation to environmental factors and its own growth, recruitment, and natural mortality.

Virtual Population Analysis (VPA) - A type of analysis that uses the number of fish caught at various ages or lengths and an estimate of natural mortality to estimate fishing mortality in a cohort. It also provides an estimate of the number of fish in a cohort at various ages.

W

Watermen - Individuals who earn an income from harvesting aquatic resources.

Wet Storage - The temporary storage, by a dealer, of shellstock from growing areas in the approved classification or in the open status of the conditionally approved classification in containers or floats in natural bodies of water or in tanks containing natural or synthetic seawater.

Working Waterfront – A shoreline area that offers direct access to water dependent enterprises such as commercial and recreational fishing, aquaculture, boat repair, boat ramps, docks, wharfs, and marinas.

Y

Year-Class - The fish spawned and hatched in a given year, a "generation" of fish.

Yield - The production from a fishery in terms of numbers or weight.

Yield Per Recruit - A model that estimates yield in terms of weight (but more often as a percentage of the maximum yield) for various combinations of natural mortality, fishing mortality, and time exposed to the fishery.

Z

z - See intrinsic rate of increase.

Z - See total mortality.

Z' - See disappearance.

Zooplankton - Diverse group of minute animals that drift freely within the water column.

16.2 Aquaculture/Mariculture

Sections 16.2.1 through Section 16.2.2.4 are taken from Supan (2002) by the author.

16.2.1 Introduction

Oysters have been cultivated to improve their growth and flavor for centuries. On-bottom or extensive oyster culture is the traditional method of farming oysters in the Gulf region and in the United States in general. Off-bottom or intensive culture is conducted in other regions of the U. S. and shows great promise in the Gulf region to diversify the oyster industry. The rights to exclusive water bottom use have allowed the farming of oysters in many coastal states for over 100 years. Such privatization is a classic and highly successful fisheries management policy. Oyster leasing allows the farmer to speculate on the market and to choose when to harvest the crop, allowing maximum economic return on public and private investment.

16.2.2 Extensive Culture

16.2.2.1 Seed Production

Wild oyster production is the traditional source of small oyster seed for farming, although hatchery technology became highly successful along the Pacific Northwest when consistent sources of seed oysters waned. This wild production may occur on private leases or public oyster grounds. Understanding and monitoring of the oyster's life cycle (Figure 3.4) allows the timely planting of cultch material or hard substrate, which traditionally consists of shells. A fresh, unfouled substrate is provided to attract the planktonic oyster larvae that attach or set on the cultch stimulating maximum spatfall of newly settled oysters. Within months, the small oyster spat (<1") grow to seed size (>1") and may be transplanted to private leases, for growth to market-size. In Louisiana, much of the public oyster resource is managed specifically for seed production. Yet in other Gulf States, such as Florida, farmers are prohibited from obtaining seed oysters from public reefs and must exclusively plant cultch material onto their private leases to promote oyster production.

The timing and location of cultch planting are important. Salinities less than 10 ppt throughout the spring and summer inhibit spawning and reduce larval survival, resulting in poor spatfall. When salinities greater than 15 ppt predominate, spatfall may be abundant, but survival may be poor due to increased fouling, predation, and disease. Submerged water bottoms should be firm, reef being the hardest and most suitable, to support the cultch and prevent the resulting attached oysters from sinking and being smothered by sediment. High-pressure hoses or water cannons may be used to wash cultch overboard evenly, usually over existing oyster grounds, at 50-100 yd^3/acre. Cultch is primarily composed of oyster shells since they reportedly "float" on soft muddy water bottoms due to their high surface-to-weight ratio and are generally available from oyster processing (i.e., shucking) facilities. *Rangia* clam shells are also utilized since their individual size and shape foster single oysters of desired shape to predominate, reducing culling (i.e., separating oysters from extraneous shell) and other labor during harvest. Surf clam shells are used as cultch, as well, along some Atlantic coast states. Other cultch materials have been tested and used, including crushed concrete, limestone, cement-fly ash mixture (Homziak et al. 1990), and other aggregates. However, it is the timing of the cultch planting, rather than the specific material, which maximizes success. Planting cultch when oysters are spawning and larvae are in the water column allows a natural biofilm to develop on the cultch (Weiner et al. 1989), and attract the pediveliger larvae to set before other fouling organisms (e.g., barnacles, algae, bryozoans, etc.) out-compete the spat for space and food.

16.2.2.2 Lease Selection

A 'private oyster lease' is a legal document or agreement between a state and a leaseholder that delineates an area of water and/or waterbottom, by survey, allowing exclusive use for growing oysters, which may or may not include subservient clauses. Oyster leases may be heritable, salable, and transferrable. Substrate type is the main criterion for selecting a lease site. The presence of naturally occurring oysters and shell is a typical sign of a good site. A cane or metal pole is the standard method used by Gulf oyster growers to sound the bottom for determining firmness. Repeated light tapping of the bottom while traversing an area via boat will tell the operator whether reef, scattered shell, sand, firm bottom, or soft mud predominates. SCUBA diving is also used to visually assess bottom type. Reef is not necessary; firm, sandy clay-mud can support oysters adequately. Hard sand should be avoided for extensive oyster farming; its shifting nature can smother a crop. Dragging a rope-drawn chain across the water bottom is another method used to feel for hard substrate 'signals'. Hydroacoustics (e.g., side-scan sonar) is a newer technology used in assessing substrates, but at present is primarily used by state resource managers due to cost.

Salinity is another important criterion in site selection. Salty oysters are highly prized in the marketplace, but high salinities bring a wrath of problems causing high oyster mortality, caused by oyster drill and conch predation, or from oyster diseases caused by parasitic protozoans such as Dermo (*Perkinsus marinus*) and, along the Atlantic Coast, MSX (*Haplosporidium nelsoni*). Low salinity regimes may allow high hooked mussel (*Ishadium recurvum*) infestation to smother a crop, causing reduced growth, reduced meat yield, and increased labor and operating costs. Black drum (*Pogonias cromis*) and cow-nose ray (*Rhinoptera bonasus*) predation can be problematic in some lease locations; large schools of these fish can decimate a crop by crushing and feeding on the oysters. Crops may be moved to different leases by oyster growers to manage such pestilence.

Tidal current is important for producing quality oysters. Fast tidal current provides large amounts of natural algal food for fast oyster growth and high meat yield. Current, combined with salinity, helps to shape and flavor oysters, forming cupped and scalloped or lightly fluted shells, and assists in the development of name recognition of oyster grounds in the marketplace.

The National Shellfish Sanitation Program (NSSP) addresses public health issues regarding molluscan shellfish within the Interstate Shellfish Sanitation Conference (ISSC). Under this program, oyster growing waters are classified by state shellfish sanitation agencies (e.g., public health, resource management) as approved, restricted, or prohibited for shellfishing based on routine monitoring of fecal coliform bacteria and other water quality parameters, as well as shoreline point-source surveying. Conditionally approved areas are periodically open for harvest during certain times of the year, depending on pollution dispersing events that degrade bacterial water quality, including high rainfall and river discharge in a given watershed. State shellfish control authorities map these classified areas as open or closed to harvesting on a seasonal or annual basis. These maps should be consulted prior to lease selection to determine pollution impacts on oyster farming operations.

The location of available seed and distance to the lease are important economic factors in reducing planting expenses. Locating leases near wild seed grounds reduces transit costs during seed planting and harvesting for market. Therefore, labor, maintenance and fuel costs can be reduced by good initial site selection. Lease distance from the dock is becoming a greater factor with changing harvesting regulations and affects farm management decisions, investment and operating costs.

16.2.2.3 Farming Practices

If permitted, seed oysters may be harvested from public oyster reefs during a state's oyster season using gear permitted by the state, or from farmers' own leases that naturally produce seed oysters. Generally, planting occurs in the fall and early winter to reduce harvest damage of the reefs during the summer, when oyster spawning and recruitment is greatest. The seed may be planted at various densities by circling the lease while spraying the oysters overboard, to obtain an even distribution reportedly ranging from 42-110 oysters/yd^2. Many farmers plant leases in different locations each year, due to the unpredictability of the estuarine environment. It may take several weeks to transplant large amounts of seed, reportedly >20 days to move 6,000 barrels.

If estuarine conditions change substantially, it may be in the best interests of the farmer to move his crop to another, more favorable, lease location. When the oyster seed are moved to high saline leases, growth rapidly increases, with seed reaching market-size within six to nine months in the Gulf of Mexico region. Farmers may work the public oyster grounds or other leases for market-size oysters until the planted seed are ready for harvest. Returns of 1.2 bushels of market oysters per 1 bushel of planted seed is a reasonable average return, yet returns of 0 to 4.0 bushels/bushel of seed have been reported (Melancon and Condrey 1992).

The ideal oyster lease has enough cultch material to attract natural oyster production so that no seed planting is necessary. The farmer may use the lease as a source of seed for other leases and/or to harvest market-size oysters while the public oyster grounds are closed to harvesting.

Dockside prices are affected by a number of factors, including high and low oyster production cycles and can be affected by the opening and closing of states' public oyster grounds to harvesting within a given region. The more successful farmers are very attentive to market conditions and harvest their crops to meet specific market demands. Some leases may be left alone to grow larger oysters for processing (shucking), or managed for producing smaller oysters for the half-shell trade. Good business practices allow farmers to know and control their production costs, yet dockside price may or may not be high enough to produce a profit. This is greatly affected by which market is being supplied.

16.2.2.4 Permitting and Licensing

Molluscan shellfish are the most regulated food in the United States (NSSP 2010). Public health controls are necessary to ensure that raw oysters are harvested from estuarine waters uncontaminated by human pathogens. Shellfish sanitation programs in many states are funded by permit and license fees that are paid by oyster harvesters and processors. The management of the wild oyster fishery by individual states, and hence the seed grounds, requires funding obtained usually from the sale of licenses and other fees. Annual lease rent, as well as harvesting, gear, and vessel licenses, may be required. To harvest from conditionally approved and restricted shellfish growing waters for depuration (i.e., purging shellfish of contaminants by exposing them to clean waters), permits and performance or security bonds may be required (Section 6.6).

16.2.3 Intensive Culture

Hatcheries can spawn billions of oyster larvae during a production season for producing cultched (e.g., on-shell) and cultchless (i.e., single) oyster seed for both extensive and intensive culture, using off-bottom containment systems. Seed nursery methods are dictated by what type of grow-out method will be used. As with all aquaculture, site selection is important, for not all water quality problems can be addressed cost effectively with water treatment technology.

16.2.3.1 Hatcheries

Hatcheries are on-shore operations that spawn adult oysters to culture larvae at high densities (1-100/ml) in tanks of ambient filtered seawater, while culturing specific strains of microalgae as food for larvae, seed, and/or broodstock. Hatcheries may be operated in the Gulf region as small, seasonal, independent companies just producing larvae using open-air confines without the need for heated seawater and insulated building(s) to large operations in specialized buildings within a vertically integrated company that produces and processes market-size oysters. The usual end product is 'eyed' larvae (i.e., pediveligers), due to the appearance of an eye spot on the larval shells and a 'foot' for crawling when reaching setting size. Hatcheries may have nursery components where the pediveligers are set on-site, or the larvae may be shipped to nursery operations for setting in remote locations.

16.2.3.1.1 Site Selection

Bivalve hatcheries are environmentally sensitive operations, demanding high water quality to achieve consistent success. Watershed evaluation is a critical method of determining point and non-point sources of pollution, particularly chemical. Examples of operations in the watershed to be aware of include: 1) heavy industry producing harmful effluents, such as produce water from oil refineries or natural gas plants, heavy metals, highly organic substances that produce elevated Biological Oxygen Demand (BOD); 2) boat yards, where anti-fouling paint is either removed or applied; 3) heavy chemical pesticide and/or herbicide applications for mosquito or weed control; 4) high density marinas, where bilge discharge is permitted; and/or, 5) poorly operated sewage treatment systems that have high BOD and chlorine-residual effluents. State agencies (i.e., natural resource, public health, and environmental) have databases to glean information to assist in hatchery site selection. Poor water quality will show up first at bivalve hatcheries due to the sensitivity of its operations.

Consistent salinity is a primary criterion for hatchery operations. Although oysters are euryhaline, oyster larvae are cultured in much higher densities than occur in the wild and respond negatively to dramatic shifts in daily salinity. Thus, riverine influence and local storm drainage can be problematical not only for carrying pollution but also causing dramatic shifts in ambient salinity. Hatcheries' high-density algal production systems are particularly sensitive to changing salinity. To address this, some hatcheries use saltwater wells for algal production, but few use them for larval rearing, due to the inorganic compounds that may be present in ground water that can be beneficial to algal culture but detrimental to larval rearing.

16.2.3.1.2 Broodstock

Bivalve hatcheries produce larvae by spawning ripe (i.e., sexually mature) adults. Broodstock maintenance, therefore, is a critical component in hatchery management to produce high quality gametes, especially eggs, for high larval competence. Adult oysters may be held near-shore in containers off docks or piers awaiting future containment inside the hatchery. All hatcheries have broodstock systems to hold ripe animals or condition them to ripeness by manipulating the system's water temperature and adding food. Researchers have proven artificial means of initiating ripeness, either via individual injection of serotonin (Matsutani and Nomura 1982), or providing supplemental non-algal feed (Buchal and Langdon 1995), but such methods are not typically used in commercial hatcheries.

16.2.3.1.3 Larval Rearing

As larvae are reared in tanks, they grow from egg (e.g., 50μ) to setting size (e.g., 320μ) over

10-12 days at 28ºC with lower water temperatures lengthening the rearing time. Tank cultures are aerated, may be static or flow-through, and are typically serviced every 48 hours by draining water over screens of specific mesh size to remove the larvae for macro and microscopic evaluation while cleaning (e.g., weak soap, bleach, or muriatic acid solutions) and rinsing the emptied tanks prior to refilling with seawater. More tanks and space may be required as the larvae grow, depending on brood size. Once the larvae reach setting size, they are harvested using a specific sized screen (i.e., depending on species and ploidy) and may be added directly to a setting tank of cultch material, or wrapped in wet paper toweling and placed in the refrigerator at 5ºC for storage or shipment for 1-5 days.

16.2.3.1.4 High Density Algal Rearing

Algal culture is a major component to hatchery operations. Several genera (*e.g., Isochrysis, Chaetocerous, Tetraselmis, Pavlova)* of microalgae of different clones (e.g., C-ISO, T-ISO, CHGRA, PLY424) specific for certain temperature and salinity regimes may be reared to feed broodstock, larval, and nursery systems. Selection is based on either past, published research results to individual hatchery or nursery performance. Hatcheries typically maintain axenic stock cultures in isolated algal rooms to maintain purity for restarting algal operations. Culture systems may include batch (i.e., solar tubes and tanks) or continuous cultures (i.e., bags) with vigilance of keeping pure cultures, free of bacterial and algal contamination via air and water. This requires simple and/or sophisticated filtration and management techniques to maintain dependable cultures to meet hatchery and/or nursery needs. High density cultures require high light intensity and nutrient supplements to maintain optimal growth and nutritional value. Therefore, it is common to see hatcheries use sophisticated lighting and add nitrogen, phosphorous, and iron-based nutrients and carbon dioxide gas to cultures to fortify dense algal growing conditions.

16.2.3.2 Nurseries

Once hatcheries produce competent larvae, they may be set on whole (e.g., shell) or micro- (e.g, crushed shell, corral, or limestone) cultch, either on-site or shipped to remote nursery locations. Remote setting (Supan 1991) allows hatcheries to serve regionally and nationally and improves economies-of-scale.

16.2.3.2.1 Methods

16.2.3.2.1.1 Cultched Seed

Cultched seed are used for extensive culture. Tanks of aged (i.e., dried for >6 months to allow), washed shell in various containment (e.g, mesh bags, trays, baskets, etc.) are filled with coarsely-filtered ambient water and aerated to disperse the added larvae. Algal food, either grown on-site or mixed from commercially available concentrates, may or may not be used, depending on local natural productivity of the water. Tanks are usually covered to allow the negatively phototaxic larvae to evenly disperse and set on the cultch. Setting typically occurs within 48 hours depending on water temperature, so heaters may be used to maintain optimal setting conditions. Once set, the cultch is removed from the tanks and deployed either directly to the growing area or in a nearshore nursery situation for hardening and to achieve refuge size to deter predation.

16.2.3.2.1.2 Cultchless or Single Seed

Single oyster seed are used for intensive culture, typically grown off-bottom (Section 16.2.3.3.1). Tanks or trays of washed, graded micro-cultch, such as crushed shell, coral, or dolomite, may be used. Single seed can also be obtained by temporarily treating the larvae to a very low concentration of epinephrine (Coon et al. 1986) to induce metamorphosis. Nursery systems are used to obtain the desired seed size prior to deployment, depending on the size mesh that will be used during grow-out.

Nurseries may involve tanks or raceways with trays to contain the seed, or silos, made from buckets, drums or other tubular plastic or fiberglass containers. Silos are the most efficient, since they provide the most direct delivery of food-laden water to the seed. High ambient water flow may be directed downward through the seed when small (i.e., downweller nursery) so that the seed don't float out (e.g. <10mm), or directed upward through the seed mass (i.e., upweller nursery) when the seed have grown heavy enough to stay in the nursery. Nurseries may be shoreside, pump-driven systems or nearshore, floating, propeller-driven upweller systems (i.e., flupsies) (Hadley and Whetstone 2007).

Seed are graded using various screen sizes to obtain a specific size range for placing into a larger mesh silo for faster nursery growth or for deployment to grow-out (Wallace et al. 2008).

16.2.3.3 Grow-Out

Methods for growing seed to market-size oysters depend on site selection and economics. Shallow (i.e., < 5 inches) or intertidal areas are more conducive for some methods, while deeper or subtidal waters allow different approaches. Deeper waters allow greater vertical deployments of longlines or stacks of containers, improving economies of scale, while shallow waters require greater horizontal deployments to achieve ideal scale, but at greater surface acreage. All grow-out methods should keep the oysters off the bottom, where predators are more prevalent.

High wave energy sites are usually avoided since they require systems with greater engineering and, thus, cost. Hence, site selection should include issues stated above, but also include fetch, wind direction, tide, current, and navigation.

The greatest obstacle to all off-bottom culture systems is biofouling; keeping mesh clean to allow suitable water flow through the oysters for adequate food delivery is key to success. Labor is driven by fouling control. Site selection, system design and use are important decisions on controlling maintenance costs and achieving financial success.

16.2.3.3.1 Methods

Rack culture is a classic method of deploying cultched and cultchless oysters off the bottom for grow-out. Racks are typically made of wood or bamboo, are set into the waterbottom, and rise out of the water for tying ropes or strings of spat-on-cultch for grow-out, or for suspending containers of single oysters. Rack and bag culture typically involves placing seed into individual, rectangular, mesh bags that are placed on racks of bent rebar to hold the bags a foot off the waterbottom. The bags are fastened to the racks with clips to keep them in place. Maintenance requires flipping the bags over periodically to keep the oysters from growing through the mesh. This also prunes the oysters to help make them cup. Rack and bag culture is mostly used in intertidal zones, where daily aerial drying helps deter biofouling of the mesh and oysters (Flimlin 2000).

Raft culture is a classic method of suspending oysters in water too deep for rack culture. Vertical longlines of spat-on-shell or containers of single oysters are also deployed in this manner. Individual floats are also used to suspend oysters for grow-out in the water column. Floatation may be provided with blocks or tubes of Styrofoam, buoys, sealed PVC pipe, or plastic drums. Grow-out containers may be any size or shape, as long as the mesh size allows adequate water flow through the oysters. Water depth is the main criteria for which type of float system is used, which dictates how deep a suspension is allowed.

Horizontal longlines are used to suspend mesh bags of oysters off-bottom. This can be achieved with individual floatation in each bag or using vertical poles anchored in the waterbottom to suspend the longlines at regular intervals. This Adjustable Longline System (ALS) can be designed to adjust the height of the longlines in the water column to allow daily, tidal, aerial exposure to control biofouling, or to place the bags in wave action to prune the oysters for improved shape and growth. This hardware intensive system can create user conflicts on public waters and should be deployed in public waters zoned for aquaculture use (Maxwell et al. 2006)

16.2.4 Genetics

Oyster genetics research, i.e., polyploidy, disease-resistance, germplasm transfer, has created superior oyster stocks for culture (Guo and Allen 1994, 1997, Guo et al. 1996).

16.2.4.1 Triploid Oysters

Reduced yield of oyster meat in the summer due to oyster spawning dramatically affects profitability in the oyster industry. Triploid oysters offer a useful remedy to this problem. Triploids are sterile because they contain three sets of chromosomes rather than two, like normal diploid oysters (Allen et al. 1989). Sterile triploid oysters do not spawn, so they keep their winter glycogen stores or ‘fat’ throughout the summer, making them a potentially new ‘summer crop’ for the oyster industry (Figure 16.1).

Triploid shellfish are produced at hatcheries during natural and induced spawning techniques that manipulate oysters’ own chromosomes.

Triploids are ideally produced by crossing normal diploid oysters with a specialized broodstock, tetraploids. Tetraploid oysters are created through research by chromosomal manipulation of triploid female oysters that, in rare instances, produce viable eggs large enough to accommodate a larger nucleus from increased chromosome number. The resulting tetraploid oysters are normally sexually reproductive, and can be spawned to produce more tetraploids, or can be used to produce triploid oysters. Tetraploids are not for consumption, but a broodstock line specifically for hatchery production of triploids.

Disease resistance can also be genetically created through broodstock development. Through research, oysters have been created that are resistant to Dermo through subsequent generational challenges. The result is a broodstock line that produces an oyster that survives disease to market size, to be harvested prior to succumbing to the disease. Such resistance has been produced at regional hatcheries by natural selection, producing broodstock lines for each oyster producing region to supply disease resistant seed oysters to farmers.

16.2.5 Effluents

All hatcheries use mechanical filtration to remove sediment, zooplankton and other particulates from ambient water for improved larval and algal rearing. Filtration systems are regularly backwashed during daily maintenance procedures and can produce concentrated effluents during short periods of time, but have little environmental consequences since such products were locally removed in the first place. Hatcheries also use small amounts of cleaning agents, (i.e., bleach, soap, and muriatic acid) to clean tanks, bottles and other culture vessels.

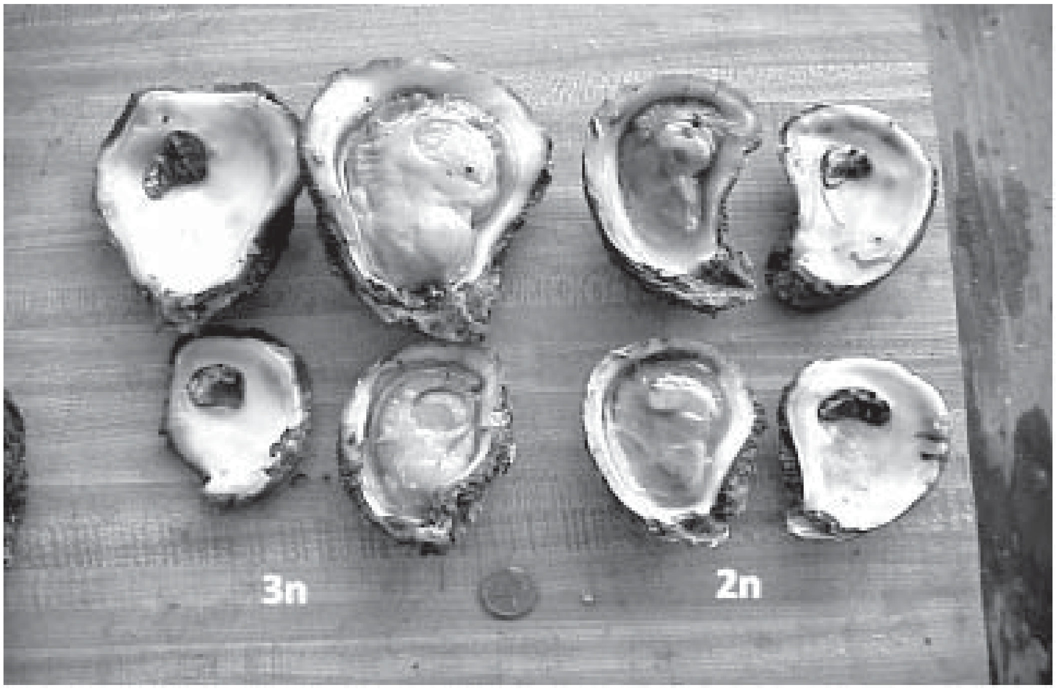

Figure 16.1 A comparison of typical summer meat condition of non-sibling triploid (3n) and diploid (2n) oysters grown in Caminada Bay, Louisiana. The photograph was taken during August.

Nursery operations primarily use raw ambient water to provide algal food to the seed and have cleaner effluents than ambient water due to oyster filter-feeding.

16.2.6 Oyster Gardening

Oyster gardening is a popular oyster recovery program being conducted in selected estuaries along the eastern and Gulf coasts. It is the recreational culture of select seedstock produced by hatcheries to adult size for oyster population recovery efforts and fish habitat. The ‘oyster gardener’ obtains seed from a nearby hatchery or recovery program, and places it in homemade oyster floats tied to piers or docks, where the oysters filter the water in the process of growing to increase the filtration capacity of ambient waters and provide adult oysters for subsequent reef reclamation projects.

The benefits of this programming are many. It is used as a basis of public environmental awareness, showing the filtration role oysters play in the estuary. It fosters individual participation and stewardship in a state’s oyster program. It typically involves those with no previous participation in the oyster fishery. The effect of the program’s contribution to resource management depends on the level of participation.

The detriments of oyster gardening are primarily public health considerations. Most oyster gardening efforts are conducted off home piers and other waterfront properties. These areas may or may not be located in approved shellfish growing waters. There is risk associated with contaminated oysters being directly or indirectly taken for human consumption instead of for the gardening program’s purpose. These issues are being addressed by the Interstate Shellfish Sanitation Program and state shellfish sanitation authorities.

16.2.7 Zoning

Zoning is a useful management tool by public entities to isolate certain activities to certain locales to help keep detrimental impacts to others from occurring. Industrial parks are a good example of siting certain businesses and industry together to foster economic development, while isolating such development from residential or environmentally sensitive areas (i.e., wetlands).

Hatcheries and nurseries are usually shore based or near-shore operations that have little environmental impacts, and in most cases, improve ambient water quality. Since certain watershed activities can negatively impact these operations, hatcheries and nurseries are usually sited by the operator in as pristine locations as possible.

Grow-out operations are typically sited in approved shellfish growing waters to allow direct harvest to market without the costly expense of purifying the oysters. Some intensive grow-out operations, creating structure in the water, can cause navigational hazards and should be located in non-navigable waters or in areas zoned for such use.

16.2.7.1 Potential

Industrial parks are areas permitted and/or zoned for the operation of prescribed businesses without the need for individual permitting. Such community programming is commonly used in the economic development of inner cities and rural areas across the nation. The U.S. Economic Development Administration provides guidelines for industrial parks to help foster their development and implementation (Stark et al. 1988). This same concept can be applied to coastal areas through establishment of aquaculture parks or marine enterprise zones as areas of coastal water delineated and permitted for certain farming activities, while carefully evaluating technical, economic, and legal considerations that may be obstacles to future sustainable aquaculture in the U.S. coastal zone.

The concept of state aquaculture parks was proposed in March 1989 by the National Research Council's Committee on Assessment of Technology and Opportunities for Marine Aquaculture in the U.S.

"Entrepreneurs could lease space, and infrastructure and be covered by an umbrella permit. Such parks would foster commercial operations, but even more importantly, would foster commercialization (i.e., parks could play an important role in technology transfer). A planned linkage between the technology centers and such aquaculture parks would facilitate the deployment of new technology" (NRC 1992).

A well-planned and administered aquaculture park can circumvent user conflicts, navigation, security, and liability issues that may otherwise hinder the aquacultural use of coastal waters. A public entity, such as a port commission, could be the authority that: (a) selects the site, (b) obtains public input, necessary permits, and Coast Guard approval, and (c) administers park operations, such as maintaining navigational aids, leasing areas to farmers, providing security, etc. Such projects can be collaborative efforts of public, industry, and university partners to establish, evaluate, and demonstrate advanced culture technologies as a cornerstone of coastal economic development by creating demand and jobs for producing and supplying seedstock, culture supplies, equipment, and labor, and by helping stabilize seafood production.

Such progressive planning, permitting, and funding have produced great economic impact in the Gulf region. Florida's hard clam industry grew from 23 million seed clams planted in 1989 to 400 million in 1999 and is now valued at over $37 million (Adams and Van Blokland 1995, FASS 1990, 1994, 1998, Chew 1999). This was initiated by job training for displaced gill-net fishermen who lost their income as a result of legislation.

The Gulf oyster industry faces many challenges, including water pollution, mortality from oyster disease and predation, public health issues, and coastal erosion. Intensive (off-bottom) culture systems, including rafts, racks, and longlines, utilize the water column to increase food availability. These methods make more efficient use of growing space, promote faster oyster growth, enhance meat yield, and increase survival from predators. These methods are commonly used around the Pacific Rim (Quayle and Newkirk 1989), the Northeast U.S. coast (MVSG 2002), and in Europe (Claus et al. 1981), but potentially create user conflicts between recreational and commercial interests in U.S. coastal waters. This can be greatly lessened through community planning with input from all partners to create marine enterprise zones for specific purposes like intensive oyster culture. Applying these culture systems in high salinity areas increases suitable oyster culture habitat, provides superior growth and survival in areas that cannot support profitable extensive culture, and helps adjust the industry farming practices away from inshore coastal restoration areas.

The technical advancements in shellfish culture around the world have been generally limited to specific areas in conjunction with biological and physical parameters, to increase yield, reduce labor, and produce the highest quality. Improved shell shape, flavor, appearance, grow-out times, survival, and shelf-life can all be achieved pre-harvest by a shift from extensive culture to that of mid-water or intensive culture. Fouling organisms are a major problem in bivalve culture (Enright 1993), affecting growth and labor costs. Methods to control biofouling and secondary set and to optimize handling parameters are needed to reduce labor cost. Additionally, since natural phytoplankton is utilized during grow-out, bivalve culture creates little effluent. This de-emphasizes the environmental issues that have recently plagued finfish mariculture in public waters (Nash 1995).

The National Aquaculture Act (NAA) of 1980 and its reauthorization in 1985 establish and promote a national policy supporting the sustainable growth of the U.S. aquaculture industry (see Section 7.1.3.18 for background). The Joint Subcommittee on Aquaculture (JSA) was established by the NAA and has been conducting and supporting research on aquaculture for the past two decades (NRC 1992). The National Aquaculture Development Plan of 1984, issued by the JSA, recognized that impediments in laws and regulations, science/technology, were continuing to stifle the growth of the national aquaculture industry (JSA 1984).

Many of these impediments identified almost 20 years ago still exist. Therefore, research, analysis and suggested amendments to the present structure remain a relevant and timely issue to streamline permitting and policy interpretations that inhibit the implementation of coastal aquaculture.

16.3 Management Issues related to Public Health

16.3.1 *Vibrio parahaemolyticus* (*V.p.*) Control Plans

All the Gulf states are required to have a *V.p.* Risk Management Plan. Each state's plan is essentially the same with regards to limited summer harvest times, but there may be differences in some of the allowances (e.g., PHP harvest, harvest for shucking only, earlier harvest times, etc.).

All producing states were required to conduct a risk assessment and determine whether or not additional controls were necessary. The FDA provided a *V.p.* risk calculator model for the states to use to determine which harvest times would offer the required protection based on several modeling factors, such as average ambient air and/or water temps, productivity, *V.p.* log reduction, etc. No states were required to use the *V.p.* risk calculator if appropriate management plans would offer the same level of protection as the calculator.

Below is a summary of each state's unique control options for *V.p.* For the complete control plans, contact the individual state shellfish control authorities.

16.3.1.1 Alabama

Alabama is requiring that oysters harvested between June 1 and September 30 be placed under refrigeration within five hours of harvest (based on average water temperatures exceeding 81°F). However, oysters harvested in Alabama outside the five hour restriction can be labeled "For PHP Only." Shellstock oysters harvested and tagged "For Shucking Only by a Certified Processor" outside of Alabama and processed in Alabama can be labeled "For Shucking Only by a Certified Processor" and "For PHP Only."

16.3.1.2 Florida

Florida is requiring that oysters harvested between June 1 and September 30 be placed under refrigeration within five hours of harvest (based on average water temperatures exceeding 81°F). Oysters may be harvested outside of the five hour restriction but they must be labeled "For Shucking Only by a Certified Processor" or "For PHP Only."

16.3.1.3 Louisiana

Louisiana is requiring that oysters harvested between June 1 and September 30 be placed under refrigeration within five hours of harvest or be labeled "For Shucking by a Certified Processor or Post Harvest Processing Only".

16.3.1.4 Mississippi

Mississippi has concluded that *V.p.* is not a reasonably likely risk based on the absence of illnesses/outbreaks, existing harvest practices, and annual closure of the public oyster fishery from May through August (sometimes September). However, the state has taken steps to voluntarily implement controls consistent with the NSSP *V.p.* Control Plan for lease holders who are permitted to harvest during the summer. Mississippi has authority to establish whatever controls it deems appropriate for lease holders. Under that authority, lease holders can only harvest after sunrise and must have their oysters under refrigeration by 11:00 AM. This approximates a five hour to refrigeration control from June through August for lease holders. If unable to refrigerate oysters by 11:00 AM, Mississippi allows a lease holder to label "For Shucking Only by a Certified Processor" or "For PHP Only".

16.3.1.5 Texas

Texas regulation prohibits the harvest of oysters between May 1 and October 31 except in Galveston Bay where harvesting is permitted from private leases. Under its existing authority, Texas has established new time to refrigeration controls for Galveston Bay private lease holders. Harvest to refrigeration limitations for lease holders in Galveston Bay include seven hours in May, five hours in June through September, and ten hours in October. For harvesters not meeting these requirements, oysters can be labeled "For Shucking Only by a Certified Processor" or "For PHP Only".

16.3.2 *Vibrio vulnificus* (*V.v.*) Control Plans

At the 2001 annual meeting, the state voting delegates agreed on a plan to reduce the rate of illnesses due to the consumption of commercially harvested raw or undercooked oysters reported in California, Florida, Louisiana and Texas. The plan was first to reduce the illness rate by 40% for years 2005 and 2006 (average) and by 60% for years 2007 and 2008 (average) from the average illness rate of 0.306/million for the years 1995-1999. *V.v.* Illness Source States are those states reporting two or more etiologically confirmed shellfish-borne *V.v.* illnesses since 1995 traced to the consumption of commercially harvested raw or undercooked oysters that originated from the waters of that state. Those source states are Texas, Louisiana, Mississippi, Alabama, and Florida. The 40% illness reduction rate was met but the 60% goal was not met.

Several steps were thus to be taken by all the Gulf states and completed by May 1, 2010 and could include increased educational efforts, limited harvest restriction, reduction in time from harvest to refrigeration, quicker oyster cool down at the processor, on-board vessel cooling, phased-in PHP, or other equivalent controls.

The states may use the FDA *V.v.* risk calculator in establishing specific control for distinct harvest areas.

16.4 Growing Area Classification

As noted in Section 6.2, one of the goals of the NSSP is to control the safety of shellfish for human consumption by preventing its harvest from contaminated growing areas. The direct relationship between sewage pollution of shellfish growing areas and disease has been demonstrated many times (Table 16.1). Shellfish-borne infectious diseases are generally transmitted via a fecal-oral route which usually begins with fecal contamination of the growing waters. Feces/pathogens on land can run off into surface waters. These standardized growing area classifications are determined after the state shellfish control authority (Authority) completes the appropriate sanitary surveys.

16.4.1 Bacteriological Standards

The NSSP recognizes the use of two different indicator organisms, fecal and total coliforms, for evaluating shellfish growing water quality. The water quality standards for the two indicators are numerically different from one another but are believed to afford the same level of public health protection. The Authority may use either of the indicators and their companion water quality standard in any growing area.

16.4.2 Bacteriological Survey

The NSSP recognizes two water quality-monitoring strategies: adverse pollution condition and systematic random sampling. Presence of point sources of pollution requires the use of the adverse pollution condition sampling strategy to collect data for the application of the water quality standard. In growing areas not affected by point sources, the state may elect to use either system. The presence or absence of point sources of pollution and the water sample monitoring strategy used dictate the frequency of samples that must be collected. If the water quality meets approved classification water quality standards, the growing area is placed in the approved classification. If the water quality does not meet the water quality standards for the approved classification or meets the water quality standards only under certain conditions, the Authority places the area in another more suitable classification. The location of water sample collection stations can markedly affect the water quality detected. The NSSP requires that stations be of sufficient number and located

Table 16.1 Action levels, tolerances and guidance levels for poisonous or deleterious substances in seafood. ***Note**: the term "fish" refers to fresh or saltwater fin fish, crustaceans, other forms of aquatic animal life other than birds or mammals and all mollusks as defined in 21 CFR 123.3(d)* (from FDA 2001).

Class of Substance	Substance	Level	Food Commodity[a]	Reference
Deleterious Substance	Aldrin/Dieldrin[c]	0.3 ppm	All Fish	CPG sec 575.100[b]
	Chlordane	0.3 ppm	All Fish	CPG sec 575.100[b]
	Chlordecone[d]	0.3 ppm	All Fish	CPG sec 575.100[b]
		0.4 ppm	Crabmeat	CPG sec 575.100[b]
	DDT, DDE, TDE[e]	5.0 ppm	All Fish	CPG sec 575.100[b]
	Diquat[g]	0.1 ppm	All Fish	40 CFR 180.226
	Glyphosate[g]	0.25 ppm	Fin Fish	40 CFR 180.364
		3.0 ppm	Shellfish	40 CFR 180.364
Toxic Elements	Arsenic	76 ppm	Crustacea	FDA Guidance Document
	Cadmium	86 ppm	Molluscan Shellfish	FDA Guidance Document
		3 ppm	Crustacea	FDA Guidance Document
	Chromium	4 ppm	Molluscan Shellfish	FDA Guidance Document
		12 ppm	Crustacea	FDA Guidance Document
	Lead	13 ppm	Molluscan Shellfish	FDA Guidance Document
		1.5 ppm	Crustacea	FDA Guidance Document
	Nickel	1.7 ppm	Molluscan Shellfish	FDA Guidance Document
		70 ppm	Crustacea	FDA Guidance Document
	Methyl Mercury	80 ppm	Molluscan Shellfish	FDA Guidance Document
		1.0 ppm	All Fish	CPG sec 540.600
	Heptachlor / Heptachlor Epoxide[f]	0.3 ppm	All Fish	CPG sec 575.100
	Mirex	0.1 ppm	All Fish	CPG sec 575.100
	Polychlorinated Biphenyls (PCBs)[g]	2.0 ppm	All Fish	21 CFR 109.30
	2,4-D[g]	1.0 ppm	All Fish	40 CFR 180.142
	Paralytic Shellfish Poison (PSP)	80 µg/100g	All Fish	CPG sec 540.250
Natural Toxins	Neurotoxic Shellfish Poison (NSP)[e]	20 MU	Clams, mussels, Oysters, fresh frozen or canned	NSSP MO
	Amnesic Shellfish Poison (ASP)	20 ppm	All Fish (except in the viscera of Dungeness crab where 30 ppm is permitted	Compliance Program 7303.842

a) Unless otherwise specified, the action levels, tolerances and other values listed apply to both the raw and processed food commodity. Procedures for sample collection and analyses are specified in Sections 420 and 450 of the ***FDA Investigations Operation Manual***; ***FDA Pesticide Analytical Manual*** **(PAM)** Volume I or II; ***AOAC Official Methods of Analysis***; ***APHA Recommended Procedures for the Examination of Sea Water and Shellfish***, Fourth Edition, 1970; or, peer reviewed literature for domoic acid (ASP) methodologies.

b) References designated as CPG represent the FDA Compliance Policy Guides and all associated numbers as they appear in appropriate sections of FDA's Compliance Policy Guides Manual.

c) The action level for aldrin and dieldrin are for residues of the pesticides individually or in combination. However, in adding amounts of aldrin and dieldrin do not count aldrin or dieldrin found at the level below 0.1 ppm for fish.

d) Previously listed as Kepone, the tradename for chlordecone.

e) The action level for DDT, TDE, and DDE are for residues of the pesticides individually or in combination. However, in adding amounts of DDT, TDE, and DDE do not count any of the three found below 0.2 ppm for fish.

f) The action level for heptachlor and heptachlor epoxide are for the pesticides individually or in combination. However, do not count heptachlor or heptachlor epoxide found below 0.1 ppm.

g) The levels published in 21 CFR and 40 CFR represent tolerances rather than guidance levels or action levels.

to capture the effect of pollution sources so that the water quality affecting the shellfish can be adequately evaluated.

A field sampling and data analysis design that employs a systematic random sampling plan, assumes that all meteorological, hydrographic, and/or other pollution events will be represented and included in the data set. Therefore, all shellfish growing area data collected shall be used during classification. Application of the water quality standards under the NSSP is based on the collection of a specified minimum number of samples at a specified frequency over a three year period. When a new growing area is under evaluation for classification, three years of historic data may not exist. This section sets the minimum number of samples that must be collected as part of the required sanitary survey to determine the appropriate growing area classification for these new growing areas. The requirements are more stringent for growing areas that have pollution sources that affect water quality. No water quality samples are required to place a growing area in the prohibited classification.

Based on the information gathered in the sanitary survey, the Authority determines the appropriate classification of the shellfish growing area. The Authority makes a decision to place a growing area in either the approved, conditionally approved, restricted, or conditionally restricted growing area classification. The growing area classification determines how the shellstock may be used following harvest. Water samples collected as part of the sanitary survey or as a required update of the sanitary survey are used to determine if the water quality meets the water quality standards for the growing area classification. If the tidal stage increases the fecal coliform concentration, the state must use samples collected under that tidal stage to classify the area.

All growing areas which:

(a) are not subjected to a sanitary survey every 12 years shall be classified as prohibited;
(b) have a sewage treatment plant outfall or other point source outfall of public health significance within or adjacent to the growing area shall have an area in the prohibited classification established adjacent to the outfall; and
(c) are subjected to a sanitary survey shall be correctly classified based on the 12-year sanitary survey, and its most recent triennial or annual reevaluation when available, as only one of the following:
    (i) Approved;
    (ii) Conditionally Approved;
    (iii) Restricted;
    (iv) Conditionally Restricted; or
    (v) Prohibited.

16.4.2.1 *Approved* Classification

Growing areas may be classified as approved when the following criteria are met.

(1) A sanitary survey is required which finds that the area is:
    (a) Safe for the direct marketing of shellfish;
    (b) Not subject to contamination from human or animal fecal matter at levels that, in the judgment of the state, present an actual or potential public health hazard; and
    (c) Not contaminated with:
        (i) Pathogenic organisms;
        (ii) Poisonous or deleterious substances;
        (iii) Marine biotoxins; or
        (iv) Bacteria concentrations exceeding the bacteriological standards for a

growing area in this classification.

(2) The bacteriological quality of every station in the growing area shall meet the fecal coliform standard.

(3) The fecal coliform median or geometric mean MPN or MF (mTEC) of the water sample results shall not exceed 14 per 100 ml, and not more than 10% of the samples shall exceed an MPN or MF (mTEC) of:
(a) 43 MPN per 100 ml for a five-tube decimal dilution test; or
(b) 49 MPN per 100 ml for a three-tube decimal dilution test; or
(c) 28 MPN per 100 ml for a twelve-tube single dilution test; or
(d) 31 CFU per100ml for a MF (mTEC) test.

A review of epidemiological investigations of disease and marine biotoxin outbreaks attributable to the consumption of shellfish reveals that three general situations prevail insofar as contamination of approved growing areas are concerned.

Improperly conducted or outdated sanitary surveys or misapplication of approved area criteria have unwittingly allowed sewage contamination of approved areas. Such areas have been shown to be the source of shellfish involved in shellfish associated disease outbreaks. The misapplication of approved area criteria includes the improper interpretation of the upper 10 percentile criteria to permit an area that is contaminated 10% of the time to be classified as approved.

Shellfish from waters meeting approved area criteria are unlikely to be involved in the spread of disease that can be attributed to fecal contamination of the shellfish. This is because, in part, a total coliform MPN of 70/100 ml is equivalent to the fecal material contributed from one person diluted in about 2.27 x 10^8 liters (8 million cubic feet) of coliform-free water. In addition, such a small amount of sewage reaching the growing area is likely to have been so treated, diluted, or aged that it will be of negligible public health significance. This also means an element of time and distance to permit mixing of sewage or fecal material with large volumes of diluting water. An increasing amount of saltwater will increase the rate at which many terrestrial microorganisms die out. Many reports have been published on the natural die-off of microorganisms in the marine environment.

The effectiveness of sewage treatment processes must be considered in evaluating the sanitary quality of a growing area since the bacterial and viral content of the effluent will be determined by the degree of treatment which is obtained. The results of bacteriological sampling must also be correlated with sewage treatment plant operation and evaluated in terms of the minimum treatment which can be expected with the possibility of malfunctioning, overloading, or poor operations.

The approved classification for a growing area requires that the sanitary survey has determined that there are no unacceptable concentrations of fecal material, pathogenic microorganisms, or poisonous and deleterious substances. There are no NSSP limitations on the harvest of shellstock from growing areas placed in this classification.

16.4.2.2 *Conditional* Classification.

The basic concept of the NSSP is to control the safety of shellfish by preventing their harvest from contaminated growing areas. In reviewing growing area classifications and sanitary surveys conducted by national and international control officials, it appears that a common misinterpretation is the classification of an area as approved when, in fact, the area should have been classified as conditionally approved. Critical investigations usually reveal that the area is subject to intermittent pollution events. Careful consideration of an intermittent pollution event, development and application of a management plan, and cooperation and compliance by all parties may also allow upgrading of an area to a conditionally approved or conditionally restricted classification instead of requiring the area to be restricted or prohibited at all times.

The conditional classifications are designed to address growing areas that are subject to intermittent microbiological pollution. These optional classifications offer the Authority an alternative to placing the area in the restricted or prohibited classification year-round when, during certain times of the year or under certain conditions, the shellstock from the growing area may be safely harvested. Public health protection and the control of shellfish safety in the use of the conditional classifications are afforded through the use of a management plan. The management plan for each growing area placed in a conditional classification is based on the information gathered during the sanitary survey. The plan establishes a strict set of criteria that must be met for the growing area to remain in the open status. Failure to meet the criteria automatically places the growing area in the closed status, with immediate notice to the public, the affected industry, and the plan's participants. Two of the most important components of the management plan are: the acceptance of and the agreement to the conditions of the management plan by one or more Authorities involved, other local, state and federal agencies which may be involved, the affected shellfish industry, and the persons responsible for the operation of any treatment plants or other discharges that may be involved; and the annual reevaluation of compliance with the plan to assure public health protection. Use of the conditional classification requires more intense monitoring and more frequent reevaluation because of the intermittent nature of the pollution event.

A common situation where this classification might be appropriate is when water quality is dependent upon the operation of a wastewater treatment plant; there is a rapid or seasonal change in water quality; water quality in an area fluctuates with the discharge of a major river, or rainfall in the area may cause runoff of pollutants into the growing area. The latter type of pollution is often referred to as non-point pollution. During periods of low runoff, such an area might be of satisfactory quality and thus be approved for shellfish harvesting. Other factors which also determine if an area may be classified as conditional include:

1. Availability of sufficient state resources to manage, survey, monitor, control harvesting, affect closures, and reopen the area as required. States electing to classify areas as conditionally approved have found the public resource investment to be substantial. When the Authority has sufficient resources to manage a conditional classification, the use of the conditional classification could allow the safe use of growing areas that might otherwise not be available to the shellfish industry.

2. Evaluating the potential sources of pollution in terms of their effect on water quality in the area. Some potential sources of pollution include: bypasses and overflows within a sewage collection and treatment system, intermittent discharges from boats, seasonally used areas, animals, land runoff, and freshwater flows.

3. Evaluate each source of pollution in terms of the water quality standards to be maintained, and to formulate performance standards for each pollution source having a significant effect on the sanitary quality of the area.

Another factor to consider in developing a conditionally approved or conditionally restricted area is that a prohibited area must be interposed between the conditionally approved or restricted area and the source of pollution. The size of such area should be based on the total time it would take for the operating agency to detect a failure, notify the state shellfish control agency, and for the latter agency to issue a notice to stop shellfish harvesting. It is recommended that the area be of such size that the flow time through the safety area is at least twice that required for the notification process to become effective. Due consideration should be given to the possibility that closure actions might be necessary on holidays or at night.

The length of time a conditionally approved or conditionally restricted area should be closed following a temporary closure will depend upon several factors including the species of shellfish, water temperature, shellfish activity and cleansing rates, presence of silt or other chemicals that might interfere with the physiological activity of the shellfish, and the degree of pollution of the area.

16.4.2.3 *Restricted* Classification

The restricted area classification is an option available to state shellfish control agencies to use instead of a prohibited classification. The establishment of a restricted area might be considered in instances where an area does not meet approved area criteria but is not grossly polluted. Another common situation where this classification might be appropriate is for areas affected by non-point pollution from either urban or rural sources that cause the water quality to fluctuate unpredictably or of sufficient frequency that a conditionally approved area is not feasible. In such instances, the state may, at its option, classify these areas as restricted and may limit the use of the shellfish to relaying, container relaying, or depuration operations.

Relaying is a process of reducing the levels of microorganisms that may be present in the shellstock by moving the shellstock to growing areas in the approved classification and using the shellstock's ability to cleanse itself naturally as a treatment process. Depuration is a process of reducing the levels of pathogenic organisms that may be present in the shellstock by using a controlled aquatic environment (i.e. a land based facility) as a treatment process.

The sanitary and bacteriological criteria to be applied by the state for classifying restricted areas are to be developed by the state shellfish control agency. The criteria may vary according to the use to be made of the shellfish and according to the effectiveness of the relay and/or depuration process to which the shellfish will be subjected. The effectiveness of the process is determined by a study the purpose of which is to establish the bacteriological quality requirements for the shellfish processing. Effectiveness of the process is likely to vary from one cleansing area to another, from one species of shellfish to another, and from one depuration plant to another. The classification criteria may be based upon the quality of the shellfish or the water in the restricted area in addition to other sanitary parameters. As a minimum for depuration activities, the fecal coliform median or geometric mean MPN of the water sample results shall not exceed 88 per 100 ml and not more than 10% of the samples shall exceed an MPN of: (a) 260 MPN per 100 ml for a five tube decimal dilution test; or (b) 300 MPN per 100 ml for a three-tube decimal dilution test; or (c) 173 MPN per 100 ml for a 12-tube single dilution test.

Before classifying an area as restricted, the state shellfish control agency should make a determination of whether sufficient state resources are available to monitor pollution sources; to provide coordination between state, local, and industry officials; to issue special harvesting permits; and to supervise harvesting and transportation of shellfish to depuration facilities or relay sites. Some states that have classified areas as restricted have found the resource investment to be substantial.

16.4.2.4 *Prohibited* Classification

The positive relationship between disease and consuming contaminated shellfish has been clearly established. Prevention of consumption of contaminated shellfish is the primary objective of the NSSP. The prohibited area classification is the most restrictive growing area classification, used for areas subject to gross pollution.

Note: The use of this classification is also required, as a precautionary measure, for any growing area where the Authority has not performed a sanitary survey, and for a growing area immediately adjacent to a sewage treatment plant outfall, irrespective of the level of effluent treatment provided. The harvesting of shellstock is not allowed for any human food use.

16.4.3 Marine Biotoxin

In Gulf coast areas, toxicity in shellfish has been associated with red tide outbreaks caused by massive blooms of the toxic dinoflagellate, *Karenia brevis* (formerly *Ptychodiscus brevis*) neurotoxic shellfish poisoning (NSP). The most common public health problem associated with *K. brevis* blooms is respiratory irritation; however, neurotoxic shellfish poisonings associated with *K. brevis* blooms have been reported in Florida.

Toxic dinoflagellates are indigenous to most coastal and estuarine waters on the Atlantic, Gulf, and Pacific coasts of America, as well as in many other parts of the world.

Shellfish growing areas closed because marine biotoxins have exceeded quarantine levels may be reopened for harvest after a sufficient number of samples and other environmental indices have established that the level of toxin will remain below quarantine levels for an extended period.

16.4.4 Contingency Plan

The suitability of some areas for harvesting shellstock is periodically influenced by the presence of toxigenic micro-algae. Recent increases in toxigenic micro-algae distribution dictate that a more comprehensive series of public health controls be adopted. The need exists to make contingency plans to address the contamination of a growing area by toxigenic micro-algae or a disease outbreak caused by marine biotoxin. This contingency plan must describe administrative procedures, laboratory support, sample collection procedures, and patrol procedures to be implemented on an emergency basis in the event of the occurrence of marine biotoxin in shellstock. The primary goal of this planning should be to ensure that maximum public health protection is provided in growing areas subject to marine biotoxin contamination.

16.4.4.1 Marine Biotoxin Monitoring

The primary purpose of a marine biotoxin-monitoring program is to prevent illness or death among the shellfish consuming public. The monitoring program should use the ‘indicator station’ and ‘critical species’ concepts to develop an early warning system to prevent harvest of biotoxin contaminated shellstock.

16.4.4.2 Marinas

Under the NSSP Guide, any growing area within the confines of the marina proper is presumed to be contaminated for some period of time. Therefore, no growing area within the marina proper can be placed in the approved classification.

The microbiological and chemical contamination associated with marina facilities may result in the contamination of adjacent shellfish growing waters. The NSSP has developed a set of evaluation criteria to be used in determining if the growing waters adjacent to a marina are affected by microbiological contaminants associated with sewage. Since there are significant regional differences in all factors that affect pollution loading from marinas, sufficient flexibility must be allowed to account for these differences. The Authority has the option of applying the specified occupancy and discharge rates necessary to conduct a dilution analysis. The Authority may also opt to conduct studies to document different rates for specific areas. Best professional judgment of qualified individuals and best available technology must be applied to determine adequate restrictions on harvesting in and around marinas.

16.5 Cultch Planting

Oysters generate their own substrate and this substrate is critical to the population stability. Clean, hard substrate is necessary for oyster setting and growth. Also, when environmental factors are conducive to oyster spawning and setting, more suitable substrate equals more oyster habitat and production. When substrate is not available or resource managers see a need to expand existing reef areas, substrate is added to the environment to enhance the population. Cultch planting is perhaps the most commonly used management strategy to maintain or increase production.

Successful cultch planting is a complex operation that requires knowledge of water temperature, salinity, and density of oyster larvae in plankton samples. The type of cultch material is perhaps a less important factor in planting, whereas the timing of cultch plants is critical. If cultch is planted too early, shells may become fouled by other marine organisms, and if planted too late, peak larval settlement may have passed. In either case, setting densities and ultimate production will be reduced. Site selection for cultch planting projects is also critical. Usually sites are chosen on or near existing reefs where oysters are usually present. Bottom conditions, water depth, sediment types, turbidity, current patterns, salinity, temperature, and historical catch data are important factors to be considered when selecting sites for creating oyster habitat. Techniques that are employed during planting operations are also important to future production. Broadcasting a relatively thin, even application of cultch may produce best on established reefs, while constructing three-dimensional reefs with distinct elevations may be more successful under certain circumstances (Lenihan and Peterson 1998).

16.5.1 Cultch Materials

Historically, oyster shells were the most widely-used material as cultch primarily because of availability, low cost, ease to plant and success rates (Dugas et al. 1997). However, the availability of processed oyster shell has become a greater problem as competition for this material for other uses has increased. While oysters will set and grow on almost any clean, hard surface, some cultch materials are preferred over others. Such preference is oftentimes determined by the expected use of the oysters which will be produced or the condition of the water bottoms upon which the cultch material will be placed. For example, if the production of single oysters for market sales is the goal, smaller cultch material pieces such as crushed oyster shell, clam shell, small limestone, or crushed concrete may be preferred. If a reef is being constructed for non-harvest uses (i.e. specifically for ecological services), whole oyster shell may be the preferred material. Whole oyster shell may also be preferred when soft water bottoms at the cultch planting location exist. Whole oyster shell, with its increased surface area and lighter weight, tends to sink less into the substrate over time as it is less dense than other cultch materials. When oysters are not shucked locally or are exported to other regions, the shell is effectively lost to the source state. In addition, ownership of the shell is complicated with interstate shipments of shellstock. When businesses purchase shellstock from other states, they claim ownership, often in conflict with state laws to the contrary.

As noted in Section 5.2.2.2.2, the non-replacement of shucked-shell cultch reduces the hard surface and reef structure, and the loss of this shell material to other uses makes reef rehabilitation and renourishment more difficult. There is a long history of using shucked shell in road beds, construction, and as calcium supplements in the livestock and poultry industries in the United States. Similarly, harvesting without the replacement of shell can ultimately reduce the function and productivity of these beds over time, if the full complement of the lost shell is not resupplied each year by natural processes. For some states, the acquisition of shell is extremely difficult given that a large majority of the shellstock is either exported, logistically difficult or expensive to obtain in sizeable quantities, or has become private property of the buyer.

Oyster shell is difficult to obtain due to limited availability and competition with non-fishery related interests. Oyster shells are also quite valuable for other purposes; their shape and compaction qualities make them a highly desirable material for road-bed construction, particularly in low-lying or swampy areas. Since this type of construction activity occurs largely in the same general area where oysters are harvested and processed, the construction industry competes with the oyster industry for shell. The construction industry is usually able to pay a higher price for shell and is better physically equipped to transport shell from process locations to use locations. These shells are thus irreclaimable to the oyster industry to use as cultch. In addition, the prohibition of mining reef shell from submerged fossil shell beds has drastically limited the availability of reef shell (clam and oyster shell) for use as a cultch material.

Since there is a continuous need to restore and refurbish oyster reef habitat all around the country, particularly following devastating catastrophic events such as hurricanes, floods, and anthropogenic actions, resource managers are relying on alternative cultch materials. Clam shells (*Rangia cuneata*) have historically been used extensively and in large volumes when they were available. Graded limestone (#57 limestone) and fossil shell are excellent sources of calcium carbonate, and are used routinely in several states to create and restore oyster reef habitat. In Florida, calico scallop shell was used successfully for cultch from local scallop processing operations when the fishery was in operation. On the East coast, materials of opportunity for cultch include surf clam shells, coal ash pellets, broken concrete, and broken porcelain from toilets.

In the Gulf, the primary material used is shucked shell, reef shell, mixed shell, graded limestone, and crushed concrete. The problem with many of the non-shell materials is subsidence. While crushed concrete works very well as a supplement to existing reefs as nourishment, it sinks quickly in most areas and requires a very thick layer to provide any long-term availability on the bottom. Limestone, likewise, sinks unless placed on a relatively hard substrate but is an excellent supplement to existing reefs. An unpublished study by the LDWF found that all the materials listed had good spat set but the heavier materials tended to settle into the mud at faster rates, reducing the total exposed surface area of that particular material. Shell, on the other hand, placed on soft mud, will dissolve and disappear much faster even though it remains on the surface better, because the substrate is naturally acidic and it deteriorates rapidly. Based on the work in Delaware Bay, it is recommended that it is better to put down a good bed of crushed limestone first in an effort to build a suitable base and then to spread shell. The type of cultch material available for use can have secondary impacts on any reef rehabilitation/construction effort. Although all materials provide an excellent recruitment substrate, limestone and concrete require a firmer water bottom on which to plant the material. This could have drastic impacts on the project as suitable bottoms may not exist within areas where suitable environmental conditions (i.e. salinity) exist.

16.5.2 Historical Application of Cultch in the Gulf States

The following sections and tables provide a brief history, where available, on the efforts to plant cultch for restoration and rehabilitation of oyster reefs in the Gulf of Mexico. When possible, the States have provided quantities of the plants as well as a relative cost of the material put down.

16.5.2.1 Florida

Florida began cultch planting on public reefs as early as 1914 (Table 16.2) to help ensure high productivity from its public reefs, and has maintained an aggressive shell-planting program since 1949 (Dugas et al. 1997). Because Florida's public oyster reefs account for 90-95% of the oysters landed in the state, management has focused on increasing production from public reefs. Resource-directed management practices have included oyster reef construction and rehabilitation (by depositing processed and mined shell on depleted oyster reefs), transplanting juvenile oysters to more favorable growing waters, and relaying market-sized oysters to minimize public health risks. Enhancing substrate by replacing cultch material (hard substrate suitable for attachment of settling oysters) has long been accepted as a beneficial management practice, and gives resource managers the opportunity to mitigate resource losses, increase production, and contribute direct economic benefit to fisheries-dependent communities. Details of this program can be found in Whitfield (1973), Futch (1983) and Berrigan (1988, 1990).

Approximately 4.2 million bushels of cultch and oyster shells were planted for cultch purposes between 1949 and 1972 (Whitfield 1973), another 1.7 million bushels were added during 1972-1981 (Futch 1983), and more than 3.5 million bushels were deposited from 1990-2009 (FDACS unpublished data). Whitfield and Beaumariage (1977) estimated that one-half of the Apalachicola Bay production is derived from constructed reefs; details of this program can be found in Whitfield (1973), Futch (1983), and Berrigan (1988 and 1990). Whitfield (1973) estimated that the potential annual value of shell plants could approximate $3,200 per acre (1973 dollars) based on a potential harvest of 400 bushels per acre. In a later report, Berrigan (1990) estimated a benefit: cost ratio of almost 21:1 and a benefit of $8,500 per acre for restored oyster reefs in Apalachicola Bay.

16.5.2.2 Alabama

The State of Alabama has planted and relayed oysters onto traditional and created public oyster reefs as an ongoing effort to enhance and/or restore Alabama's Oyster Reefs since the early 1900s (Table 16.3). The earliest official documentation of oyster shell and seed oyster planting in Alabama was recorded in 1910 (Moore 1913), though oyster shell planting and seed transplanting most likely occurred in Alabama prior to this date. From 1942-1969, Alabama planted approximately 1,002,977 AL barrels (≈182,267 yd^3) of oyster shell and 574,006 AL barrels (≈104,312 yd^3) of seed oysters as documented in the Alabama Department of Conservation Annual Reports (various years). From 1972-2009, approximately 3,555,816 AL barrels (≈646,183 yd^3) of various cultch materials have been planted by the State to enhance production on Alabama oyster reefs (AMRD unpublished records). In 2010 and 2011 Alabama relayed a total of 50,706 AL barrels (≈9215 yd^3) of live oysters and cultch material from Conditionally Restricted waters in northern Mobile Bay to Conditionally Approved waters to populate some areas of a newly created oyster reef (AMRD unpublished records).

The majority of the plantings and both relay operations conducted from 2005-2010 included the help of local oyster catchers to transport and deploy cultch material and live oysters as part of the federally funded Emergency Disaster Relief Programs (EDRP I and II) instigated to aid in oyster reef recovery after hurricanes Ivan (2004) and Katrina (2005).

The cost of oyster shell has become a limiting factor for planting operations over the last four years. From 2005 to 2009 the price of oyster shell has drastically increased from ≈ $30 to $60 per yd^3 (price includes oyster shell + contractor fees for handling, delivery, and deployment of material). To help counter the increasing cost of oyster shell and planting operations, the State of Alabama has implemented a mandatory sack fee to be paid by Alabama Oyster Shops in addition to commercial oyster catcher license sales and sack tag fees (see Section 7.2.2.1.5). The Alabama Department of Conservation and Natural Resources, Marine Resources Division plans to continue to plant cultch material and transplant oysters as need dictates and funding allows.

16.5.2.3 Mississippi

The MDMR and its predecessor, the Mississippi Oyster Commission, established by state legislature in 1902, have been refurbishing its oyster reefs since its inception. In the late 19th century, oyster processing factories and harvesters started planting oyster shells in Mississippi waters (Table 16.4).

> "Messrs. Lopez & Co. have their new schooner, the Castelaro, employed in bringing oysters from outside and planting them on their bedding grounds. These gentlemen intend to keep well supplied with oysters, and be ready to meet the demand when the trade opens again." *The Pascagoula Democrat-Star, 'Biloxi Items' May 21, 1880, p. 3*

Unfortunately a complete set of records of past cultch plants was lost during Hurricane Katrina. Although oyster shells are the preferred material for cultch planting, limestone, crushed concrete, and *rangia* shells have been used. Cultch material deployments usually begin mid-April to June in the spring and mid-August to October in the fall to maximize optimal spawning periods. Mississippi uses a shell retention fee on each sack of oysters landed in the state to help fund these cultch deployments. Other sources of funding include 2004 Hurricane Ivan disaster money, the Emergency Disaster Recovery Programs (EDRP I and II) resulting from Hurricanes Katrina and Rita which are funded by NOAA, as well as other federal and private grants.

Mississippi also relays live oysters and shells from closed areas to the public harvesting reefs to enhance the cultch plants. These relays have used local harvesters and the R/V Conservationist to move the oysters. Since 2005, Mississippi has planted 202,997 cubic yards of cultch material and 145,429 sacks of oysters over 3600 acres. Mississippi will continue using disaster and other funds to enhance and refurbish its oyster harvesting grounds in the future.

16.5.2.4 Louisiana

Cultch planting on the public oyster grounds has a long history in Louisiana (Table 16.5), dating back at least to 1926 (Perret et al. 1991), although Louisiana Department of Wildlife and Fisheries (LDWF) records suggest that the state of Louisiana first planted cultch material in 1917 in Sister Lake (Terrebonne Parish). Moore (1899) reported extensive planting of shells by oystermen in many parts of coastal Louisiana for the purposes of oyster production and also described the transplanting of small oysters from one area to another in order to establish new reefs. The LDWF continues this practice today on the public oyster grounds as this management strategy has shown to provide an estimated 2:1 to 20:1 benefit:cost ratio in past projects. Additionally, cultch planting has recently been promoted via subsidies on private oyster leases as part of the federally-funded Private Oyster Lease Rehabilitation (POLR) Program in the wakes of Hurricanes Katrina and Rita.

For much of the nearly 100 years of cultch planting by the state of Louisiana, oyster shell and clam shell were the materials of choice. However, a ban on shell dredging from within Louisiana's coastal water bottoms (namely Lake Pontchartrain and the Vermilion/Atchafalaya basin) forced LDWF to investigate the use of alternative cultch materials. Studies on the performance of alternative materials were conducted in 1994 and in 2000 in coastal Louisiana. These studies showed that both limestone and crushed concrete performed well as cultch material provided that

Table 16.2 Florida cultch plant history (FWC unpublished data).

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1970	Apalachicola Bay	Processed Oyster Shell	18,649	74.6	100 - 200				
1971	Apalachicola Bay	Processed Oyster Shell	10,136	40.5	100 - 200				
1972	Apalachicola Bay	Processed Oyster Shell	9,675	38.7	100 - 200				
1972	Escambia Bay	Processed Oyster Shell	8,864	35.5	100 - 200				
1972	Escambia Bay	Dredged Oyster Shell	1,775	7.1	100 - 200				
1972	Escambia Bay	Dredged Clam Shell	12,520	50.1	100 - 200				
1972	Indian River	Limestone	1,987	7.9	100 - 200				
1973	Escambia Bay	Dredged Clam Shell	14,020	56.1	100 - 200				
1973	Apalachicola Bay	Processed Oyster Shell	7,660	30.6	100 - 200				
1974	Dixie County	Limestone	4,036	16.1	100 - 200				
1974	Apalachicola Bay	Processed Oyster Shell	5,780	23.1	100 - 200				
1975	Apalachicola Bay	Processed Oyster Shell	5,055	20.2	100 - 200				
1976	Indian River	Limestone	922	3.7	100 - 200				
1976	Bay County	Processed Oyster Shell	893	3.6	100 - 200				
1977	Apalachicola Bay	Processed Oyster Shell	2,751	11	100 - 200				
1977	Bay County	Processed Oyster Shell	3,759	15	100 - 200				
1977	Indian River	Limestone	782	3.1	100 - 200				
1978	Apalachicola Bay	Processed Oyster Shell	10,139	40.6	100 - 200				
1979	Apalachicola Bay	Processed Oyster Shell	6,258	25	100 - 200				
1979	Indian Lagoon, Gulf County	Processed Oyster Shell	1,440	5.8	100 - 200				
1980	Apalachicola Bay	Processed Oyster Shell	5,709	22.8	100 - 200				
1980	Bay County	Processed Oyster Shell	3,856	15.4	100 - 200				
1981	Apalachicola Bay	Processed Oyster Shell	8,570	34.3	100 - 200				PL 88-309
1982	Apalachicola Bay	Processed Oyster Shell	6,501	26	100 - 200				PL 88-309
1983	Apalachicola Bay	Processed Oyster Shell	14,030	56.1	100 - 200				PL 88-309
1984	Apalachicola Bay	Processed Oyster Shell	26,164	104.7	100 - 200				
1984	Bay County	Dredged Clam Shell	3,006	12	100 - 200	$50,000	$16.25	$4,165	
1985	Apalachicola Bay	Processed Oyster Shell	13,949	55.8	100 - 200				
1985	Indian Lagoon, Gulf County	Processed Oyster Shell	2,516	10.1	100 - 200				
1986	Apalachicola Bay	Processed Oyster Shell	24,567	120	250	$416,200			FCSWA
1986	Apalachicola Bay	Dredged Clam Shell	56,470	225	250	$918,000	$16.25	$4,080	CFDA/PL 88-309 (4B)
1986	Escambia Bay, Santa Rosa. Co	Dredged Clam Shell	2,890	11.5	250	$47,000	$16.25	$4,080	CFDA/PL 88-309 (4B)

Table 16.2 Con't Florida cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd³/Acre	Cost	Price/Yd³	Cost/Acre	Notes
1986	East Bay, Bay County	Dredged Clam Shell	1,895	7.5	250	$30,800	$16.25	$4,100	CFDA/PL 88-309 (4B)
1987	East Bay, Santa Rosa Co.	Dredged Clam Shell	3,925	16	250	$55,000	$13.89	$3,400	CFDA/PL 88-309 (4B)
1987	Choctawhatchee Bay, Walton Co.	Dredged Clam Shell	1,925	7.7	250	$27,000	$13.89	$3,475	CFDA/PL 88-309 (4B)
1987	West & East Bay, Bay Co.	Dredged Clam Shell	3,170	12.5	250	$44,450	$13.89	$3,525	CFDA/PL 88-309 (4B)
1987	Apalachicola Bay	Dredged Clam Shell	39,760	160	250	$553,950	$13.89	$3,460	CFDA/PL 88-309 (4B)
1987	Apalachicola Bay	Processed Oyster Shell	14,901	60	250	$178,800		$2,980	
1988	Apalachicola Bay	Processed Oyster Shell	9,104	36.4	100 - 200	$109,250		$3,000	
1988	East Bay, Santa Rosa County	Dredged Clam Shell	2,333	9.5	250	$44,900	$19.24	$4,725	Contract
1988	West & East Bay, Bay Co.	Dredged Clam Shell	3,298	13	250	$63,450	$19.24	$4,900	Contract
1989	Apalachicola Bay	Processed Oyster Shell	10,013	40	250	$120,000		$3,000	
1989	Escambia Bay, Santa Rosa Co.	Dredged Clam Shell	2,050	8.2	250	$44,850	$21.88	$5,500	Contract
1989	West, East &North Bay, Bay Co.	Dredged Clam Shell	4,850	20	250	$106,100	$21.88	$5,300	Contract
1990	Apalachicola Bay	Processed Oyster Shell	7,297	36	200	$87,500		$2,400	
1990	East Bay, Santa Rosa County	Dredged Oyster Shell	1,900	12	100 - 200	$52,200	$24.60	$4,350	Contract
1990	West and East Bay, Bay Co.	Dredged Oyster Shell	2,400	16	100 - 200	$64,000	$24.60	$4,000	Contract
1991	East Bay, Santa Rosa County	Dredged Oyster Shell	2,450	12	100 - 200	$62,400	$27.15	$5,200	Contract
1991	Choctawhatchee Bay, Walton Co.	Dredged Oyster Shell	1,200	6	100 - 200	$33,400	$27.15	$5,570	Contract
1991	West & East Bay, Bay Co.	Dredged Oyster Shell	2,920	15	100 - 200	$80,800	$27.15	$5,400	Contract
1992	Apalachicola Bay	Processed Oyster Shell	2,100	8.4	100 - 200	$25,200		$3,000	
1992	Escambia Bay, Santa Rosa Co.	Dredged Oyster Shell	1,810	12	100 - 200	$49,500	$26.90	$4,125	Contract
1992	West & East Bay, Bay Co.	Dredged Oyster Shell	2,140	14	100 - 200	$57,560	$26.90	$4,100	Contract
1992	Bay County	Limestone	50	0.2	100 - 200				Experimental
1993	East Bay, Santa Rosa County	Dredged Oyster Shell	1,728	7	250	$47,660	$27.35	$6,800	Contract
1993	Choctawhatchee Bay, Walton Co.	Dredged Oyster Shell	2,438	10	250	$66,680	$27.35	$6,660	Contract
1993	West Bay, Bay County	Dredged Oyster Shell	2,056	8	250	$56,630	$27.35	$7,080	Contract
1993	East Bay, Bay County	Scallop Shell	555	2.8	200		$0.55		
1993	Apalachicola Bay	Scallop Shell	4,415	22	200	$55,200	$0.55	$2,500	
1993	Apalachicola Bay	Processed Oyster Shell	6,250	25	100 - 200	$75,000		$3,000	
1994	East Bay, Santa Rosa County	Dredged Oyster Shell	1,459	6	250	$38,080	$26.10	$6,350	Contract
1994	Choctawhatchee Bay, Walton Co.	Dredged Oyster Shell	1,291	5	250	$33,700	$26.10	$6,740	Contract

Table 16.2 Con't Florida cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1994	West Bay, Bay County	Dredged Oyster Shell	1,630	6.5	250	$42,500	$26.10	$6,540	Contract
1994	East Bay, Bay County	Scallop Shell	550	2	250		$0.55		
1994	Apalachicola Bay	Processed Oyster Shell	1,440	6	250	$17,280		$2,880	
1994	Apalachicola Bay	Processes Oyster Shell	923	5	200	$44,300		$8,860	EDA/JTPA/ FCSWA
1994	Apalachicola Bay	Scallop Shell	7,841	39	200	$375,000	$0.55	$9,600	EDA/JTPA/ FCSWA
1995	Apalachicola Bay	Dredged Oyster Shell	8,940	45	200	$457,700	$20.00	$10,170	EDA/JTPA/ FCSWA
1995	Apalachicola Bay	Processed Oyster Shell	10,935	43.7	250	$131,200		$3,000	
1996	Apalachicola Bay	Processed Oyster Shell	9,000	36	250	$108,000		$3,000	
1996	East Bay, Bay County	Processed Oyster Shell	475	1.9	100- 200	$11,400		$5,700	
1996	East Bay, Santa Rosa County	Dredged Oyster Shell	2,000	10	100 - 200	$63,000		$6,300	
1996	East Bay, Bay County	Dredged Oyster Shell	2,000	10	100 -200	$63,000		$6,300	
1997	Apalachicola Bay	Processed/Dredged Shell	9,705	39	250	$116,460		$3,000	
1998	Apalachicola Bay	Processed Oyster Shell	7,680	31	200	$92,160		$3,000	
1998	East Bay, Bay County	Processed Oyster Shell	1,585	6.5	100 - 200	$38,040		$5,850	
1999	Apalachicola Bay	Processed Oyster Shell	1,750	7	250	$21,000		$3,000	
2000	Apalachicola Bay	Processed Oyster Shell	7,316	29.3	100 - 200	$87,800		$3,000	
2001	Apalachicola Bay	Processed Oyster Shell	9,828	40	250	$216,200	$12.00	$5,400	FDOT
2002	Apalachicola Bay	Processed Oyster Shell	12,508	50	250	$275,200	$12.00	$5,500	FDOT
2003	Apalachicola Bay	Processed Oyster Shell	12,744	51	250	$280,370	$12.00	$5,500	FDOT
2004	Apalachicola Bay	Processed Oyster Shell	528	2.1	250	$11,600	$12.00	$5,530	FDOT
2005	East Bay, Santa Rosa County	Fossil Shells	648	2.6	100 - 200	$31,000	$26.95	$11,915	NOAA
2006	Escambia Bay, Santa Rosa County	Fossil Shell	3,912	15	250	$187,000	$26.95	$12,470	NOAA
2006	East Bay, Santa Rosa County	Fossil Shell	840	3.5	250	$40,150	$26.96	$11,500	NOAA
2006	Choctawhatchee, Walton County	Fossil Shell	720	3	250	$32,400	$26.95	$10,800	NOAA
2007	West Bay, Bay County	Fossil Shell	2,688	11	100 - 200	$116,900	$26.95	$10,630	NOAA
2007	East Bay, Santa Rosa County	Fossil Shell	1,248	6	100 - 200	$59,650	$26.95	$9,950	NOAA
2007	North Bay, Bay County	Processed Oyster Shell	360	1.4	100 - 200	$8,640	$12.00	$6,000	NOAA
2007	East Bay, Bay County	Fossil Shell	432	2	100 - 200	$18,800	$26.95	$9,400	NOAA
2008	Apalachicola Bay	Processed Oyster Shell	7,700	31	100 - 200	$169,400	$12.00	$5,500	EDRP1
2008	Escambia Bay, Santa Rosa County	Fossil Shell	275	1.1	250	$13,150	$26.95	$12,000	EDRP1
2008	East Bay, Bay County	Fossil Shell	2,681	10.7	100-200	$116,600	$26.95	$10,900	EDRP1

Table 16.2 Con't Florida cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
2009	West Bay, Bay County	Fossil Shell	2,156	8.6	100-200	$93,800	$26,95	$10,900	EDRP1
2009	Apalachicola Bay, Franklin County	Processed Oyster Shell	4,345	20	100 - 200	$95,600	$12.00	$4,800	EDRP1
2009	Waccasassa Bay, Levy County	Hard Clam Shell	709	2.8	200	$24,800	$24.25	$8,860	EDRP1

the water bottoms were relatively firm. Both materials have been used extensively since 2000 and yielded successful reef restoration/rehabilitation efforts. As much of the Louisiana oyster harvest is shipped out-of-state, very little oyster shell is available to the Department of Wildlife and Fisheries for cultch planting purposes and an increased reliance of alternative cultch materials (i.e. limestone, crushed concrete) has resulted.

Since 1917, over 1.5 million cubic yards of cultch material have been planted on public oyster grounds covering nearly 30,000 water bottom acres. As expected, the cost has risen significantly from around $0.60 per cubic yard in 1917 to nearly $80 in 2009. On average, these projects provide cultch material at a density of nearly 70 cubic yards to the acre although, since 2000, the cultch planting density has averaged approximately 225 cubic yards to the acre. This significant increase in cultch plant density is due to the recent practice of using heavier materials (limestone and concrete) which experience increased subsidence and must be planted at a higher density to remain above the mud line.

Aside from the POLR Program mentioned above, little data exist on cultch planting activities on private leases throughout the long history of the Louisiana oyster industry. During the POLR Program (roughly 2006-2009), over $1.25 million in reimbursement monies were paid to qualifying oyster leaseholders for planting approximately 29,300 cubic yards of cultch material on their private leases during post-hurricane rehabilitation efforts. The cultch planting was carried out on 106 different leases totaling 15,565 acres.

16.5.2.5 Texas

Much of the shell loss in Texas' coastal ecosystems has been the result of industrial shell dredging or mining activities (Table 16.6). Between 1910 and 1969 approximately 220 million cubic yards of shell was removed from Texas bays and used for a variety of industrial and construction purposes (Ward 1993). In later years, shell dredging operators were required to use 3% of all shell removed during dredging operations for building/refurbishing exposed reefs and pay a royalty of $1.25 per cubic yard that was to be used for acquiring additional cultch material.

Cultch plantings in Texas have been sporadic through the years and were done primarily to rehabilitate public reefs destroyed by natural disasters such as floods and hurricanes or by industrial shell dredging. Between 1947 and 1982, forty-one shell reefs covering just over 1,300 acres were planted in Texas coastal ecosystems, primarily in Galveston and San Antonio Bays. Cultch materials included live oysters, dead oyster shell, or clam shells. A resurvey of these reefs in 1984 indicated 21 of 41 shell reefs created or rehabilitated still remained, all or in part.

Following Hurricanes Katrina and Rita in 2005 and Hurricane Ike in 2008, Texas has utilized federal funds to restore some of the public reefs lost due to hurricane-induced sedimentation in Galveston Bay. The cost of oyster shell has become prohibitive, resulting in the use of alternative materials such as river rock (metamorphic), limestone, or clean, crushed concrete.

Table 16.3 Alabama cultch plant history (AMRD unpublished data).

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1972			20,231.0			$70,067.00	$3.46		
1973			2,657.0						
1974			29,545.0			$127,075.00	$4.30		
1975			29,562.0			$129,718.00	$4.36		
1976			None						
1977									
1978									
1979			2,500.0			$35,005.00	$14.00		
1980			123,000.0			$1,284,630.00	$10.44		
1981									
1982			9,383.0			$110,196.00	$11.74		
1983			4,375.0			$78,804.00	$18.01		
1984			34,591.0			$466,975.00	$13.50		
1985			14,458.0			$200,000.00	$13.83		
1986			84,402.0			$1,153,786.00	$13.67		
1987			22,588.0			$246,213.00	$10.90		
1988									
1989			3,500.0			$42,000.00	$12.00		
1990			16,699.0			$397,250.00	$23.79		
1991									
1992									
1993			6,000.0			$85,850.00	$14.31		
1994			7,000.0			$72,527.00	$10.36		
1995			3,500.0			$36,450.00	$10.41		
1996			3,990.0			$38,426.00	$9.63		
1997			3,695.0			$41,444.00	$11.22		
1998			6,114.0			$82,873.00	$13.55		
1998			10,000.0			$207,000.00	$20.70		
1999			21,948.0			$479,996.00	$21.87		
1999			23,866.0			$464,664.00	$19.47		
2000			10,000.0			$138,900.00	$13.89		
2001			7,503.0			$109,763.00	$14.63		
2002			20,288.0			$400,000.00	$19.72		

Table 16.3 Con't Alabama cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd³/Acre	Cost	Price/Yd³	Cost/Acre	Notes
2003			5,500.0			$122,000.00	$22.18		
2004			none						
2005			10,060*			299,300	$29.93		DW
2005			10,000.0			$333,370.00	$33.37		SW
2006			18,000.0			$66,860.00	$34.27		DW
2006			8,995.0			$397,489.00	$44.19		SW
2007			20,000.0			$799,200.00	$39.96		DW
2007			7,500.0			$295,575.00	39.41**		SW
2007			10,000.0			$348,700.00	$34.87		SW

Table 16.4 Mississippi cultch plant history (MDMR unpublished data).

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1997	Telegraph Reef	Oyster Shell/ Concrete		300					
1997	Kittiwake Toning Reef	Oyster Shell		8.4					
1997	St. Stanislaus	Oyster Shell		8.5					
1997	Waveland	Oyster Shell		11.5					
1999	Telegraph Reef	Oyster Shell		20					
2000	Square Handkerchief	Oyster Shell		50					
2000	Pt. Clear	Oyster Shell		50					
2000	St. Joe	Oyster Shell		65					
2001	Pass Christian	Oyster Shell		100					
2002	Henderson Point	Oyster Shell		80					
2002	Telegraph Reef	Oyster Shell		80					
2003	Kittiwake Toning Reef	Oyster Shell		14					
2003	Telegraph Reef	Limestone		85					
2003	Between the Bridges	Oyster Shell		5					
2003	St. Stanislaus	Oyster Shell		14					
2003	Square Handkerchief	Oyster Shell		65					
2004	Square Handkerchief	Oyster Shell		60					
2004	Telegraph Reef	Oyster Shell		90					
2005	Telegraph Reef	Limestone		215					
2005	Long beach	Oyster Shell		10					
2005	Henderson Point	Oyster Shell		75					
2006	Henderson Point	Oyster Shell	5,022.0	50	100.0	$139,526.00	$27.78		
2006	Telegraph Reef	Limestone	9,352.0	125	75.0	$4,995,007.00	$61.44		
2007	Bay St. Louis	Oyster Shell	439.0	4					
2007	Biloxi Bay	Limestone	1,763.0	10	176.0	$82,000.00	$46.50		
2007	Henderson Point	Limestone		108					
2007	Pass Marianne	Limestone	37,000.0	375					
2007	Pass Christian	Limestone	20,168.0	200			$46.93		

Table 16.5 Louisiana cultch plant history (LDWF unpublished data).

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1917	Sister Lake		2,243.0	75	29.9				
1917	Cabbage Reef		825.0	23	35.9				
1917	Not Stated		18,941.0	631	30.0				
1919	Not Stated		166.0	6	27.7				
1919	Cabbage Reef		701.0	23	30.5				
1919	Sister Lake		2,243.0	75	29.9				
1929	Mississippi Sound/Turkey Bayou		8,296.4	276	30.1				
1930	Bay Boudreau/Fox Bay		6,216.0	207	30.0				
1931	Fox Bay		4,834.0	161	30.0				
1932	Quarantine Bay		2,074.1	69	30.1				
1933	Bay Boudreau		7,597.0	253	30.0				
1934	Bay Boudreau		10,359.0	345	30.0				
1935	Quarantine Bay		2,762.0	92	30.0				
1936	Not Stated		20,740.9	691	30.0				
1938	Mississippi Sound/Half Moon Island		4,704.0	157	30.0				
1939	Mississippi Sound/Half Moon Island		8,118.1	270	30.1				
1941	Mississippi Sound/Half Moon Island		9,679.1	322	30.1				
1941	Sister Lake		6,913.6	230	30.1	$10,000.00	$1.45	$43.48	
1943	East of MS River		7,822.0	261	30.0				CV
1943	East of MS River		1,004.0	34	29.5				CV
1943	Bay Du Chene		4,211.0	140	30.1				CV
1943	Lake Felicity	Oyster	4,557.0	152	30.0				CV
1943	Sister Lake	Oyster	3,891.0	130	29.9				CV
1944	Lake Felicity	Oyster	4,012.9	118	34.6	$10,738.14	$2.68	$91.00	
1944	Sister Lake	Oyster	4,035.5	118	34.6	$10,798.45	$2.68	$91.51	
1945	Bay Boudreaux		5,664.3	187	30.3	$18,024.60	$3.18	$96.39	
1945	Sister Lake	Oyster	2,741.3	91	30.1	$7,137.00	$2.60	$78.43	
1945	Lake Tambour		2,265.3	75	30.2	$5,897.88	$2.60	$78.64	
1945	Bay Du Chien (Hackberry Bay)		2,108.8	70	30.1	$5,490.36	$2.60	$78.43	
1946	Bay Boudreaux	Clam	5,530.9	186	29.7	$17,813.75	$3.22	$95.77	
1946	Vermillion Bay		1,381.0	46	30.0				CV
1946	Lake Felicity	Clam	4,076.0	92	44.3	$10,317.30	$2.53	$112.14	
1946	Lake Tambour		2,763.0	92	30.0				CV

Table 16.5 Con't Louisiana cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1946	Bay Du Chien	Clam	2,772.1	92	30.1	$7,016.80	$2.53	$76.27	
1946		Clam	2,656.6	89	29.8	6724.55	$2.53	$75.56	
1948	Bel La Pass	Seed	1,468.2	49	30.0				
1948	Mississippi Sound/West of 3-mile Bayou	Reef	2,629.1	88	29.9				
1949	Lake Felicity	Oyster	2,425.2	81	29.9	$9,734.15	$4.01	$120.17	
1949	Sister Lake	Oyster	2,981.2	99	30.1	$11,965.80	$4.01	$120.87	
1949	Mississippi Sound	Oyster	1,979.2	66	30.0				
1949	Bayou Le Mere	Seed	1,141.4	38	30.0				
1950	Grand pass	Clam	362.0	12	30.2				
1950	Sister Lake	Clam	4,787.0	159	30.1	$19,733.40	$4.12	$124.11	
1950	Lake Felicity	Clam	2,356.4	78	30.2	$9,713.94	$4.12	$124.54	
1950	Bay Gardene	Seed	2,001.5	67	29.9				
1950	Bay Gardene	Seed	1,705.6	57	29.9				
1951	Sister Lake	Oyster	5,538.8	184	30.1	$26,037.05	$4.70	$141.51	
1951	Lake Felicity	Oyster	1,382.7	46	30.1	$6,300.00	$4.56	$136.96	
1951	Bay Gardene	Seed	1,472.6	49	30.1				
1952	Sister Lake	Oyster	7,068.1	235	30.1	$28,114.35	$3.98	$119.64	
1952	Half-moon Island	Reef	4,955.8	165	30.0				
1953	Sister Lake	Oyster	4,213.7	140	30.1	$14,627.52	$3.47	$104.48	
1953	Half-moon Island	Reef	4,122.9	137	30.1				
1954	Half-moon Island	Reef	5,006.2	167	30.0				
1955	Petit Pass/Bay Boudreaux	Reef	4,823.4	161	30.0				
1956	Black Bay	Reef	2,763.0	92	30.0				
1956	Snake Island	Reef	2,725.0	91	29.9				CV
1956	Petit Pass	Reef	4,214.8	140	30.1				
1959	Petit Pass	Reef	18,717.9	220	85.1				
1959	Black Bay	Clam	34,703.9	1155	30.0				
1959	Half-moon Island	Reef	2,127.0	71	30.0				CV
1959	Little Raccoon Island	Steamed Oyster	1,198.4	40	30.0				
1960	Grassy Island	Reef	14,871.3	321	46.3				
1960	Lake la Fortune	Clam	9,890.8	329	30.1				
1960	Bay Boudreaux	Reef	755.0	25	30.2				CV
1960	Bay Boudreaux	Reef	5,730.0	191	30.0				CV
1961	Bel La Pass	Clam	19,200.0	640	30.0				CV

Table 16.5 Con’t Louisiana cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1961	Black Bay	Clam	25,370.0	845	30.0				CV
1961	Three Mile Bay	Reef	11,890.0	23	517.0				CV
1961	Little Raccoon Island	Reef	6,840.0	228	30.0				CV
1962	Snake Island	Clam	19,452.1	670	29.0				
1963	Calcasieu Lake	Live Oyster	1,762.9	59	29.9				
1966	Black Bay	Clam	19,533.0	550	35.5				CV
1966	Bay Boudreaux	Clam	17,386.0	585	29.7				CV
1967	Half-moon Island	Clam	15,150.0	500	30.3				
1967	Black Bay	Clam	18,182.0	549	33.1				
1969	Calcasieu Lake	Clam	7,200.0	24	300.0				CV
1969	Black Bay	Clam	15,000.0	551	27.2				
1969	Three Mile Pass	Clam	15,000.0	446	33.6				
1970	California Bay	Clam	8,901.0	360	24.7				CV
1970	Sister Lake	Clam	7,039.0	273	25.8				CV
1970	Bay Crabe	Clam	21,668.0	742	29.2				CV
1970	Bay Boudreaux	Clam	23,830.0	853	27.9				CV
1970	Mississippi Sound	Clam	7,241.0	127	57.0				CV
1970	Lake Pontchartrain	Clam	400.0	8	50.0				CV
1973	Hackberry Bay	Clam	22,500.0	450	50.0				
1974	Bay Gardene	Clam	33,800.0	676	50.0				
1974	Lake Borgne	Clam	23,400.0	468	50.0				
1975	Sister Lake	Clam	10,697.9	174	61.5				
1975	Bel La Pass	Clam	11,850.0	237	50.0				
1977	Black Bay	Clam	10,000.0	200	50.0				
1978	Bay Gardene	Clam	750.0	15	50.0				
1979	Bay Gardene	Clam	2,950.0	59	50.0				
1979	Bay Boudreaux	Clam	50,850.0	1017	50.0				
1979	Lake Borgne	Clam	195,000.0	390	500.0				
1979	Black Bay	Clam	25,400.0	508	50.0				
1979	Black Bay	Clam	29,900.0	598	50.0				
1979	Sister Lake	Clam	24,997.6	458	54.6				
1981	Black Bay	Clam	33,000.0	660	50.0				
1981	Bay Gardene	Clam	15,000.0	300	50.0				
1983	Black Bay	Clam	32,500.0	650	50.0				

Table 16.5 Con't Louisiana cultch plant history

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1983	Sister Lake	Clam	19,527.2	435	44.9				
1983	California Bay	Clam	7,500.0	150	50.0				
1984	Sister Lake	Clam	24,352.6	307	79.3				
1989	Sister Lake	Clam	18,579.0	178	104.4				
1994	Sister Lake	Reef	42,576.1	306	139.1	$891,118.61	$20.93	$2,912.15	
1994	Marsh Island	Oyster	19,595.0	27	725.7	$410,123.35	$20.93	$15,189.75	
1994	Bay Crabe	Oyster	8,594.0	137	62.7	$202,130.88	$23.52	$1,475.41	
1994	Black Bay	Oyster	29,655.0	708	41.9	$697,485.60	$23.52	$985.15	
1994	Hackberry Bay	shell, limestone, concrete	10,585.0	145	73.0	$304,212.90	$28.74	$2,098.02	
1995	Sister Lake	Oyster	70,902.0	672	105.5	$1,730,008.80	$24.40	$2,574.42	
2000	Half-moon Island	shell, limestone, concrete	3,800.00	70	54.3	$138,776.00	$36.52	$1,982.51	
2001	California Bay - Pelican Island	limestone	19,700.00	394	50.0	NO COST TO STATE - OIL COMPANY MITIGATION PROJECT			
2004	Hackberry Bay	crushed concrete	2,322.40	10	232.2	$85,835.90	$36.96	$8,583.59	
2004	Hackberry Bay	crushed concrete	4,005.00	25	160.2	$148,024.80	$36.96	$5,920.99	
2004	Barataria Bay	crushed concrete	7,536.30	40	188.4	$228,600.00	$30.33	$5,715.00	
2004	Lake Chien	limestone	6,083.00	25	243.3	$419,727.00	$69.00	$16,789.08	
2004	Lake Felicity	crushed concrete, limestone	9,179.00	40	229.5	$302,907.00	$33.00	$7,572.68	
2004	Sister Lake	shell, limestone, crushed concrete	10,300.00	67	153.7	$399,949.00	$38.83	$5,969.39	
2004	Lake Mechant	limestone	9,460.00	40	236.5	$406,780.00	$43.00	$10,169.50	
2007	Black Bay - Lonesome Island	limestone	30,421.83	200	152.1	$1,725,830.42	$56.73	$8,629.15	
2007	MS Sound - Turkey Bayou	limestone	29,944.98	200	149.7	$1,607,446.53	$53.68	$8,037.23	
2008	Hackberry Bay	shell, limestone, crushed concrete	10,171.75	50	203.4	$559,039.38	$54.96	$11,180.79	
	Totals		**1,517,454.7**	**29,751.0**					
	Averages		**12,337.0**	**241.9**	**66.6**	**$291,505.03**	**$19.27**	**$3,269.30**	

CV = can't verify data from old biennial reports

Table 16.6 Texas cultch plant history (TPWD unpublished data).

Date	Location	Cultch Type	Cubic Yards	Acreage	Yd^3/Acre	Cost	Price/Yd^3	Cost/Acre	Notes
1980	Galveston Bay	Processed Oyster Shell	51,652.3	773.4	66.8				
1989	San Antonio Bay	Clam Shell	8,000.7						
1991	Galveston Bay	Processed Oyster Shell	4,100.4	81.5	50.3	$482,002.02	$117.55	$5,914.14	
2009	Galveston Bay	River Rock	12,857.0	20	642.9	$719,992.00	$56.00	$35,999.60	
2009	Galveston Bay	Crushed Concrete	1,285.0	2	642.5	$90,348.35	$70.31	$45,174.18	***

*** This was for 9 small pads totaling approximately 2 acres for fish habitat enhancement.

17.0 Oyster Atlas for the Gulf of Mexico Region

The following maps provide an overview of the primary production reefs currently identified in the Gulf of Mexico. These maps are not meant to represent all the known oyster habitats in each state but to indicate at the time of this publication, the extent the reefs which tend to provide most of the oyster landings have been mapped. In addition, some historical reef areas are included even if they are no longer considered public or open to harvest. The scale of each reef area is not necessarily representative of the actual area and in no way should be considered as more than simply a relative location.

The data provided was obtained from the five Gulf state marine agencies. The LDWF also provided lease area boundaries for their waters. There have not been any kind of survey of these areas and therefore give no indication of quality or extent of the reefs in the lease areas.

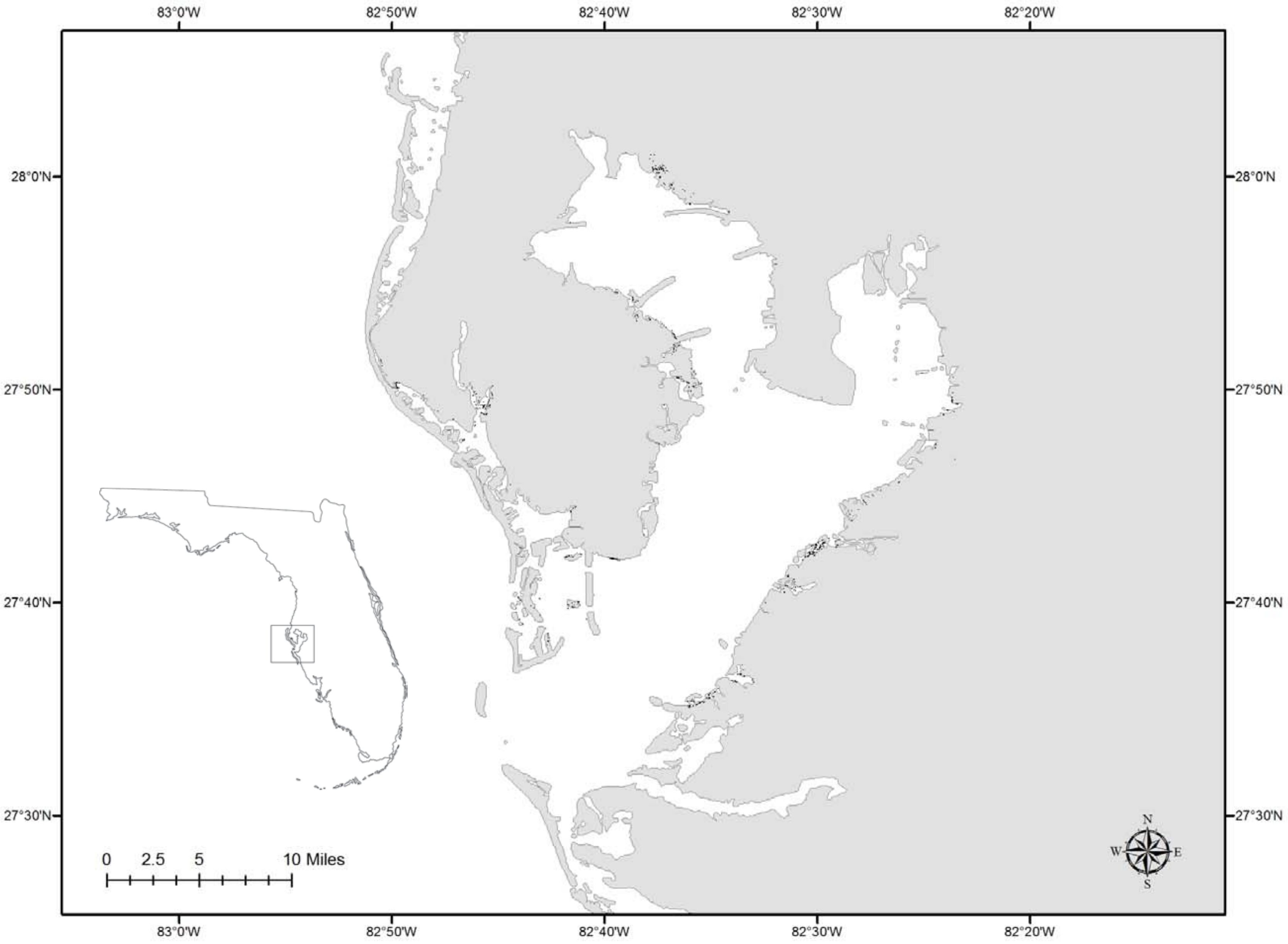

Figure 17.1 Mapped oyster beds in Tampa Bay, Florida.

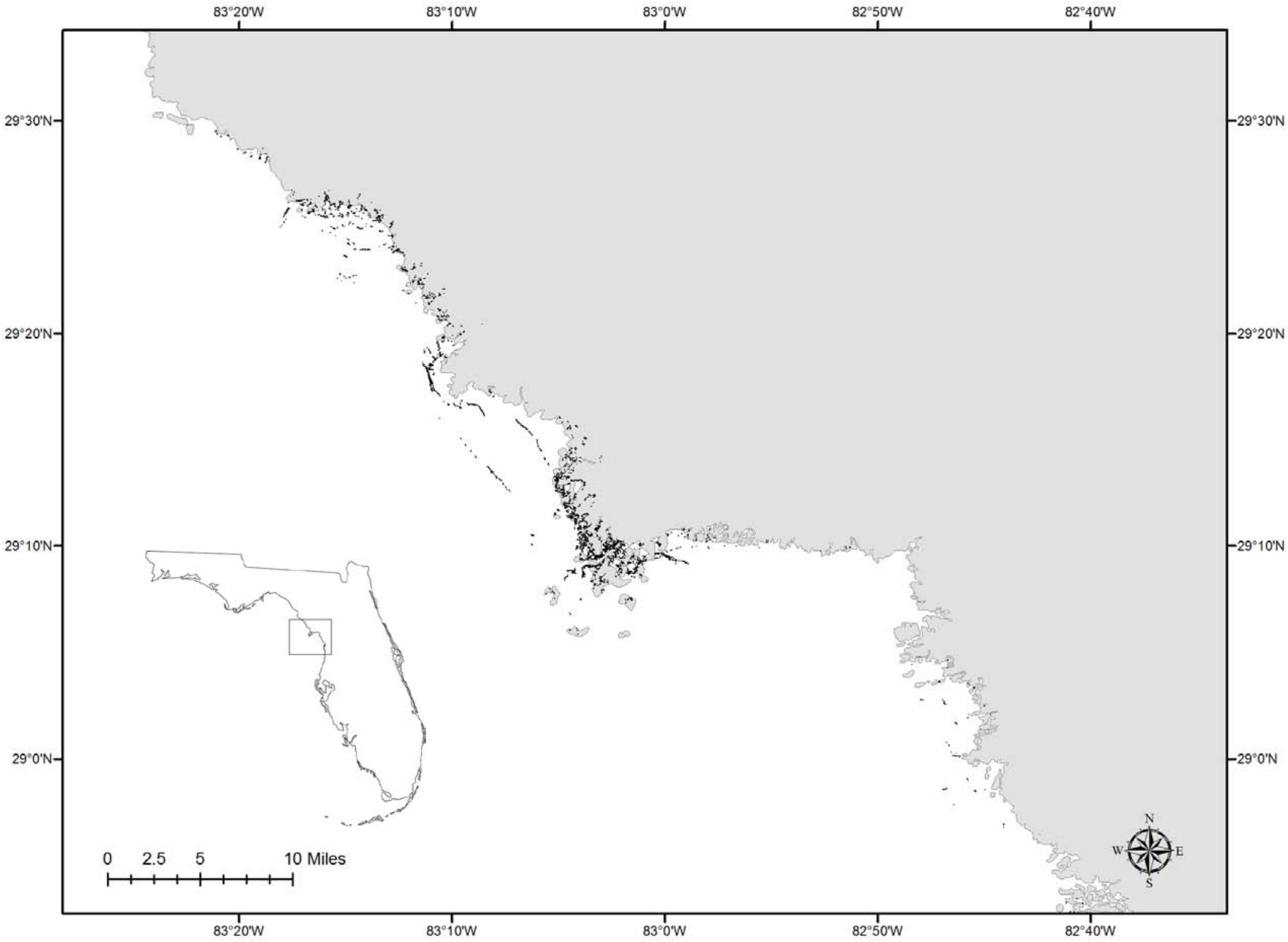

Figure 17.2 Mapped oyster beds in Suwannee Sound and Waccasassa Bay, Florida.

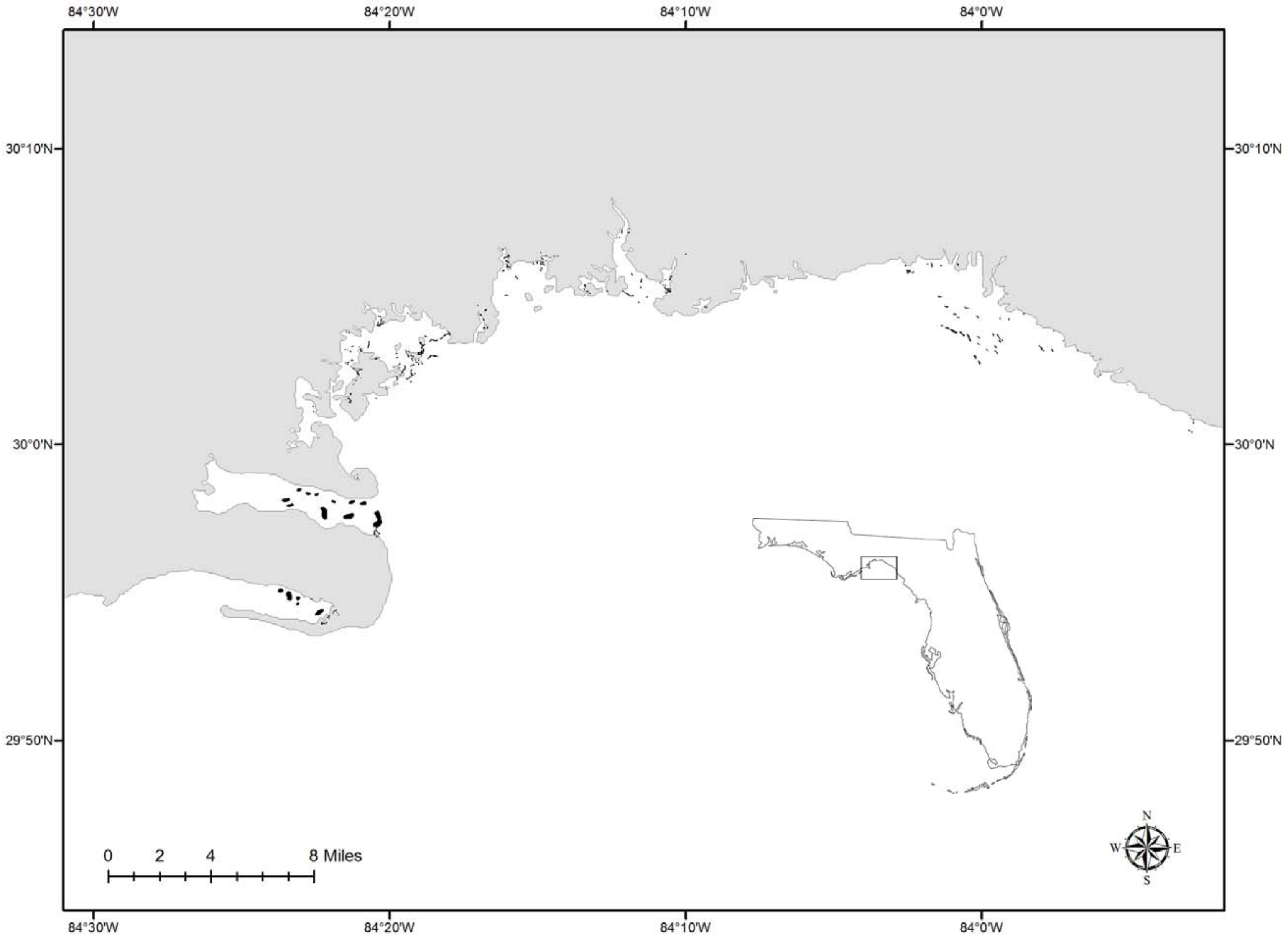

Figure 17.3 Mapped oyster beds in Apalachee Bay, Ochlockonee Bay, and Alligator Harbor, Florida

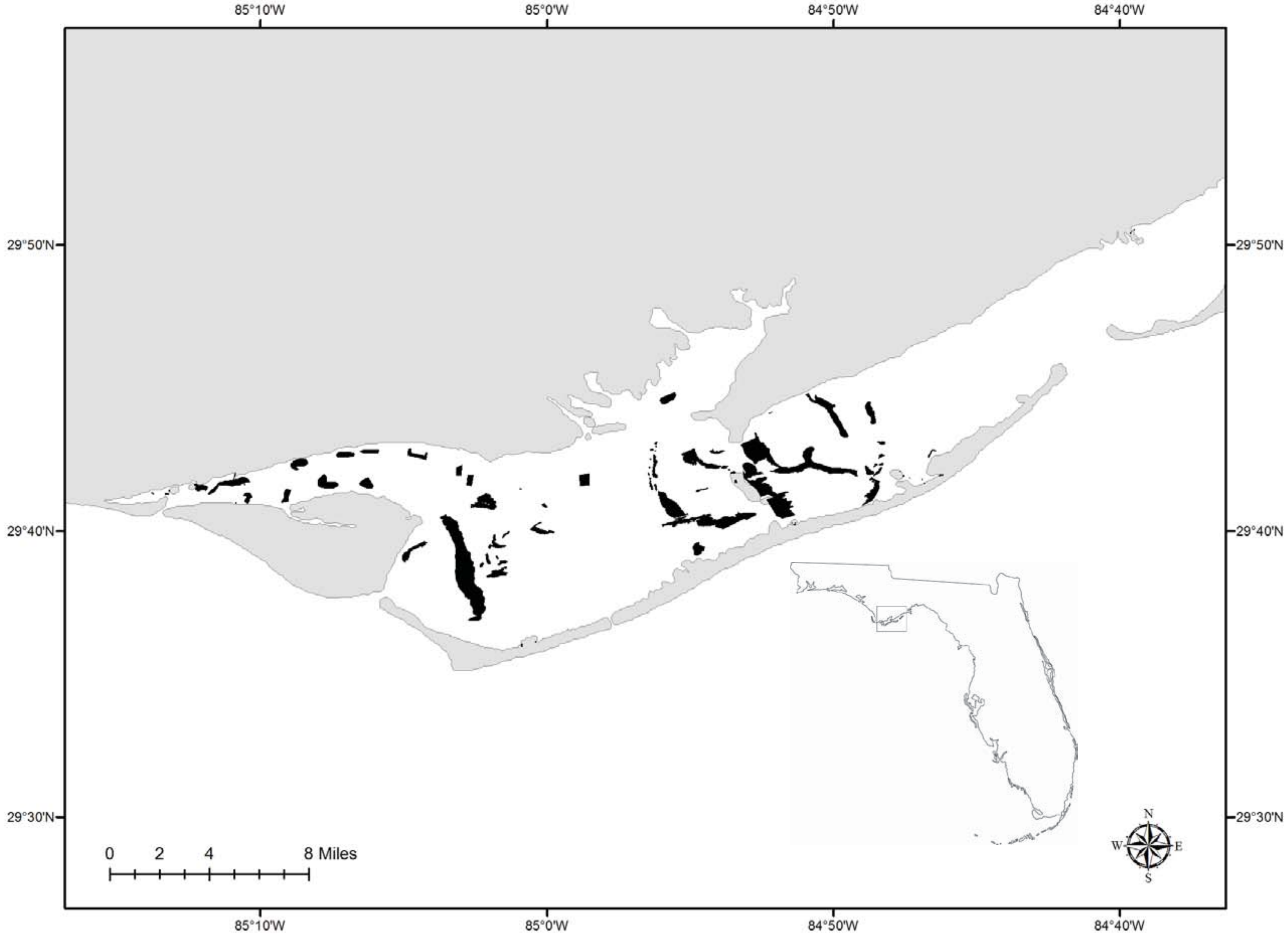

Figure 17.4 Mapped oyster beds in Apalachicola Bay, Florida.

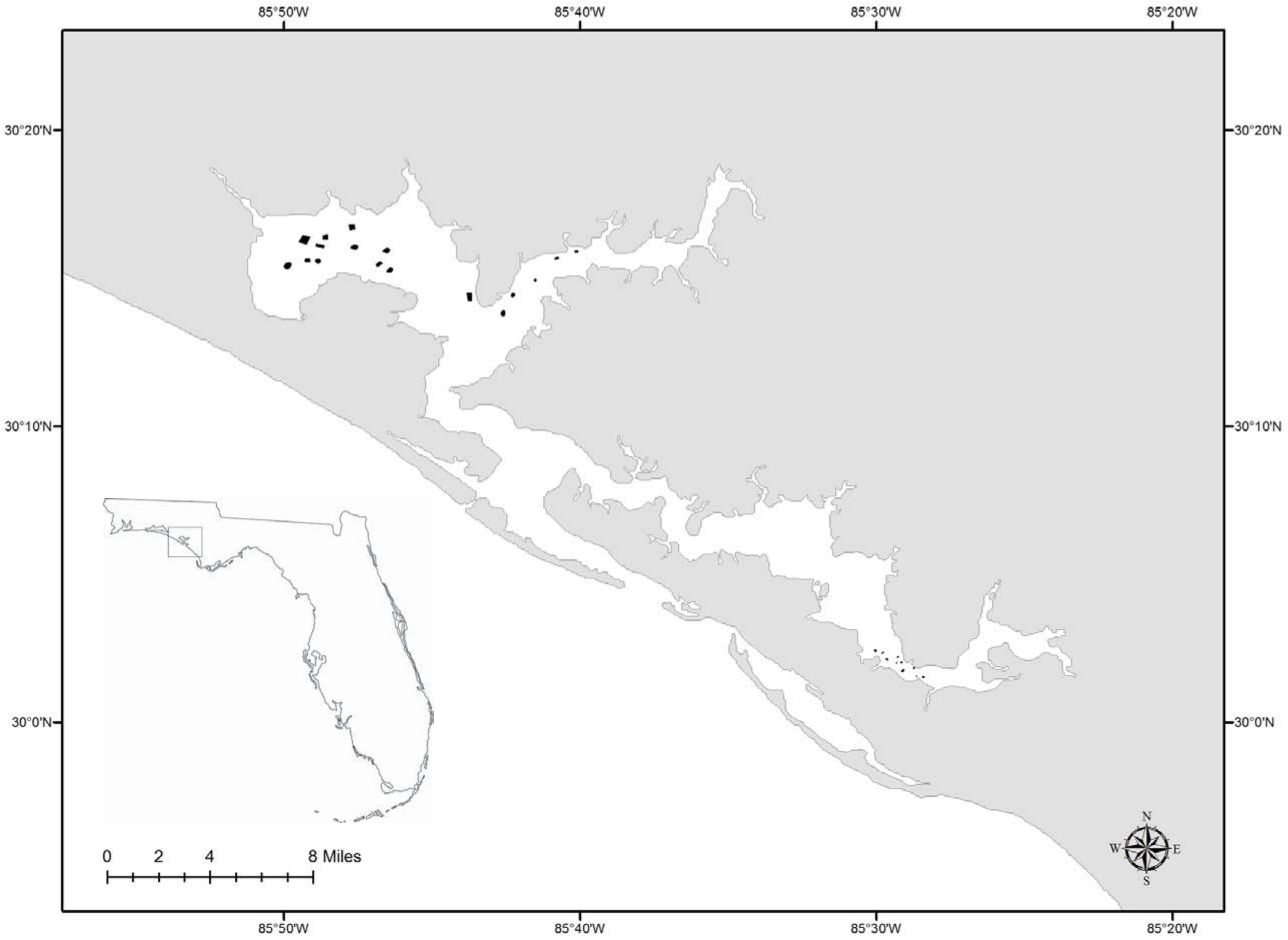

Figure 17.5 Mapped oyster beds in the St Andrews Bay system, Florida

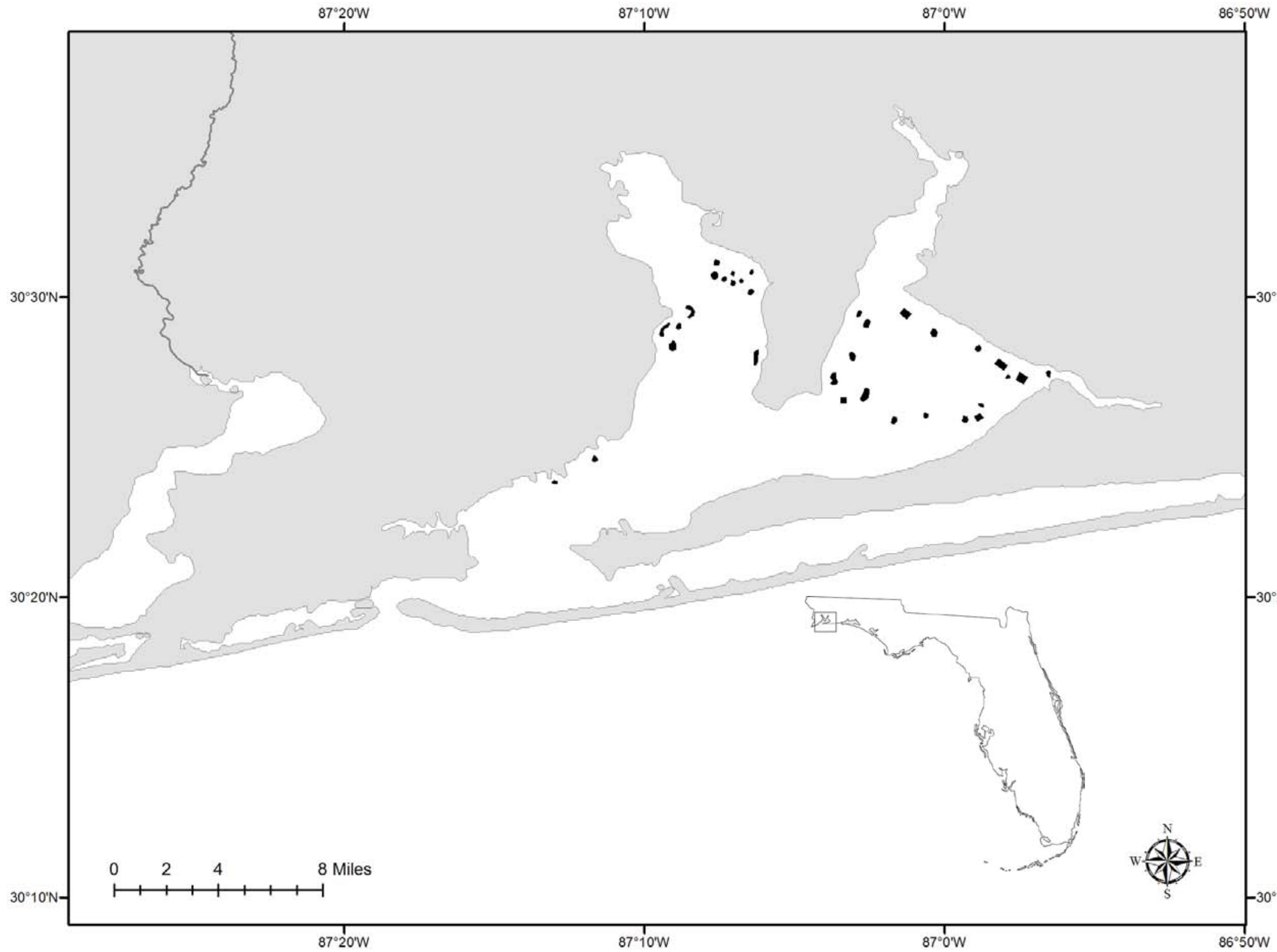

Figure 17.6 Mapped oyster beds in the Pensacola Bay system, Florida.

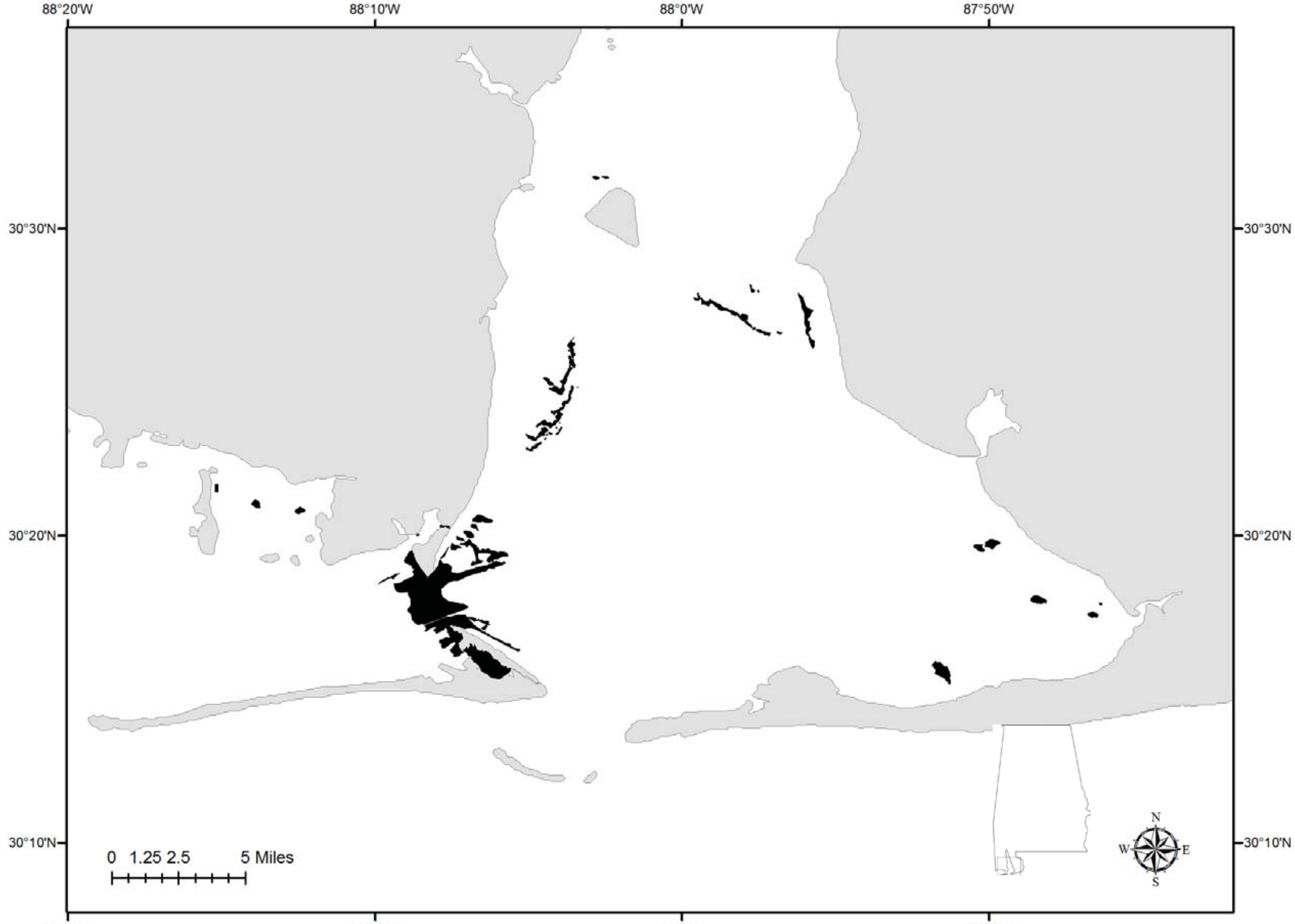

Figure 17.7 Mapped oyster beds in Mobile Bay, Alabama.

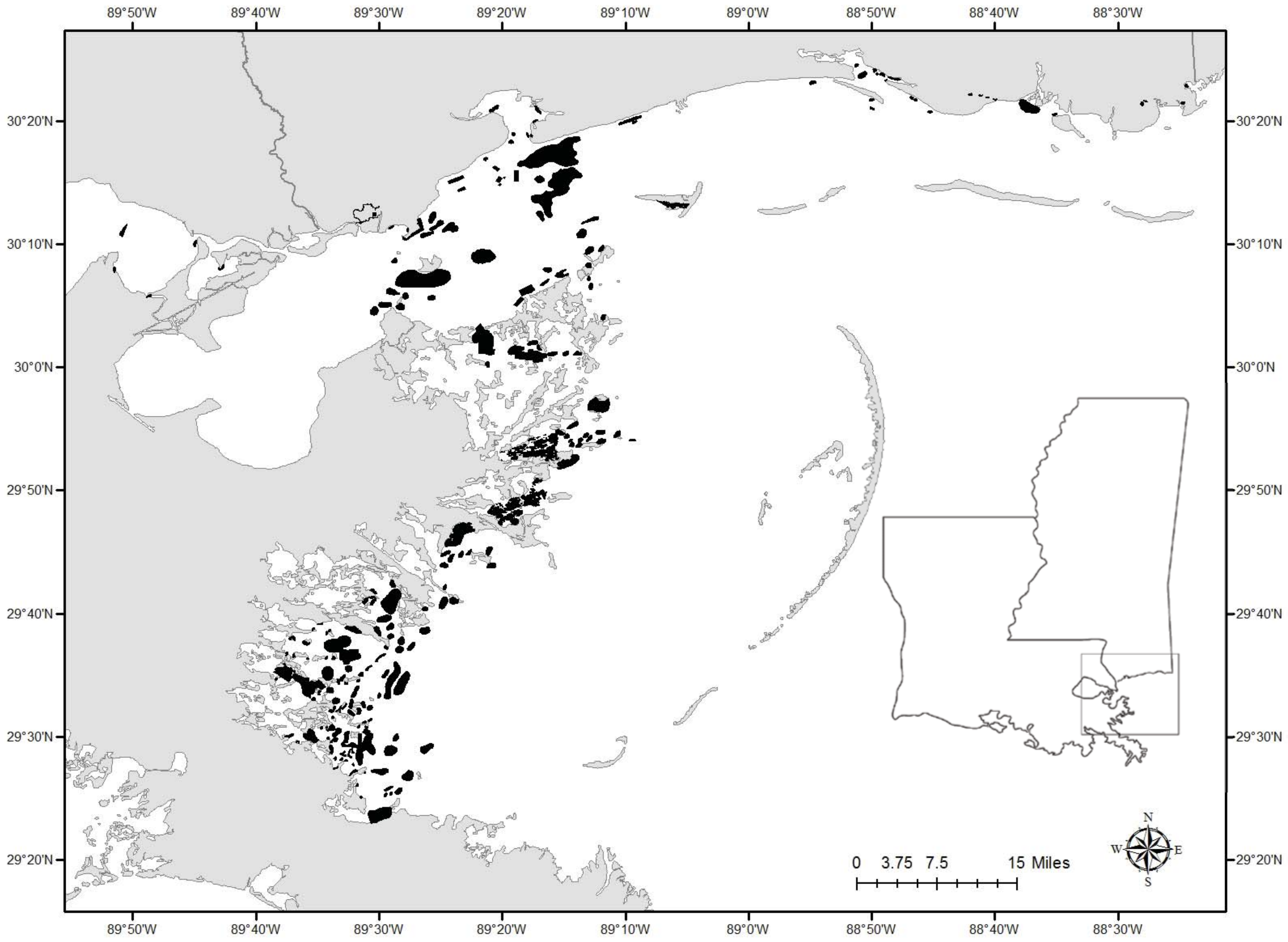

Figure 17.8 Mapped oyster reefs on public grounds in Mississippi Sound, Mississippi and Chandeleur and Breton Sounds, Louisiana.

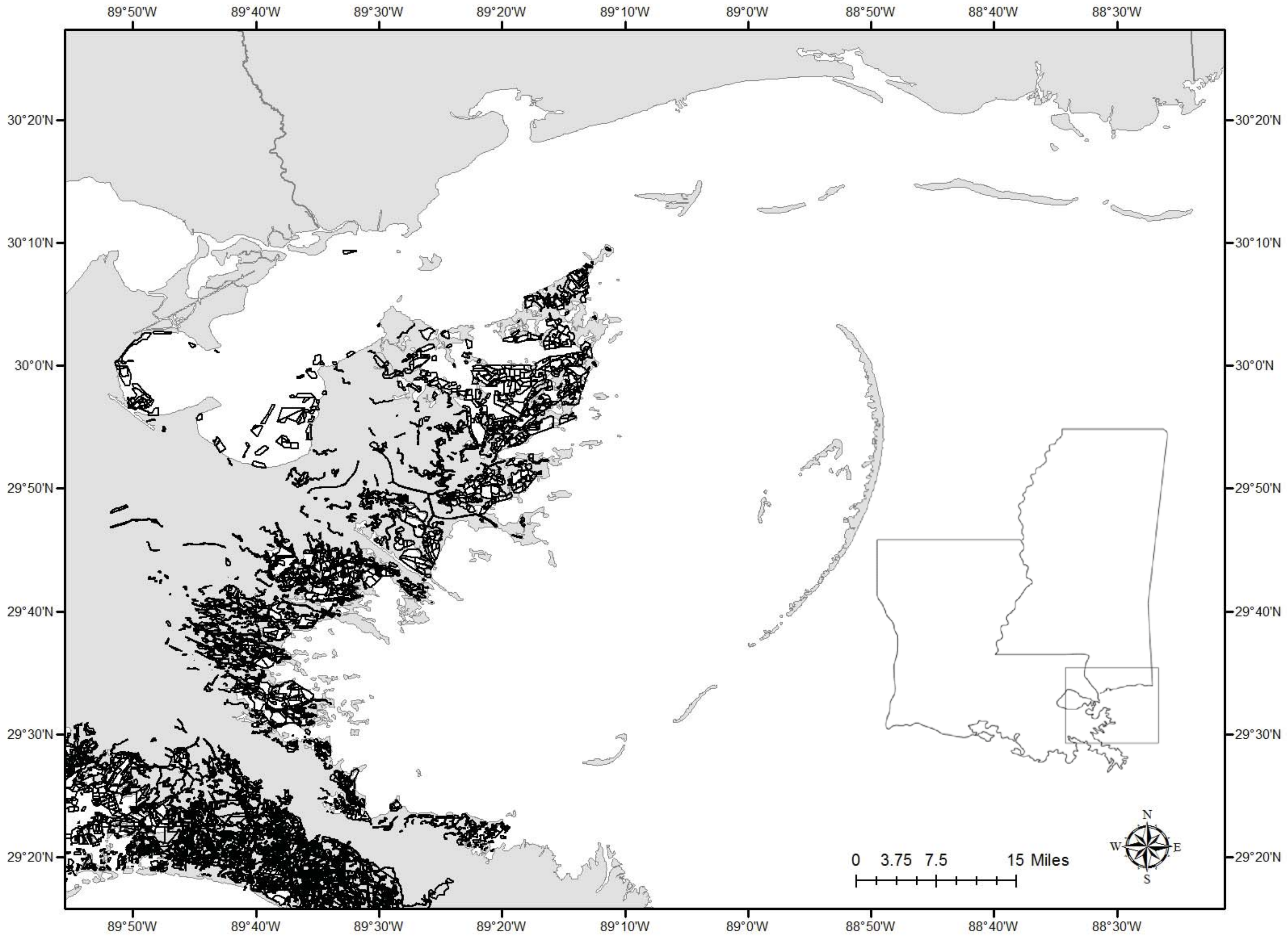

Figure 17.9 Mapped oyster lease areas in Chandeleur and Breton Sounds, Louisiana.

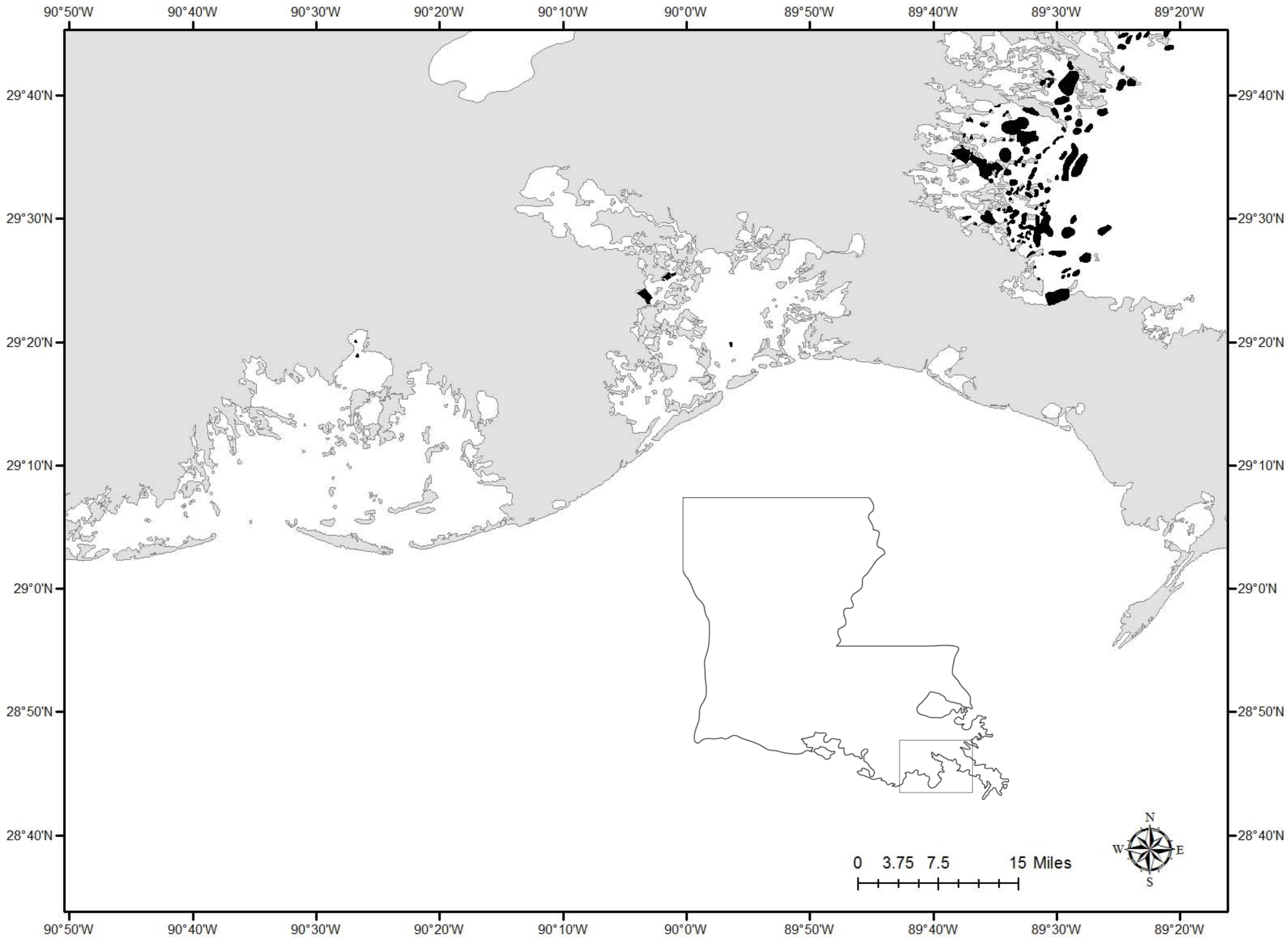

Figure 17.10 Mapped oyster reefs on public grounds in Barataria and Terrebonne bays, Louisiana.

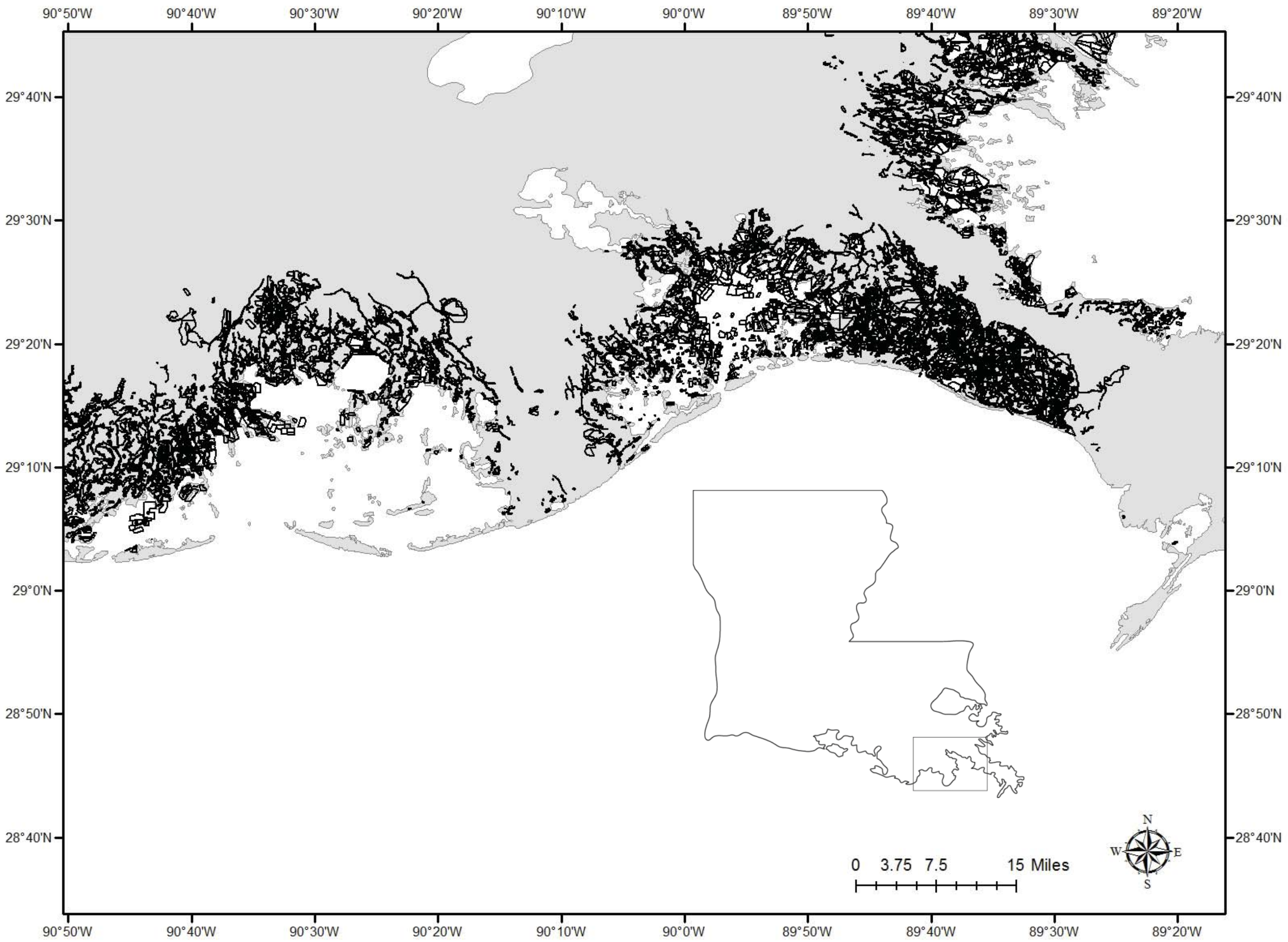

Figure 17.11 Mapped oyster leases in Barataria and Terrebonne bays, Louisiana.

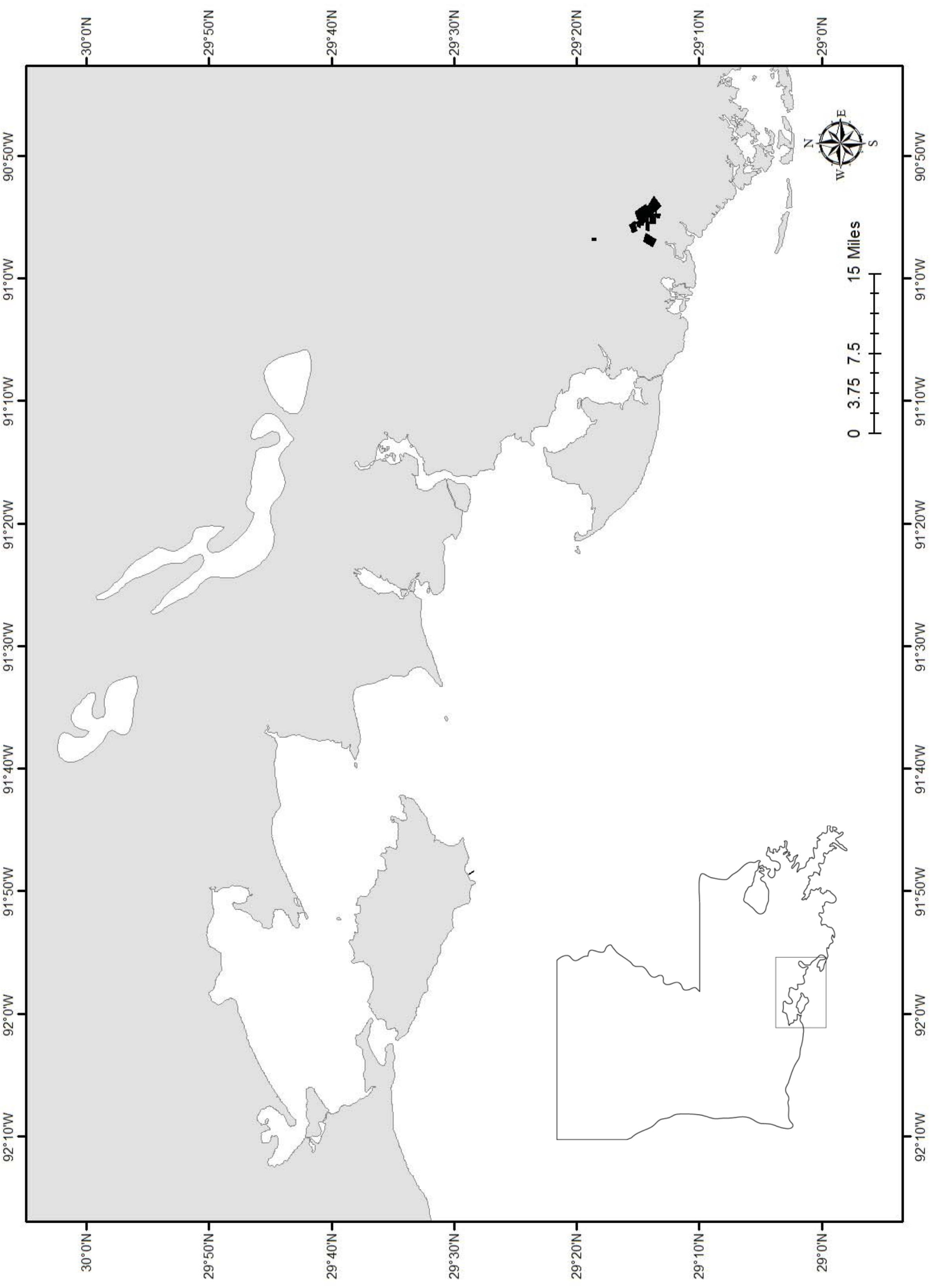

Figure 17.12 Mapped oyster reefs on public grounds in Atchafalaya Bay, Louisiana.

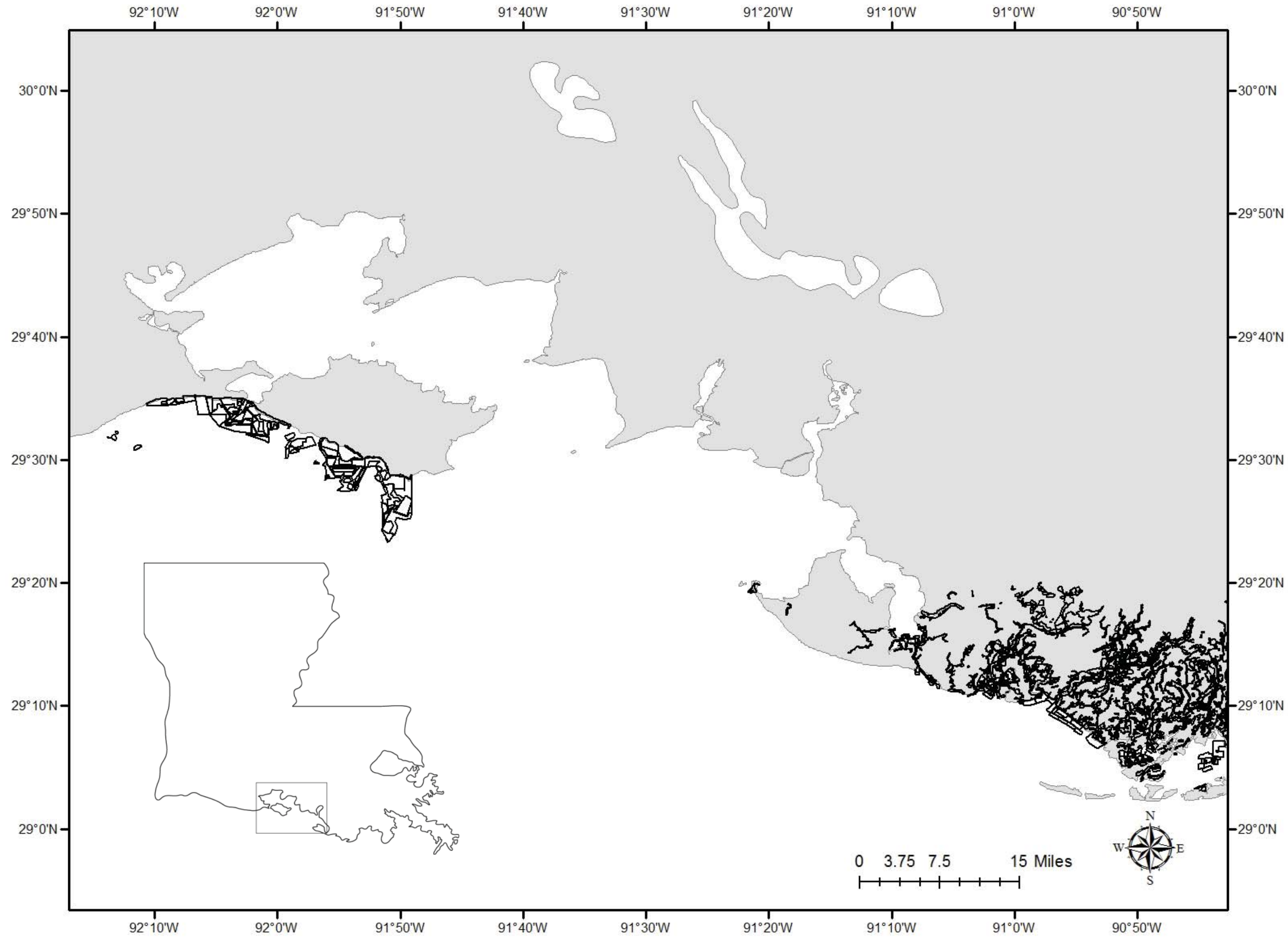

Figure 17.13 Mapped oyster leases in Atchafalaya Bay, Louisiana.

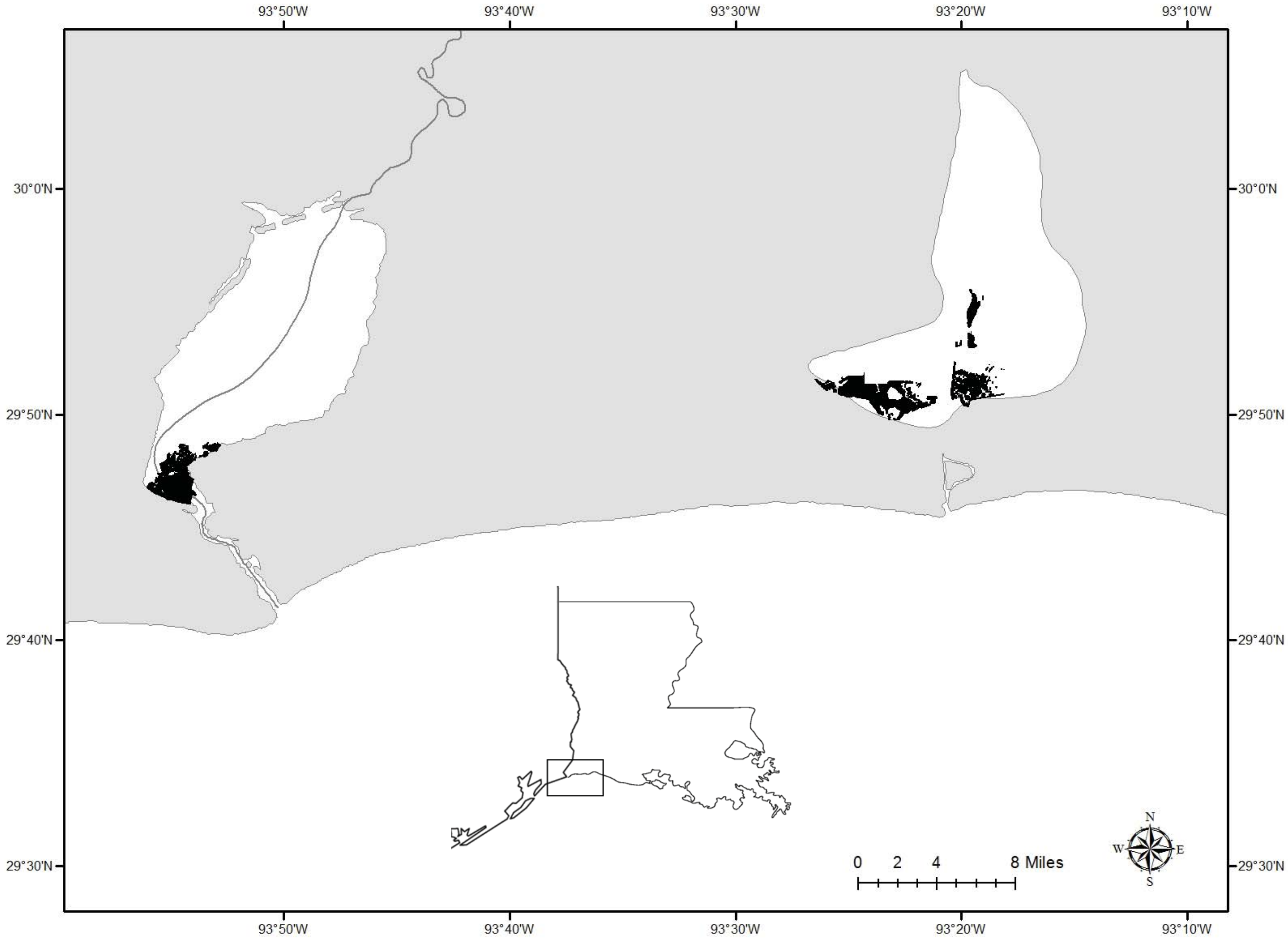

Figure 17.14 Mapped oyster reefs on public grounds in Cameron and Sabine Lakes, Louisiana and Texas.

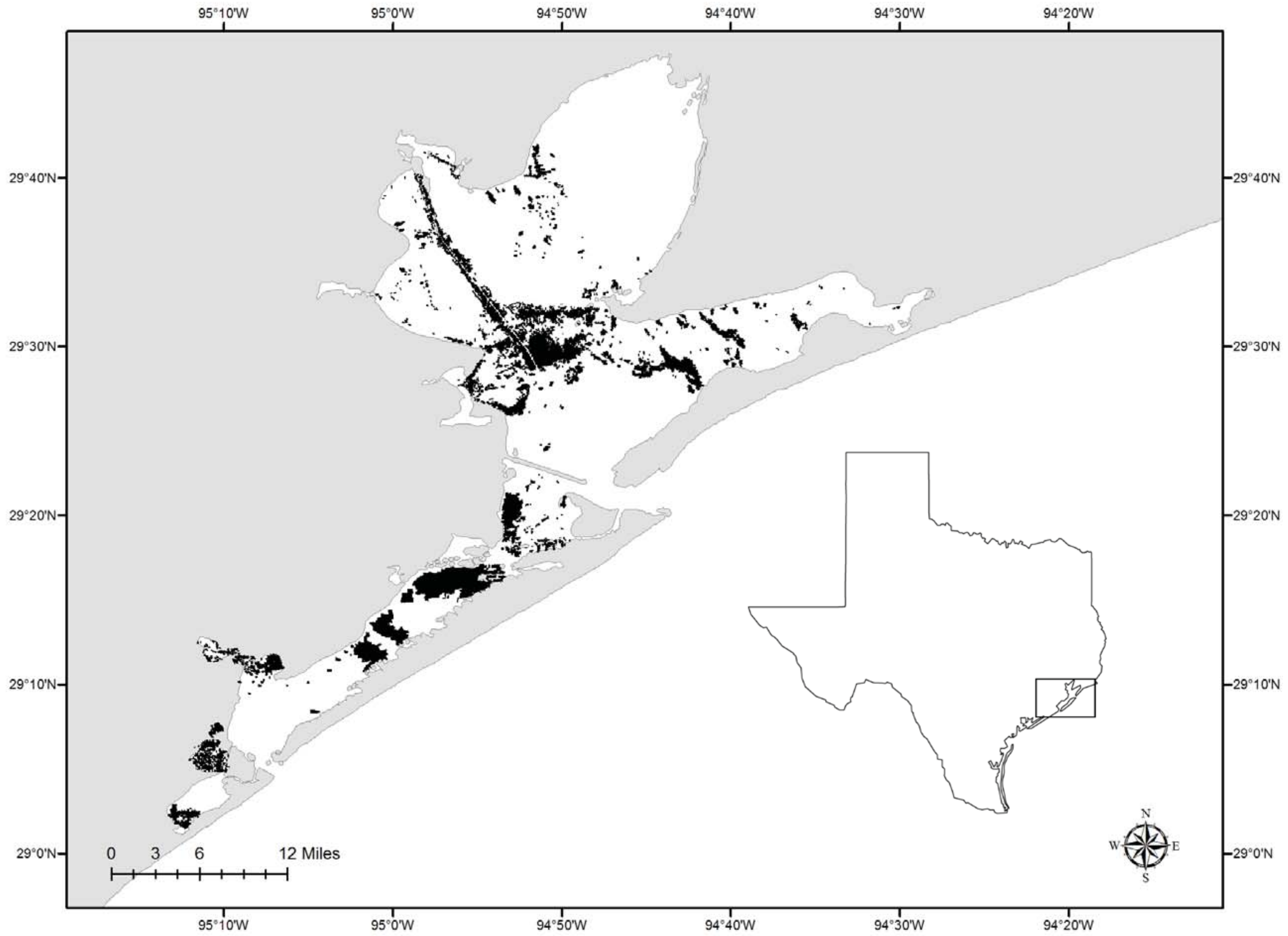

Figure 17.15 Mapped oyster beds in Galveston Bay, Texas.

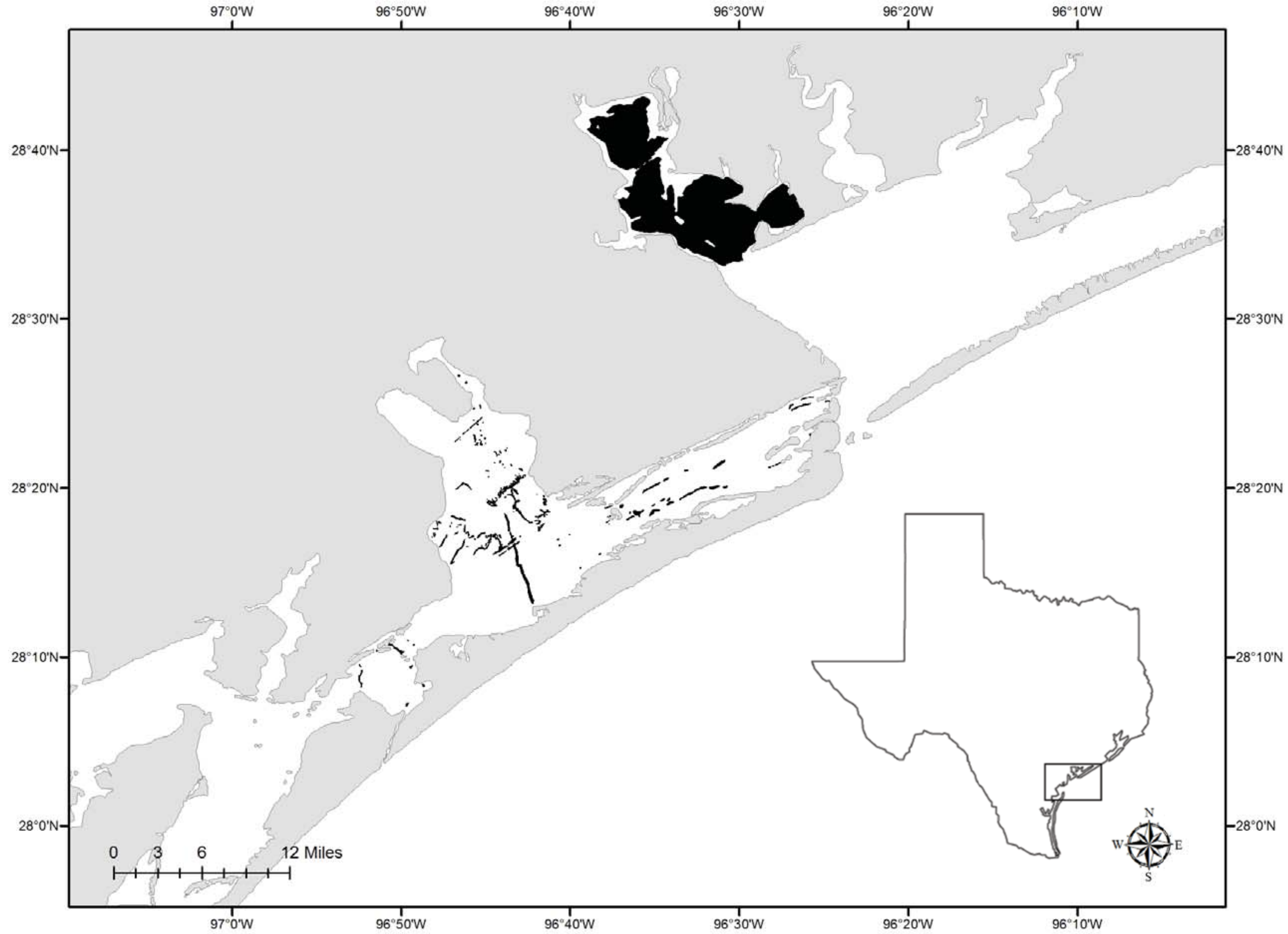

Figure 17.16 Mapped oyster beds in Matagorda and San Antonio bays, Texas.

About the Artist

Brenda Guild Gillespie

Brenda Guild Gillespie grew up in the Canadian Rockies and only came to the marvels of the sea coast in her mid-teens. At university, she took an honors B.S. in Zoology and an M.S. in Environmental Education. In ecology and invertebrate courses, she came to know shellfishes from the inside out and by the company they keep.

She began illustrating fishes and shellfishes in 1979, taking a contract for a seafood marketing booklet almost on a dare. She quickly learned why most wildlife artists stick to birds and mammals - the colors and sheen of aquatic life are tricky; the shapes of shellfishes, in particular, are complicated.

Her early watercolors have evolved to much more refined work. Her growing library of images is used for food marketing, educational, scientific, souvenir, and decorative purposes. While painting each species, in technically accurate detail using an intricate layering technique, she enjoys imagining their mysterious lives in a magical water world.

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