

CHAPTER 8

SHELLFISH OF THE GULF OF MEXICO

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8.1 INTRODUCTION

Historically, the Gulf of Mexico and the Gulf of Maine produce the greatest amount of seafood by volume and value in the United States after Alaska (Upton 2011; NMFS 2011). During 2007–2009, the Gulf of Mexico annual average commercial landings by poundage was 1.4 billion pounds (635,000 metric tons) and value was \$660 million (NOS 2011). Four of the top five species by poundage and value in the Gulf of Mexico were shellfish, or invertebrates (brown shrimp, white shrimp, blue crab, and Eastern oyster). Menhaden was the only species of finfish in the top five. Shrimp are the most valuable shellfish industry in the Gulf, followed by the Eastern oyster and blue crab. At least 49 species of shellfish are taken as seafood in Gulf of Mexico waters from its three surrounding countries (the United States, Mexico, and Cuba). Penaeid shrimp (brown, white, and pink), Eastern oyster, and blue crab are widely taken and make up the main commercial industry species, whereas there are numerous additional local and artisanal shellfish fisheries for many other different species in Mexico and Cuba. The northern Gulf of Mexico is warm temperate, and the southern Gulf is subtropical to tropical. Iconic Caribbean species, like conch and spiny lobsters, have been taken commercially and recreationally in South Florida, Cuba, and Mexico. The purpose of this chapter is to summarize the primary commercial, marine and estuarine shellfish species of the northern Gulf of Mexico and their status and trends in the decades preceding the Deepwater Horizon oil spill of April 2010. However, since the waters and species of the Gulf do not recognize political boundaries, since many species range much wider than just the northern Gulf, and since the Gulf of Mexico is recognized as a Large Marine Ecosystem, an overview of all Gulf shellfish species is provided for better understanding of the species and their aquatic habitats. Readers interested in other aspects of fisheries should also review two other chapters presented in this series: Chapters 9 and 10 (in Volume 2). The latter focuses on the same five key species as this chapter, but its primary focus is on the economic value of the species and the fishing industry.

The term *shellfish* is usually used to refer to the edible species of invertebrates, as opposed to the term finfish, which is reserved for the true fishes. The largest shellfish groups include the mollusks (e.g., clams, oysters, conchs) and crustaceans (e.g., shrimps, crabs, lobsters), but shellfish also include invertebrate species without shells, such as sea cucumbers, octopus, squid, and jellyfish. The term *commercial invertebrates* is used to describe those invertebrate species that are captured for purposes other than food, such as ornamental shells and corals (Orensanz and Jaimieson 1998; Jennings et al. 2001). Within the Gulf of Mexico, as within all oceans of the world, the harvested species include only a very small percentage of the total biodiversity of any of the targeted fishery groups. For instance, a recent survey of all biota within the Gulf of Mexico revealed a total of 15,419 species (Felder and Camp 2009). Of that total 9,063 would be considered invertebrates, but only about 49, or 0.54 %, are taken as seafood. The primary commercial shellfish of the Gulf of Mexico are critically linked to estuaries for part (shrimp) or

all of their life cycles (blue crabs and oysters), and they are characterized by large numbers of eggs/young, rapid growth, and fairly short life cycles.

Historically, fishes and shellfishes have served as a source of food, commerce, and recreation for humans since ancient times (Ross 1997). Within the Gulf of Mexico, and considering our three primary shellfish groups, oysters were probably the first to be harvested by Native Americans due to their ease of capture near shorelines. Because of their popularity as a seafood delicacy and their importance as a significant commercial product, the Eastern oyster is perhaps the most studied marine species in the Gulf of Mexico (Berrigan et al. 1991). Although taken as seafood much earlier, the first commercial catches of shrimp and blue crabs were not recorded until the 1880s (Condrey and Fuller 1992; Steele and Perry 1990).

Today, finfish and shellfish are harvested intensively around the world as a source of protein in the family diet, for commercial or economic gain, or for recreational purposes (Ross 1997). Over 198 billion pounds (90 million metric tons) of finfish and shellfish are harvested annually around the world (www.fao.org, FAO 2011). In the United States in 2009 over 7.8 billion pounds (over 3.5 million metric tons) were harvested, and from the northern Gulf of Mexico, over 1.5 billion pounds (over 0.7 million metric tons) were taken (NMFS 2011). In the Gulf of Mexico, as in the rest of the United States, shellfish top the economic value list of species, indicating their continued importance to the fishery, and finfish top the weight or poundage list (NOS 2011). Using a 3-year average between 2007 and 2009, 78 % of all U.S. landings of shrimp came from the Gulf of Mexico with a 3-year average of 221 million pounds, and 62 % of all U.S. oyster landings came from the Gulf with a 3-year average of 22 million pounds of meats (NOS 2011).

Numerous techniques are utilized to evaluate the health or status of a selected fishery. This chapter will focus more on the biological populations of selected species through time, since the Commercial and Recreational Fisheries chapter will focus mainly on economic value and the fishing industry. Fishery scientists and managers use fishery-dependent and fishery-independent techniques to evaluate a given fishery, and both kinds of evaluation are critical in determining a fishery status through time. Fishery-dependent data are collected by state and federal fishery management agencies, so they can manage various species stocks, or populations, as well as the fishers who take them. Fisheries-independent data are collected by most Gulf States (e.g., Louisiana Department of Wildlife and Fisheries, [LDWF]), and these too are critical in fishery management work, because they reveal population trends that are independent of issues affecting the fishing industry. Within Federal waters (offshore) of the Gulf of Mexico fishery-independent data are collected by the Southeast Area Monitoring and Assessment Program (SEAMAP). SEAMAP is a cooperative state, federal, and academic program for the collection, management, and dissemination of fishery-independent data and information in the southeastern United States. Shrimp trawl surveys for SEAMAP occur in the summer and fall each year on the continental shelves of the northern Gulf. Fishery-dependent data are subject to numerous and varying conditions and circumstances, such as inaccurate "landings" (usually defined as pounds landed by the fishery, but not all landings are reported and not all reported landings are accurate), varying regulations (by state and federal agencies), and economic factors, such as fuel costs, market values, and foreign competition with some species (shrimp). Fishery-independent data are best for tracking time series of various species, but since this type of data is not universal, it will be used where available alongside fishery-dependent data in this document. For the purposes of fishery-independent data for this chapter, SEAMAP will be used for shrimp in the offshore areas. For inshore data on shrimp, oysters, and crabs, LDWF data will be used, as Louisiana has the highest catches, and it is not within the scope of this chapter to individually review all state fishery-independent programs.

Jurisdictional oversight and boundaries for the Gulf of Mexico shellfisheries vary in all three countries, but basically they are under federal jurisdiction in Cuba and Mexico with some province/state involvement, and in the United States both state and federal entities are involved. The five U.S. states have jurisdiction in the state territorial waters, or seas, which extend out into the Gulf of Mexico 3 nautical miles (5.6 km) off the shoreline of Louisiana, Mississippi, and Alabama, and 9 nautical miles off Texas and western Florida (NMFS 2010). Within each of these states their state fish and wildlife agency manages each fishery within its State Territorial Waters, and they all work together via the regional Gulf States Marine Fisheries Commission (GSMFC). In federal waters, the Exclusive Economic Zone (EEZ) extends from the seaward boundary of the State Territorial Waters out 200 nautical miles from the shoreline. The agency responsible for federal fishery management is the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA). Stakeholders within the Gulf fishery, along with NMFS, are engaged via the Gulf of Mexico Fisheries Management Council (GMFMC).

The Magnuson-Stevens Fishery Conservation and Management Act in the United States provides for the management and conservation of fishery resources within the U.S. EEZ (NMFS 2011). Under the Magnuson-Stevens Act, the GMFMC is charged with preparing fishery management plans for the fisheries needing management within the U.S. Gulf of Mexico. Of the three main shellfish groups covered in this document, only penaeid shrimp have a Gulf of Mexico Fishery Management Plan (FMP), since the other two main groups (blue crabs and oysters) are primarily inshore, or estuarine, species within State Territorial Waters. For blue crabs and oysters, each U.S. Gulf state may have its own rules and regulations regarding these two fisheries (Cody et al. 1992; Guillory 1996; Heath 1998; Perry et al. 1998; Quast et al. 1988; Steele and Bert 1998), but they all operate under a regional management plan prepared collectively by the GSMFC composed of members from each state (oysters, VanderKooy 2012; blue crabs, Guillory et al. 2001).

Understanding the biology, life cycles, and distribution of targeted species is central to understanding how they are affected by fishing and the environment. These aspects and environmental parameters are well known for Gulf of Mexico penaeid shrimp, blue crabs, and Eastern oysters. An examination of them along with their living space will help reveal the status and recent trends of their populations prior to the Deepwater Horizon oil spill in 2010. Healthy Gulf of Mexico waters and habitats are critical to the productivity and sustainability of Gulf shellfisheries. Diverse estuarine habitats provide nursery grounds (food, habitat, protection) for juvenile and young of many species. Seagrass beds, salt marshes, mangrove forests, and oyster reefs are particularly critical in the life cycles of many shellfish species. Indeed, these have all been labeled as Essential Fish Habitat (EFH) by both state and federal management authorities and warrant protection and conservation for future stocks of these species. Density, growth, and survival of the three primary Gulf taxa covered in this document are dependent upon the continued health of these key habitats and surrounding areas (Zimmerman et al. 2000; Beck et al. 2001, 2003; Minello et al. 2003; Jordan et al. 2009).

Substantial, long-term increases in shellfish harvests, along with increased human population levels and coupled coastal development, water quality issues, and habitat loss/degradation have all had impacts on fished stocks. Parasites and diseases, economic conditions, and management/regulatory decisions have also had effects and therefore can cause annual fluctuations in the fisheries (Lotze et al. 2006; Halpern et al. 2008; Jackson 2008).

In summary, regarding current status and historical trends of shrimp, oysters, and crabs in the northern Gulf of Mexico, it will be shown that there have been natural population fluctuations over the past several decades in all three groups. In addition, some fisheries, like shrimp, have been greatly affected in recent years by exogenous factors, such as rising fuel costs,

market competition from imported shrimp, and fleet damage by hurricanes. Overall, shrimp populations seem to be flourishing, while the shrimp fishery is in decline. Oyster populations, which have been lost or degraded worldwide, appear to be fairly stable in the Gulf of Mexico, showing variable annual and multiyear fluctuations due mainly to environmental conditions but also sometimes due to economic/market conditions (VanderKooy 2012). In addition, there has been damage to some oyster reefs and oyster fisheries due to hurricanes, and a decadal decline in oyster stock assessment in Louisiana (LDWF 2010). There is considerable concern in the Gulf over the continued loss of oyster reef habitat. The blue crab fishery is quite variable from state to state with Louisiana showing a continued growth and the largest fishery in the northern Gulf over the past two decades, while Texas shows a decrease in not only the fishery, but species populations statewide during the same time frame. Gulf-wide there is agreement that healthy bays and estuaries lead to more productive fisheries, and therefore some habitats need to be conserved, while others need to be restored.

8.2 JURISDICTIONAL BOUNDARIES AND GOVERNING AGENCIES

It is important to know the jurisdictional boundaries of the three countries involved in Gulf of Mexico shellfisheries, as well as the agencies and organizations responsible for shellfish fisheries management, in order to better understand the status and trends of shellfish populations. In the United States, both state and federal jurisdiction and agency/organization management is important, but in Mexico most shellfisheries jurisdiction and management belongs to the federal government, although the States can make suggestions and become involved. In Cuba, jurisdiction and management is at the Federal level, but provincial fishing associations also have responsibilities. All three countries, of course, recognize the 200 nautical mile EEZ marked from the shoreline seaward.

8.2.1 The United States (Federal and State)

Unlike Mexico and Cuba where all Gulf waters are considered to be under federal jurisdiction, the United States allows Gulf States the sovereign right to govern and manage their own state territorial waters, or seas. These waters vary by state with Louisiana, Mississippi, and Alabama having 3 nautical miles out from the shoreline, and Texas and western Florida declaring 9 nautical miles. Shellfisheries in the northern Gulf States are managed by each state's fish and wildlife agency and include (east to west): Florida Fish and Wildlife Conservation Commission, Alabama Department of Conservation and Natural Resources, Mississippi Department of Marine Resources, LDWF, and Texas Parks and Wildlife Department. Each state, according to its own laws, can establish fishery management plans and regulations for species within its waters, or it can work collaboratively with other states under the fishery management plans of the GSMFC. This commission, established in 1949, maintains an active web site (www.gsmfc.org, GSMFC 2011) for programs, publications, regulations, databases of landings, and much more. Fishery management plans for the two major shellfishery groups discussed herein (blue crabs and oysters) can be found at this site, as well as news releases, regulations, and licenses and fees for all five states.

At the federal level, the Magnuson-Stevens Fishery Conservation and Management Act of 1976 established eight Regional Fishery Management Councils around the United States to assist in the stewardship of federal fishery resources that occur beyond state waters (ELI and CMDA 2011). Each council is charged with preparing and implementing fishery management plans for harvested stocks, which in turn must be reviewed and approved by the NMFS of

NOAA. Enforcement of fishery management plans is accomplished by the NOAA Office of Law Enforcement via shipboard observers and dockside enforcement, the U.S. Coast Guard through sea patrols, and the states via joint enforcement agreements with the Office of Law Enforcement. In addition, the fishery management plans must identify EFH, including ways to minimize adverse effects to EFH caused by fishing, as well as actions to conserve and enhance EFH (ELI and CMDA 2011).

The Gulf of Mexico Fishery Management Council (GMFMC) performs fishery management within the EEZ of the Gulf of Mexico, and it has developed three fishery management plans for Gulf shellfish species (shrimp, spiny lobster, and stone crab). The GMFMC maintains an extensive web site (www.gulfcouncil.org) with regulations, meetings, management plans, committees, and panels on Gulf fisheries and issues, news, and many other resources (library, stock assessments, scoping documents and proposed amendments, education information, and FAQs, to mention a few). Each fishery management plan on the web site has a current list of amendments documenting changes since the first fishery management plan was passed, so it is very easy to follow the history of adaptive management of each fishery through time. Appointed science and statistical committees within the Council are charged with the responsibility of ascertaining if a federally managed species is overfished, and if so, to decide on an appropriate rebuilding plan.

8.2.2 Mexico (Federal with State Input)

In Mexico, the majority of fishery development occurred in the late 1970s with the creation of the Departamento de Pesca (Fisheries Department) and a consequent, substantial investment in state-owned fishing fleets and industrial plants (Diaz-de-Leon et al. 2004). Mexican fisheries catches peaked in the early 1980s, followed by decreasing catches due to overexploitation and overcapitalization of most fisheries through the 1990s. During a 1999 public review of the Ley de Pesca 1992 (Fishery Law), the Instituto Nacional de Pesca (IPN, National Fishery Institute) proposed that the Carta Nacional Pesquera (National Fisheries Charter) should inform Mexican fisheries by defining, inventorying, managing, regulating, and conserving the resources. The National Fisheries Charter subsequently became the regulatory instrument rather than just informing the fishery in the early to middle first decade of the 2000s (Diaz-de-Leon et al. 2004).

Today, the regulation of harvested species is established mainly by the Ley General de Pesca y Acuicultura Sustentable (General Law on Fisheries and Sustainable Aquaculture; ELI and CMDA 2011). This new law was published in 2007 with the main objective to promote and manage the exploitation of fisheries resources and aquaculture in a sustainable way. The main powers of the Federal government in regard to fisheries and aquaculture are implemented through the Comision Nacional de Acuicultura y Pesca (CONAPESCA, National Commission of Aquaculture and Fisheries), which is a decentralized component of the Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca, y Alimentacion (SAGARPA, Ministry of Agriculture, Livestock, Rural Development, Fisheries, and Foods). The General Law of Fisheries and Sustainable Aquaculture emphasizes the joint collaboration of CONAPESCA with the Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT, Ministry of the Environment and Natural Resources) concerning conservation and restoration of the environment to maintain healthy fisheries.

8.2.3 Cuba (Federal with Provincial Fishing Associations)

In Cuba, most Cuban fisheries were focused on the continental shelves of the island nation before 1960, using artisanal fishing gear and small boats (3–11 m; 9.9–36 ft), and most boats

were without engines. Larger vessels (20–25 m; 72–89 ft) were restricted to the tuna fishery, along with a few shrimp trawlers (Claro et al. 2001, 2009). After the Cuban Revolution in 1959, growth of the fisheries industry was an important objective of the new government (Baisre 2006). Domestic catches dominated and increased throughout the 1960s, but increases in a significant long-distance fleet increased international catches during the 1970s to 1980s, which dominated as much as two-thirds of the Cuban catch (Baisre et al. 2003; Baisre 2006). However, as the Soviet Union assisted in the fishery fleet buildup in the 1960s and 1970s, its collapse and withdrawal from Cuba in the early 1990s severely curtailed the offshore fisheries (Adams et al. 2000). After this, the Cuban fishing industry changed dramatically with the emphasis shifting from high-volume, but low-value pelagic fisheries to high-value, coastal fin- and shell-fish species caught mainly in nearshore waters (Adams et al. 2000). The principal marine fisheries of Cuba today are lobster (most valuable), shrimp, small pelagics, demersal reef fishes, mullets, crabs, some mollusks, and sponges (Baisre 2006).

For statistical and data gathering purposes, the insular shelf of Cuba is divided into four sectors: Zone A—Southeast; Zone B—Southwest; Zone C—Northwest; and Zone D—Northeast (Claro et al. 2001; Baisre 2006). Zone C, the Northwest shelf and Gulf of Mexico portion of Cuba, is the smallest shelf area and therefore contributes the lowest amount to the catches (only 2–3 % of the total). A 60-year trend analysis by Baisre (2000) showed sustained increases in catches from the mid-1950s to 1970s, decreasing growth rate during the 1980s, and a revealing impact on overall fisheries during the 1990s. His study revealed that about 39 % of the fishery resources were in a senescent phase, about 49 % were in a mature phase with high exploitation, and only about 12 % were still in the developing phase with a possibility of increased catches. None of the fisheries remained underdeveloped.

Fisheries management in Cuba is under the control of the Ministerio de la Industria Pesquera (MIP, Ministry of Fishing Industries). Formerly it was more centralized, but today it is quite decentralized. The MIP is directly responsible for the national legal and administrative functions, but the production activities, control, and services have been delegated to Provisional Fishing Associations (PFAs) around the country. The PFAs are responsible for producing fin- and shellfish landings, which are in compliance with species-specific harvest plans. These harvest plans, which are developed by the individual PFAs, are then consulted on and approved by the Executive Board of MIP. The PFAs have legal and jurisdictional authority with independent control over the resources (e.g., vessels, fuel, supplies, ice, and labor) (Adams et al. 2000; Baisre et al. 2003).

The current regulatory framework for Cuban fisheries management is under Decreto Ley 164 (Decree Law 164, “Rules for Fisheries”) passed in 1996. Other important laws passed in the late 1990s and early 2000s deal with protection and conservation of the environment, establishment of a national system of protected areas, and coastal zone management, all of which work together today to attempt to make Cuba’s fisheries more sustainable (Baisre 2006).

8.3 SHELLFISH OF THE GULF OF MEXICO

At least 49 species of shellfish are fished within the Gulf of Mexico in the coastal and marine waters of Cuba, Mexico, and the United States (Table 8.1). For purposes of this chapter, shellfish of the Gulf of Mexico (Figure 8.1) are defined as those that live within Gulf marine habitats, coastal waters, and tidal wetlands as defined by Felder and Camp (2009). These include all the waters of Florida Bay and the Florida Keys west of a line from Key Largo to Punta Hicacos, Cuba, and north of a line between Cabo San Antonio, Cuba, and Cabo Catoche, Quintana Roo, Mexico. The northern Gulf of Mexico from Cabo Rojo, Veracruz, in the western Gulf of Mexico to Cape Romano, Florida, in the eastern Gulf is considered warm temperate, or

Table 8.1. Shellfish Fisheries of the Gulf of Mexico

Species ^a	Common Name ^b English (Spanish)	Country ^c /Remarks ^d /Citation ^e
Phylum Mollusca/Class Gastropoda/Family Strombidae		
1. <i>Aliger costatus</i> (syn. <i>Strombus costatus</i>)	Milk Conch (Caracol Blanco or Lanceta)	MX—fishery species in danger of extinction (Baqueiro 2004; Diario Oficial 2010)
2. <i>Eustrombus gigas</i> (syn. <i>Strombus gigas</i>)	Queen Conch (Caracol Rosado, de Abanico or Reina)	MX—fishery deteriorated in MX (Diaz-de-Leon et al. 2004); CU—populations controlled (Claro et al. 2001); US (South Florida)—overfished (CFMC 1996)
3. <i>Strombus pugilis</i>	West Indian Fighting Conch (Caracol Canelo or Lancetita)	MX—species with fishery potential (Baqueiro 2004; Diario Oficial 2010)
Family Fascioliariidae		
4. <i>Fasciolaria liliium</i>	Banded Tulip (Caracol Campechana)	MX—currently fished (Baqueiro 2004)
5. <i>Fasciolaria tulipa</i>	True Tulip (Caracol Campechana)	MX—currently fished (Baqueiro 2004; Diario Oficial 2010)
6. <i>Triplofusus giganteus</i> (syn. <i>Pleuroploca giganteus</i>)	Horse Conch (Caracol Rojo or Chac Pel)	MX—fishery species in danger of extinction (Baqueiro 2004; Diario Oficial 2010)
Family Melongenidae		
7. <i>Busycon perversum</i>	Knobbed Whelk (Sacabocados, Lix, or Caracol Trompillo)	MX—currently fished (Baqueiro 2004, listed as <i>B. carica</i> ; Diario Oficial 2010)
8. <i>Melongena bispinosa</i>	Crown Conch (Caracol Negro or Moloncito)	MX—species with fishery potential (Baqueiro 2004, listed as <i>M. corona bispinosa</i> ; Diario Oficial 2010)
9. <i>Melongena melongena</i>	Crown conch (Caracol Chivita or Chirita, or Molon)	MX—species with fishery potential (Baqueiro 2004; Diario Oficial 2010)
Family Turbinellidae		
10. <i>Turbinella angulata</i>	West Indian Chank (Caracol Tomburro or Negro)	MX—currently fished (Baqueiro 2004; Diario Oficial 2010)
Class Cephalopoda/Family Loliginidae		
11. <i>Doryteuthis pealeii</i>	Longfin Inshore Squid	All three species lumped in the US and MX statistics as “squids”; MX—incidental in shrimp trawls (Baqueiro 2004); US—primarily caught as bycatch in shrimp trawls (Patillo et al. 1997)

(continued)

Table 8.1. (continued)

Species ^a	Common Name ^b English (Spanish)	Country ^c /Remarks ^d /Citation ^e
12. <i>Doryteuthis plei</i>	Slender Inshore Squid	
13. <i>Lolliguncula brevis</i>	Atlantic Brief Squid (all = calamar)	
Family Octopodidae		
14. <i>Octopus maya</i>	Yucatán Octopus (Pulpo Rojo)	MX (Yucatán, Campeche)—current important fishery (Baqueiro 2004; Diario Oficial 2010); maximally exploited (Díaz-de-León et al. 2004)
15. <i>Octopus cf. vulgaris</i>	Common Octopus (Pulpo Paton)	MX—current fishery (Baqueiro 2004; Diario Oficial 2010); potential for exploitation (Díaz-de-León et al. 2004)
Class Bivalvia/Family Arcidae		
16. <i>Anadara transversa</i>	Transverse Ark (Arca Transversa)	MX—species with fishery potential (Baqueiro 2004)
Family Mytilidae		
17. <i>Geukensia granosissima</i>	Southern Ribbed Mussel (Mejillon Amarillo)	MX—species with fishery potential (Baqueiro 2004, listed as <i>G. demissa</i>)
18. <i>Modiolus americanus</i>	American Horse Mussel (Mejillon)	MX—species with fishery potential (Baqueiro 2004)
Family Ostreidae		
19. <i>Crassostrea rhizophorae</i>	Mangrove Oyster (Ostion de Mangle)	MX—current fishery (Diario Oficial 2010); CU—current fishery (Baisre 2000)
20. <i>Crassostrea virginica</i>	Eastern Oyster (Ostion Americano)	MX—current fishery (Baqueiro 2004; Diario Oficial 2010); US—major fishery (Berrigan et al. 1991)
Family Pinnidae		
21. <i>Atrina rigida</i>	Stiff Pen Shell (Callo de Hacha)	MX—current fishery (Baqueiro 2004)
Family Pectinidae		
22. <i>Argopecten irradians</i>	Bay Scallop (Almeja Abanico)	MX—species with fishery potential (Baqueiro 2004); US (Florida)—closed (Patillo et al. 1997)
Family Lucinidae		
23. <i>Codakia orbicularis</i>	Tiger Lucine (Almeja Rayada or Blanca)	MX—species with fishery potential (Baqueiro 2004; Diario Oficial 2010)
Family Corbiculidae		
24. <i>Polymesoda caroliniana</i>	Carolina Marsh Clam (Almeja negra)	MX—current fishery (Baqueiro 2004; Diario Oficial 2010)

(continued)

Table 8.1. (continued)

Species ^a	Common Name ^b English (Spanish)	Country ^c /Remarks ^d /Citation ^e
Family Veneridae		
25. <i>Chione elerata</i> (syn. <i>Chione cancellata</i>)	Florida Cross-barred Venus (Almeja China or Ronosa)	MX—species with fishery potential (Baqueiro 2004; listed as <i>C. cancellata</i>)
26. <i>Mercenaria campechensis</i>	Southern Quahog (Concha or Almeja Bola)	MX—species with fishery potential (Baqueiro 2004; Diario Oficial 2010)
Family Mactridae		
27. <i>Rangia cuneata</i>	Atlantic Rangia (Almeja Gallito)	MX—current fishery (Baqueiro 2004; Diario Oficial 2010)
28. <i>Rangia flexuosa</i>	Brown Rangia (Almeja Chira)	MX—species with fishery potential (Baqueiro 2004; Diario Oficial 2010)
Phylum Arthropoda/Subphylum Crustacea/Class Malacostraca/Order Decapoda/Family Penaeidae		
29. <i>Farfantepenaeus aztecus</i>	Brown Shrimp (Cameron Café)	MX (Tamaulipas, Veracruz, Tabasco)—current fishery (Diario Oficial 2010), maximal exploitation (Diaz-de-Leon et al. 2004); US (Texas, Louisiana)—current significant fishery (GMFMC 1981; Caillouet et al. 2008, 2011)
30. <i>Farfantepenaeus duorarum</i>	Pink Shrimp (Cameron Rosado)	MX (Campeche Bay) current fishery (Diario Oficial 2010), deteriorated fishery (Diaz-de-Leon et al. 2004); US (Southwest Florida)—current important fishery (GMFMC 1981; Hart 2008; Hart and Nance 2010)
31. <i>Litopenaeus setiferus</i>	White Shrimp (Cameron Blanco)	MX (Campeche Bay)—deteriorated fishery (Diaz-de-Leon et al. 2004); US (Northern Gulf of Mexico)—current significant fishery (GMFMC 1981; Nance et al. 2010)
32. <i>Xiphopenaeus kroyeri</i>	Atlantic Seabob (Cameron Siete Barbas)	MX (Tabasco)—potential for fishery development (Diaz-de-Leon et al. 2004), important coastal fishery (Wakida-Kusunoki 2005); US—important northern Gulf fishery (Gusmao et al. 2006)
Family Sicyonidae		
33. <i>Sicyonia brevirostis</i>	Rock Shrimp (Cameron de Roca)	MX (North Quintana Roo)—small fishery (Diario Oficial 2010); US—small deep-sea fishery (Stiles et al. 2007)

(continued)

Table 8.1. (continued)

Species ^a	Common Name ^b English (Spanish)	Country ^c /Remarks ^d /Citation ^e
Family Solenoceridae		
34. <i>Pleoticus robustus</i> (syn. <i>Hymenopenaeus robustus</i>)	Royal Red Shrimp	US (Deep Gulf)—small deep-sea fishery (Stiles et al. 2007)
Family Palinuridae		
35. <i>Panulirus argus</i>	Spiny Lobster (Langosta del Caribe)	CU (Northern Coast)—most valuable Cuban fishery (Claro et al. 2001); MX (Yucatán, Quintana Roo)—exploited to deteriorated fishery (Diaz-de-Leon et al. 2004), US (Florida Keys)—(GMSAFMC 1982)
36. <i>Panulirus guttatus</i>	Spotted Lobster (Langosta Pinta)	MX—small fishery, incidental with Spiny Lobster (Diario Oficial 2010)
Family Portunidae		
37. <i>Callinectes bocourti</i>	Bocourt Swimming Crab (Jaiba Roma)	MX—coastal zone fishery (Diario Oficial 2010)
38. <i>Callinectes danae</i>	Dana Swimming Crab (Jaiba Siri)	MX—coastal zone fishery (Diario Oficial 2010)
39. <i>Callinectes ornatus</i>	Swimming Crab (Jaiba)	MX—coastal zone fishery (Diario Oficial 2010)
40. <i>Callinectes rathbunae</i>	Sharptooth Swimming Crab (Jaiba Prieta)	MX—coastal zone fishery (Diario Oficial 2010)
41. <i>Callinectes sapidus</i>	Blue Crab (Jaiba Azul)	MX—coastal zone fishery (Diario Oficial 2010); US—significant fishery (Guillory et al. 2001); CU—current fishery (Baisre 2000)
42. <i>Callinectes similis</i>	Lesser Blue Crab (Jaiba Pequena Azul)	MX—coastal zone fishery (Diario Oficial 2010)
Family Menippidae		
43. <i>Menippe adina</i>	Gulf Stone Crab (Congrejo Moro or Congrejo de Piedra Negro)	MX (Tamaulipas)—coastal zone fishery, mainly incidental with Jaiba fishery (Diario Oficial 2010); US—small northern Gulf fishery (Patillo et al. 1997)
44. <i>Menippe mercenaria</i>	Florida Stone Crab (Congrejo Moro or Congrejo de Piedra Negro)	US (West Coast of Florida) southwest Florida fishery mainly (Patillo et al. 1997)
45. <i>Menippe nodifrans</i>	Cuban Stone Crab (Congrejo Moro or Congrejo de Piedra Negro)	US (Florida Keys)—Caribbean species fishery (Patillo et al. 1997); CU (Northwest Coast)—coastal fishery (Baisre 2000; Claro et al. 2001); MX (Southern Gulf)—coastal zone

(continued)

Table 8.1. (continued)

Species ^a	Common Name ^b English (Spanish)	Country ^c /Remarks ^d /Citation ^e
		fishery, mainly incidental with Jaiba fishery (listed as <i>M. mercenaria</i> in Diario Oficial 2010)
Family Gecarcinidae		
46. <i>Cardiosoma guanhumii</i>	Blue Land Crab (Congrejo Azul or de Tierra)	MX—terrestrial crab fishery, up to 2 miles inland (Diario Oficial 2010); CU—small land crab fishery (Baisre 2000)
Phylum Echinodermata/Class Holothuroidea/Family Holothuridae		
47. <i>Holothuria floridana</i>	Sea Cucumber (Pepina del Mar)	MX (Yucatán)—local artisanal fishery at Progreso (Mexicano-Cintora et al. 2007)
Family Stichopodidae		
48. <i>Astichopus multifidus</i>	Sea Cucumber (Pepina del Mar)	MX (Yucatán)—local artisanal fishery at Progreso (Mexicano-Cintora et al. 2007)
49. <i>Isostichopus badionotus</i>	Sea Cucumber (Pepina del Mar)	MX (Yucatán)—local artisanal fishery at Progreso (Mexicano-Cintora et al. 2007)

^aSpecies names and higher classification follow Felder and Camp (2009), except for Class Bivalvia, where Tunnell et al. (2010) is followed

^bCommon names are given in English and Spanish where appropriate and available; English common names follow the "official" common names used on the NOAA Fisheries (NOAA 2011a): Office of Science and Technology, Fisheries Statistics Division (ST1) data web site (<http://www.st.nmfs.noaa.gov/st1/>) or from McLaughlin et al. (2005) for crustaceans or Turgeon et al. (1998) for mollusks

^cCountry (and sometimes State): CU Cuba; MX Mexico; US United States. Country or State listing is when a fishery for that species is present, not just distribution of the species

^dRemarks note the status or type of fishery in that country or state, such as large active and small artisanal only

^eCitation—only key references are listed, either the Fishery Management Plan for that species, a recent paper with extensive citations or information, or a status of the species

Carolinian Province, by zoogeographers (Briggs 1974). From Cabo Rojo southward throughout the entire southern Gulf of Mexico, Yucatán Peninsula, northwest Cuba, and the Florida Keys up to Cape Romano is considered tropical, or Caribbean Province (Figure 8.1).

Of the 49 species of shellfish taken as fishery species within the Gulf of Mexico, 28 are mollusks, 18 are crustaceans, and three are echinoderms (Tables 8.1 and 8.2). Eleven of the species are warm temperate, or Carolinian Province, species that live in the northern Gulf of Mexico, and 47 are distributed in the tropical, or Caribbean Province, waters of the southern Gulf, including south Florida. Regarding the three countries that surround the Gulf of Mexico, 16 of the species are taken within the United States, 46 from Mexico, and six from Cuba (Tables 8.1 and 8.2). Some species, such as oysters, penaeid shrimp, and blue crabs overlap the biogeographic, as well as political boundaries, and are found in two or more provinces or countries, respectively. As is true in most places in the world, diversity (number) of species is higher in the tropical waters of the southern Gulf of Mexico and productivity of selected

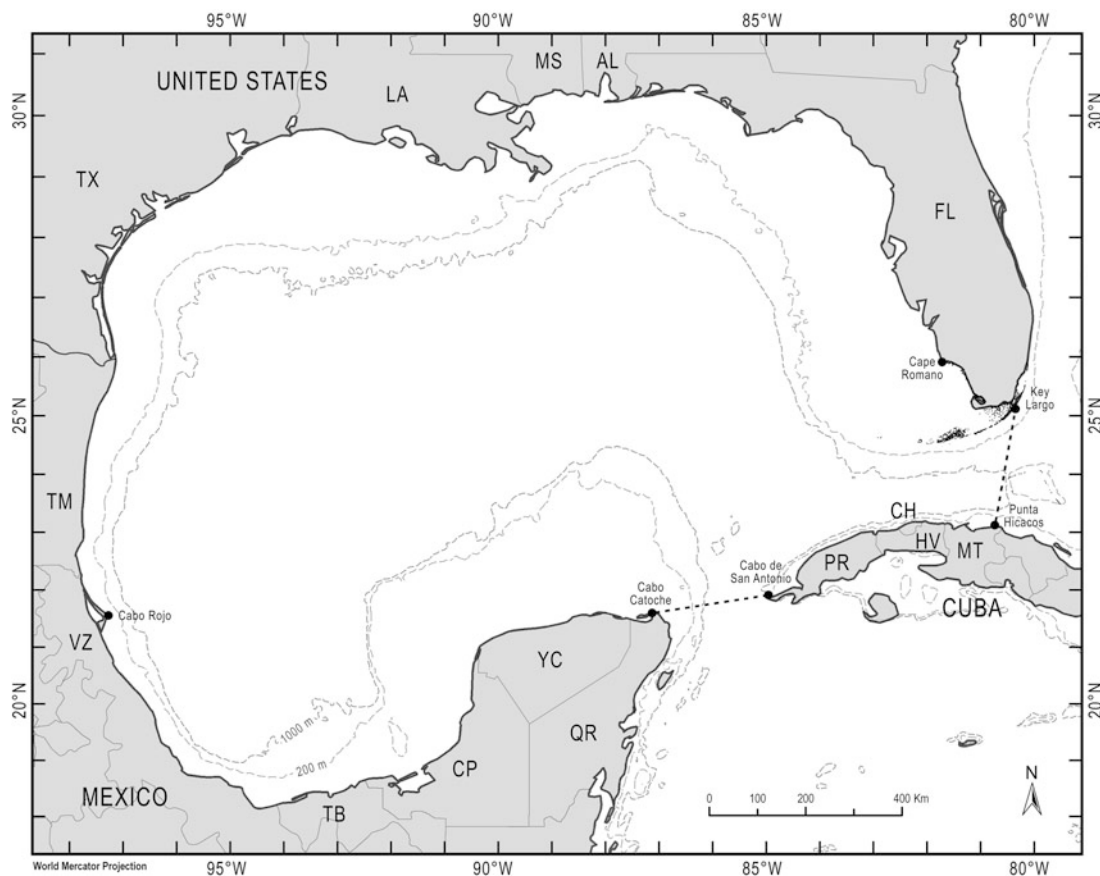


Figure 8.1. Gulf of Mexico, delimiting the geographic boundaries considered in this chapter. Abbreviations for the states (or provinces in Cuba; *counterclockwise*) from Florida: FL Florida, AL Alabama, MS Mississippi, LA Louisiana, TX Texas, TM Tamaulipas, VZ Veracruz, TB Tabasco, CP Campeche, YC Yucatán, QR Quintana Roo, PR Pinar del Rio, CH Ciudad de la Habana, HV La Habana, MT Matanzas (map by Fabio Moretzsohn (used with permission of the Harte Research Institute, Texas A&M University - Corpus Christi); adapted from Felder and Camp 2009).

fishery species is higher in northern Gulf temperate waters (Ekman 1953; Pianka 1966; Briggs 1974).

For purposes of presentation and discussion within this chapter, shellfisheries of the Gulf of Mexico have been divided into three categories according to the relative size and importance of each fishery: major, moderate, or minor (Table 8.3). A major, or primary, fishery is a large fishery of significant economic importance to one or more of the three countries. A moderate, but important, fishery is one which is either widely or regionally of modest economic importance, and a minor fishery is one which is only of local or artisanal importance. Major fishery species (five species) are widely distributed and abundant, moderate species (six species) are, or were, abundant in a specific region or habitat, and minor species (38 species) can be locally or regionally abundant, especially within specific habitats. The fisheries listed in this document have been recognized as such in the published literature or “federal register” (i.e., Diario Oficial 2010) of a given country. There are undoubtedly other shellfish species that are not listed that have been taken by local individuals either recreationally or commercially in various regions of the Gulf.

Table 8.2. Numbers of Gulf of Mexico Shellfish by Classification Category, Zoogeographic Distribution, and Country

Classification Category	
Taxonomic group	Number of species
Mollusks	28
Gastropods	10
Cephalopods	5
Bivalves	13
Crustaceans	18
Shrimp	6
Lobsters	2
Crabs	10
Echinoderms	3
Total	49
Zoogeographic distribution	Number of species
Warm temperature/Northern Gulf of Mexico (Carolinian Province)	11
Tropical/Southern Gulf of Mexico (Caribbean Province)	47
Country	Number of species
United States	16
Mexico	46
Cuba	6

8.3.1 Mollusks

Molluscan shellfish species include gastropods (snails, conchs, whelks, and others), cephalopods (squids, octopi), and bivalves (mussels, oysters, scallops, clams, and others). Of the ten gastropod species listed in Table 8.1, most are minor fishery species taken by local or small artisanal fisheries in Mexico, and only the queen conch is a moderate, but important species that has been widely, or commonly, taken in all three Gulf countries. Regarding the five species of cephalopods in Table 8.1, squid (three species) are minor species that are primarily taken as incidental bycatch in shrimp trawls in the United States and Mexico, and only the Yucatán octopus sustains a moderate, but important, regional fishery in the Yucatán Peninsula states of Campeche and Yucatán. Of the 13 species of bivalves listed, most are minor shellfish species taken in small local or artisanal fisheries of Mexico with only the Eastern oyster making a major, or primary, fishery in the United States and Mexico, so it will be covered in detail in Sections 8.4 and 8.5. The mangrove oyster is a moderate, but important, fishery in both Mexico and Cuba, and will therefore be covered below.

8.3.1.1 Queen Conch

The queen conch is a large and beautiful marine snail reaching over 30 cm (12 in.) in length and weighing up to 2.3 kg (5 lb). It has a flared outer lip with a bright pink or rosy aperture giving it the sometimes-used common name of pink conch (Figure 8.2) (Tunnell et al. 2010).

Table 8.3. Relative Size and Importance of Gulf of Mexico Shellfish Fisheries

Major fishery	Country
1. Eastern Oyster	US, MX
2. Brown Shrimp	US, MX
3. Pink Shrimp	US, MX
4. White Shrimp	US, MX
5. Blue Crab	US, MX
Moderate but important fishery	Country
1. Queen Conch	US, MX, CU
2. Yucatán Octopus	MX
3. Mangrove Oyster	MX, CU
4. Atlantic Seabob	US, MX
5. Spiny Lobster	US, MX, CU
6. Florida Stone Crab	US
Minor fishery	Country
1. Milk Conch	MX
2. West Indian Fighting Conch	MX
3. Banded Tulip	MX
4. True Tulip	MX
5. Horse Conch	MX
6. Knobbed Whelk	MX
7. Crown Conch	MX
8. West Indian Chank	MX
9. Squids (three species)	US, MX
10. Common Octopus	MX
11. Transverse Ark	MX
12. Southern Ribbed Mussel	MX
13. American Horse Mussel	MX
14. Stiff Pen Shell	MX
15. Bay Scallop	US, MX
16. Tiger Lucine	MX
17. Carolina Marsh Clam	MX
18. Florida Cross-barred Venus	MX
19. Southern Quahog	MX
20. Atlantic Rangia	MX
21. Brown Rangia	MX
22. Rock Shrimp	US, MX
23. Royal Red Shrimp	US
24. Spotted Lobster	MX
25. Swimming Crabs (six species)	MX
26. Gulf Stone Crab	US, MX
27. Cuban Stone Crab	US, MX, CU
28. Blue Land Crab	MX, CU
29. Sea Cucumbers (three species)	MX

US United States, MX Mexico, CU Cuba



Figure 8.2. Queen Conch (*Eustrombus gigas*) (photo by J.W. Tunnell).

It prefers sand, seagrass, and coral rubble habitats in warm, tropical seas of generally less than 21 m (70 ft). It is found throughout the Caribbean Sea and southern Gulf of Mexico, and it ranges as far north as Bermuda and as far south as Brazil (CFMC 1996).

Because the queen conch is prized for its meat and shell, population declines began throughout its range prior to the 1960s; however, most authorities and fishers did not acknowledge that overharvesting was occurring until the 1980s (Brownell and Stevely 1981; Iversen and Jory 1985; Appeldoorn and Meyers 1993; CFMC 1996). Conch fisheries in some localities, such as Florida Keys and Cuba, virtually collapsed due to overharvest (CFMC 1996). Once common on the Veracruz coral reefs, the queen conch essentially disappeared from that area in the 1980s (Tunnell et al. 2007). Likewise, it was common and being overfished during the 1980s on Alacran and other Campeche Bank reefs, but now it has low population levels due to overharvesting (Figure 8.3) (Baqueiro 2004; Diaz-de-Leon et al. 2004; Tunnell et al. 2007).

Historically, the queen conch ranked second only to the spiny lobster in terms of export value of Caribbean-wide fishery products, and only second to a variety of finfish (mostly reef fish) in terms of local consumption (CFMC 1996). Even archaeological evidence strongly suggests its use and importance as a food source long before discovery of the New World (Stevely 1979). However, even though queen conch were once abundant and an important fishery resource throughout the wider Caribbean, today most localities no longer have a viable fishery due to overfishing (CFMC 1996).

In the United States, in the Florida Keys and surrounding area, commercial and sport conch fisheries (taken by hand while snorkeling or diving) had completely collapsed by the mid-1970s, primarily due to overharvest. Commercial harvest of queen conch was banned in the Florida Keys in 1975, and a ban on all commercial and recreational harvest was implemented in 1986 (CFMC 1996; SEDAR 2007). In Mexico, the queen conch fishery has deteriorated (Diaz-de-Leon et al. 2004), but some exploitation continues on Alacran and other Campeche Bank coral reefs. In Cuba, due to intense harvesting and overexploitation, takings have been prohibited since 1992, except small-quota catches permitted under special authorization in very selected areas (Claro et al. 2001, 2009). Interestingly, in Cuba the queen conch was historically, and even recently, taken as not only food but for bait. In all localities, the shells of the queen conch have historically been used in the shell-craft and handicraft trades.



Figure 8.3. Queen Conch fishing boat on Alacran Reef, Yucatán, Mexico (photo by J.W. Tunnell).

8.3.1.2 Yucatán Octopus

The Yucatán octopus fishery is one of the most important fishery resources in the southern Gulf of Mexico (Arreguin-Sanchez et al. 2000). The endemic Yucatán octopus makes up approximately 80 % of the catch, and the common octopus the remainder. The octopods are common in the nearshore limestone rocky bottom of the states of Campeche and Yucatán, with the latter having the largest part of the fishery. There are three fleets that participate in this fishery, two artisanal operating in shallow waters, and a mid-sized fleet of boats that operate in deeper waters. The fishing gear for all of these is locally known as the *jimba*, a long cane or bamboo pole extending from either end of a small boat with multiple lines on each (Figure 8.4) (Arreguin-Sanchez et al. 2000; Mexicano-Cintora et al. 2007). Small crabs (usually majids or portunids) are tied to the end of the line and allowed to drag at or near the bottom as the boat drifts with the current on the surface. When the octopus grabs the crab, the fisherman gently pulls the catch into the boat, kills it, and puts it into a storage box with ice. Fishermen operate out of nine small ports in Campeche and Yucatán, with many operating directly off the open Gulf beaches (Figure 8.5).

With upwards of 2,000 pangas (small fishing boats) and many more very small skiffs launched from the pangas, as well as about 500 mid-sized vessels with about ten skiffs each operating in the three fleets, catches in recent years have ranged from 11 to 22 million pounds, with a high of over 39 million pounds in 1997. The latter take is considered an overexploitation level, as noted by Arenas and de Leon (1999) and Arenas-Fuentes and Jimenez-Badillo (2004), who suggest a 22–26 million pounds sustainable level.



Figure 8.4. *Jimba* fishing rigs (cane or bamboo poles with multiple fishing lines) on Mexican fishing pangas at Chicxulub Puerto, Yucatán, Mexico (photo by J.W. Tunnell).



Figure 8.5. Mexican octopus fishermen on the beach at Chicxulub Puerto, Yucatán, Mexico (photo by J. W. Tunnell).

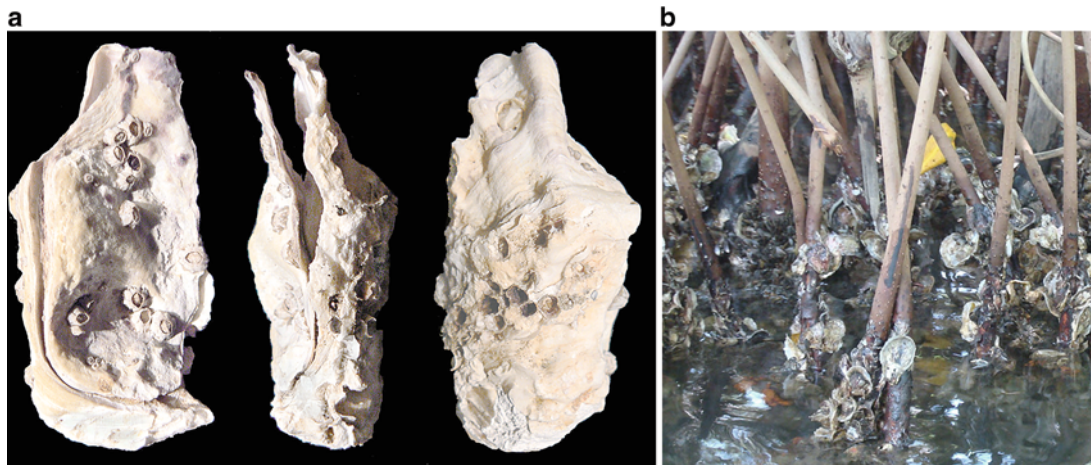


Figure 8.6. (a) Mangrove oysters (*Crassostrea rhizophorae*) and (b) growing on prop roots of red mangroves (photo 8.6a by John Wiley (used with permission of the Harte Research Institute, Texas A&M University - Corpus Christi) and 8.6b by Project Noah, <http://www.projectnoah.org/>).

8.3.1.3 Mangrove Oyster

Mangrove oysters, as implied by their common name, grow on the roots of mangrove trees (Figure 8.6) in estuarine conditions and are harvested commercially in both Mexico and Cuba (Baqueiro 2004; Baisre 2000). In Mexico, the largest catch of this species was taken along the mangrove-dominated coastline north of the town of Campeche (city), Campeche (state), in the western Yucatán Peninsula, but that population was apparently decimated by the Ixtoc I oil spill in 1979 and 1980 (Tunnell, personal communication with fishermen in 2010). The majority of mangrove oysters in Cuba are taken on the southern coast where extensive mangroves exist, but some are taken in the several small estuaries of the northwest coast facing the Gulf of Mexico.

8.3.2 Crustaceans

Crustacean shellfish species in the Gulf of Mexico include shrimp, lobster, and crab. Of the six shrimp species listed in Table 8.1, three are major shellfish species (brown, white, and pink shrimp), one is a moderate, but important, species (Atlantic seabob), and two are minor deep-sea species (rock shrimp and royal red shrimp (Stiles et al. 2007)). Two lobster fishery species are listed, one moderate (spiny lobster) and one minor (spotted lobster). Of the ten species of crab shellfishery species, only one is a major fishery (blue crab), one a moderate, but important, fishery (Florida stone crab), and all the rest are minor fishery species. In addition, there are two deep-sea crabs that are found within the Gulf of Mexico, golden crab (*Chaceon fenneri*) and deep-sea red crab (*C. quinquedens*), that are fished in the Atlantic and have unexploited potential in the Gulf (Waller et al. 1995; Trigg et al. 1997; Kilgour and Shirley 2008). Below are brief overviews of the moderate fishery species mentioned above: Atlantic seabob in the United States and Mexico; spiny lobster in the United States, Mexico, and Cuba; and, the Florida stone crab in the United States (Florida). The major fishery species mentioned above will be covered in detail in Sections 8.4 and 8.5 below.

8.3.2.1 Atlantic Seabob

The Atlantic seabob is a wide-ranging penaeid shrimp species that extends from North Carolina to southern Brazil and includes the entire Gulf of Mexico and Caribbean Sea



Figure 8.7. Seabob (*Xiphopenaeus kroyeri*). Photograph by Darryl L. Felder, University of Louisiana at Lafayette (all rights reserved by D.L. Felder).

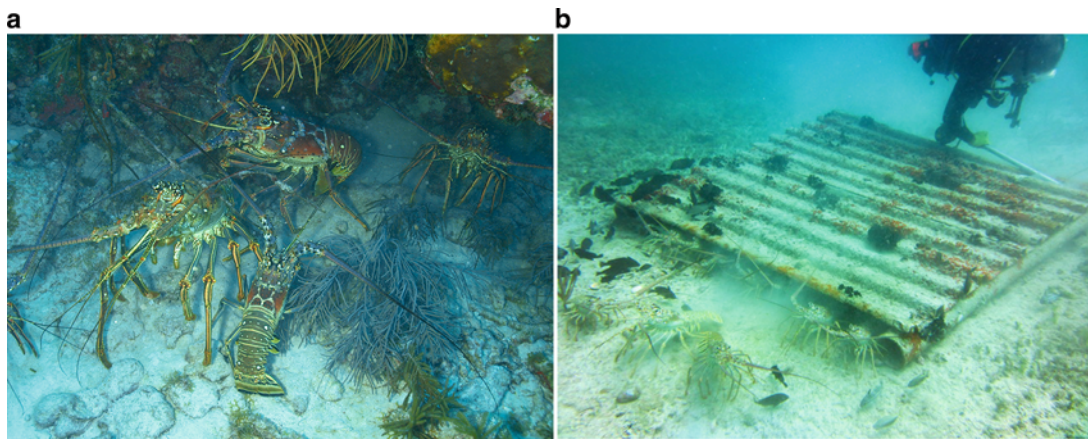


Figure 8.8. (a) Spiny lobster (*Panulirus argus*), Cayos Arcas coral reef, southern Gulf of Mexico (photograph by Dr. Jose Borges Souza, Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, used with permission). (b) Lobster house or casita, which is commonly used in Mexico and Cuba (photograph from NOAA, <http://www.habitat.noaa.gov/images/lobstertraps2.jpg>).

(Figure 8.7). It is found on sandy and muddy bottoms of 1–70 m (3–230 ft) depth, but it seems to prefer water less than 27 m (88 ft) and near heavy freshwater outflows of estuaries and deltas. It is a very important shrimp fishery in two rather small specific areas within the Gulf of Mexico: In the United States between Pensacola, Florida, and Texas, and in Mexico off eastern Tabasco and western Campeche, specifically near Isla del Carmen and Laguna de Terminos in the Gulf. Annual landings of 3–4 million pounds of whole shrimp have been recorded in the distinctive seabob fishery near Ciudad del Carmen (Wakida-Kusunoki 2005).

8.3.2.2 Spiny Lobster

Like the queen conch, the spiny lobster is an iconic Caribbean species (Figure 8.8). It is widespread in shallow, warm tropical waters throughout the wider Caribbean and up to North Carolina on offshore banks and south to Brazil. Its preferred habitat is rocky bottom or coral

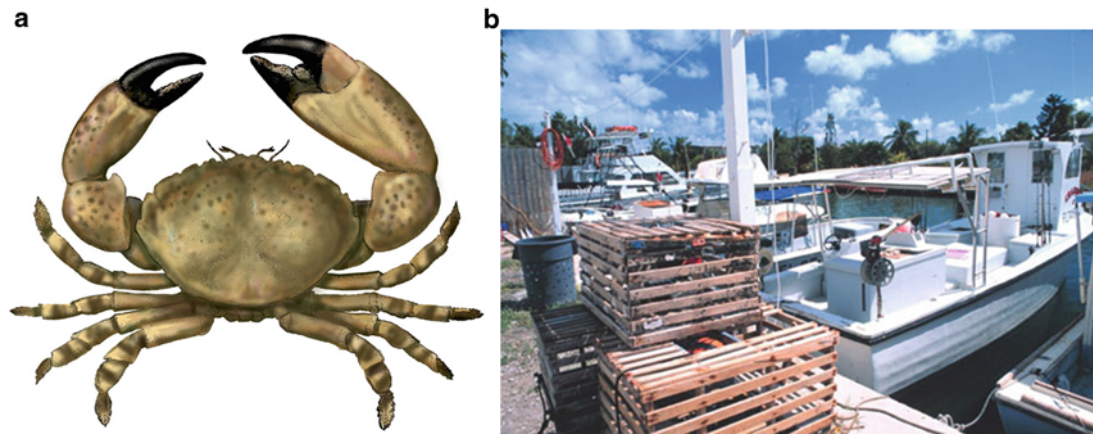


Figure 8.9. (a) Florida stone crab and (b) stone crab traps (image 8.9a and photo 8.9b by NOAA).

reefs where it can hide. Spiny lobsters can grow up to 1 m (3 ft) in body length and are of high value in the market.

In the continental United States, it is only taken commercially in South Florida, primarily in the Florida Keys. It is taken there commercially by diving or using wooden, plastic, or metal traps, and it constitutes the most valuable commercial fishery in Florida. Recreationally in the United States, it is primarily taken by diving. Spiny lobster is Florida's second most valuable recreational fishery (next to spotted sea trout), and overfishing is not occurring, according to the NOAA Fisheries Fish Watch program. The managed catch has averaged about 5.6 million pounds per year over the past decade. In Mexico, it has been maximally exploited on the Campeche Bank coral reefs and nearshore waters of Yucatán State (Diaz-de-Leon et al. 2004). In Cuba, spiny lobster is the most valuable fishery, but the majority of lobsters are taken along the southern portion of the country with only a small number/percentage being taken along the northwest coast facing the Gulf of Mexico (Claro et al. 2001). Landings in the mid-1990s were in the 21–27 million pounds range for Cuba (Baisre 2000), but most of those landings (60 %) are from the southwest shelf, and only 2–3 % are taken from the northwest (Claro et al. 2001).

8.3.2.3 Florida Stone Crab

The Florida stone crab (Figure 8.9) is one of three stone crab species within the Gulf of Mexico, but it is the only one with a targeted commercial fishery (Costello et al. 1979; Patillo et al. 1997). The Florida stone crab ranges from the Big Bend area of Florida near Apalachicola Bay and extends down the west coast around the tip of Florida and up the east coast to North Carolina (Williams and Felder 1986; Williams 1984). It also occurs in the Yucatán and Caribbean. Stone crab pots (wooden or plastic traps) are utilized off southwest Florida and in the Florida Keys for this distinctive regional fishery. Captured crabs have the large claw removed, and then they are replaced back into the environment, which makes this a uniquely sustainable fishery, since the crabs can regenerate the claw (Restrepo 1992). No overfishing is occurring in this fishery. There is a fishery management plan for stone crabs in the Gulf, but since their data are not separated by species the fishery is for “stone crabs” and not the three individual species (GMFMC 1979).

8.3.3 Echinoderms

Only three species of echinoderms are harvested commercially in the Gulf of Mexico, and all are minor shellfisheries located out of the Port of Progreso, Yucatán (Zetina et al. 2002; Mexicano-Cintora et al. 2007).

8.4 MAJOR SHELLFISH SPECIES

Since populations of key shellfish species vary naturally and greatly from year to year, it is important to understand the biology, ecology, and distribution of these species. General life cycles of each species, as well as affecting environmental parameters will be presented in this section. As the most valuable Gulf fishery, the penaeid shrimp (brown, pink, and white) will be discussed first, followed by Eastern oyster and blue crab.

8.4.1 Penaeid Shrimp

There are 20 species of shrimp in the Family Penaeidae in the Gulf of Mexico (Felder et al. 2009), but only three are of major importance as Gulf shellfisheries (brown, pink, white). These decapod (10 feet or legs) crustaceans are common to abundant in coastal estuaries and continental shelf waters of the Gulf. All three species have a similar life cycle, which includes spawning offshore with rapid development of eggs into larvae and juveniles that are carried inshore into extensive estuaries. These estuarine habitats serve as critical habitat and nursery grounds for the shrimp (Nelson et al. 1992; Patillo et al. 1997; Osborn et al. 1969). After 2–3 months of rapid growth, the shrimp approach maturity and migrate back offshore to complete their life cycle (Figure 8.10). The average life span of the three species is about 18 months, although they can live up to 3 years (Williams 1984). Regarding the shrimp fishery, these species are all considered to be an annual crop, but harvest time varies depending upon the species. The shrimp fishery is seasonal with most (about 80 %) of the catch taken between June and December each year. Historically, brown shrimp have been the largest fishery (usually over 50 %), followed by white shrimp and then pink shrimp, although white shrimp surpassed brown catches in 2005 and 2008 for the first time in 50 years (Nance 2011). The majority of shrimp by weight (about 80 %) are taken offshore and the remainder inshore (Osborn et al. 1969).

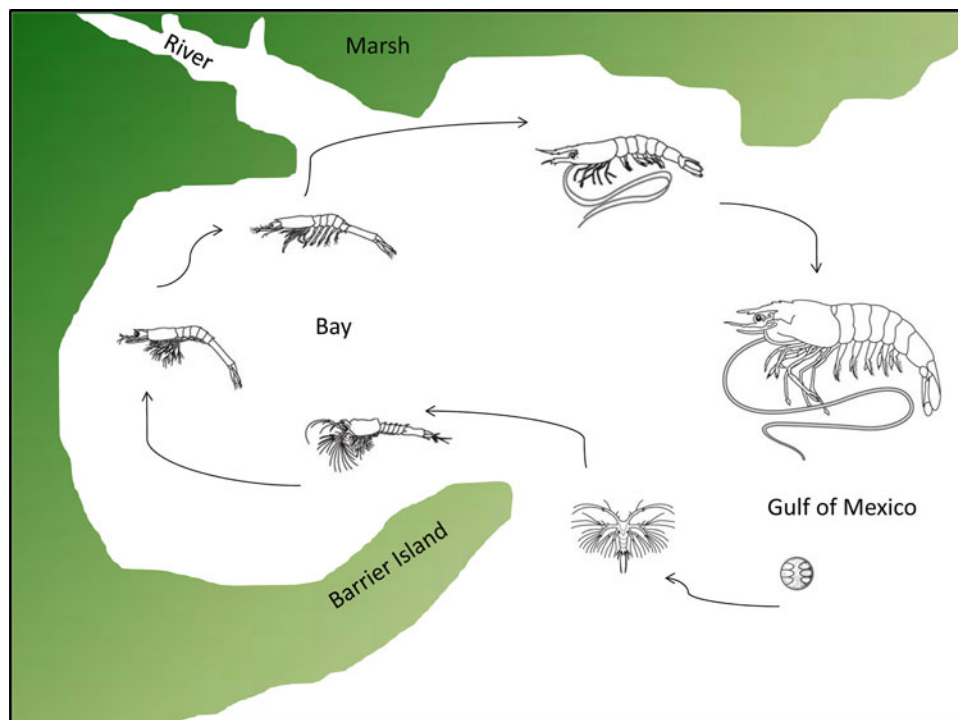


Figure 8.10. Typical life cycle of a penaeid shrimp in the Gulf of Mexico (drawing by J. W. Tunnell).

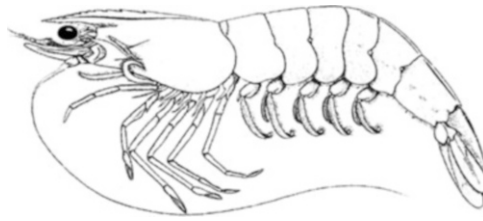


Figure 8.11. Brown shrimp (*Farfantepenaeus aztecus*) (drawing by NOAA).

8.4.1.1 Brown Shrimp

Brown shrimp (*Farfantepenaeus aztecus* Ives, 1891) (Figure 8.11) range farther north than any other U.S. penaeid shrimp, extending from Martha's Vineyard southward along the Atlantic coast around the tip of Florida, then around the Gulf to the northwestern Yucatán Peninsula (Williams 1984; Carpenter 2002). Adult brown shrimp females reach up to 236 mm (9.3 in.) in size; males reach 195 mm (7.7 in.) (Carpenter 2002) and have a brownish color. Ecologically, brown shrimp are an important food source for many species of finfish, with the type of fish varying with the size or life stage of the shrimp, and shrimp in turn feed upon a wide variety of food, depending on their life stage. Larval stages feed upon phytoplankton and zooplankton, and postlarvae feed on epiphytes, phytoplankton, and detritus. Juveniles and adults prey upon polychaetes, amphipods, and chironomid larvae, but they also feed upon algae and detritus (Cook and Lindner 1970; Patillo et al. 1997).

Habitat for brown shrimp ranges from offshore continental shelf waters for adults and eggs to shallow estuarine vegetated (preferred) and unvegetated bottoms for postlarvae and juveniles (Patillo et al. 1997). Salinity tolerance is generally wide-ranging, and optimal salinity depends on the life stage. Larvae tolerate salinities ranging between 24.1 and 36 ppt (Cook and Murphy 1966), and postlarvae have been collected in salinities from 0.1 to 69 ppt but grow best between 2 and 40 ppt. Juveniles range between 0 and 40 ppt, but they seem to prefer 10–20 ppt (Cook and Murphy 1966; Copeland and Bechtel 1974; Zimmerman et al. 1990). Adults tolerate salinities of 0.8–45 ppt, but their optimum salinity range is between 24 and 38.9 ppt (Cook and Murphy 1966). Adult brown shrimp generally spawn between depths of 46 and 91 m (151–299 ft), but they can range between 18 and 137 m (59–450 ft) (Renfro and Brusher 1982). The major spawning period is September through May, but it can occur throughout the year at depths greater than 46 m (150 ft). Brown shrimp usually spawn at night (Henley and Rauschuber 1981), and they may spawn more than once during a season (Perez-Farfante 1969). Generally, estuarine recruitment occurs when brown shrimp postlarvae move into estuaries from February to April with incoming tides and migrate into shallow and often vegetated nursery areas (Copeland and Truitt 1966; King 1971; Minello et al. 1989). In the northern Gulf, this recruitment can occur all year long (Baxter and Renfro 1966). Juveniles move out into open bays and then subadults migrate into coastal waters. Emigration to offshore spawning grounds occurs from May through August, coinciding with full moons and ebb tides (Copeland 1965).

The brown shrimp fishery (see Section 8.5 for more detail) is centered in the northwestern Gulf of Mexico, primarily off Texas and Louisiana, but there is a small fishery in the southeastern part of the Bay of Campeche (Carpenter 2002). Brown shrimp are most abundant from March to December but optimal catches are during March to September (Copeland and Bechtel 1974). Brown shrimp are caught at night when they are out and most active. They usually bury in the substrate during the day and are not caught by fishing gear (Osborn et al. 1969).

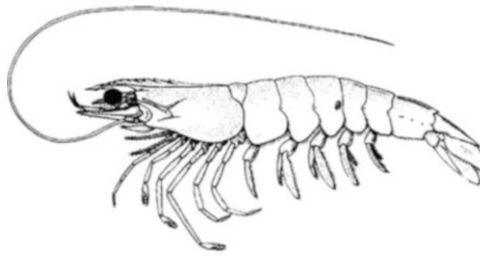


Figure 8.12. Pink shrimp (*Farfantepenaeus duorarum*) (drawing by NOAA).

8.4.1.2 Pink Shrimp

Pink shrimp (*Farfantepenaeus duorarum* Burkenroad, 1939) (Figure 8.12) range from the lower Chesapeake Bay area through the Straits of Florida and around the Gulf of Mexico to Cabo Catoche down to Isla Mujeres in the northeastern Yucatán Peninsula (Williams 1984; Carpenter 2002). The largest populations, and hence the largest catches, of pink shrimp are concentrated in two Gulf localities where the bottom is composed of calcareous muds and sands or a mixture of mud and sand (Hildebrand 1954, 1955; Springer and Bullis 1954): (1) off southwestern Florida, and (2) off the State of Campeche in the southeastern Bay of Campeche west of the Yucatán Peninsula. Adult pink shrimp females reach up to 280 mm (11 in.) in size and males reach 269 mm (10.6 in.), but are usually more in the 190 mm (7.5 in.) range, and color is quite variable from gray, blue gray, blue, or purplish in juveniles and young adults from estuaries and nearshore waters. Offshore adults from deeper waters often tend to be red, pinkish, blue gray, or nearly white (Williams 1984). Almost all are distinctly characterized by a dark spot of varying color at the juncture of the third and fourth abdominal segment. Ecologically, pink shrimp seem to prefer seagrasses in general and shoal grass (*Halodule wrightii*) in particular (Patillo et al. 1997). Large populations of juveniles appear to be important in supporting large populations of juvenile fish in these habitats. They also provide an important link in the estuarine food web by converting detritus to more available biomass for fish, birds, and other predators.

Habitat for pink shrimp eggs and planktonic larvae is pelagic, whereas postlarval and juvenile stages occur in oligohaline to euhaline estuarine waters and bays (Patillo et al. 1997). Adults occur in estuaries and nearshore waters to 64 m (210 ft), and mature pink shrimp in deep offshore waters but have highest concentrations between 9 and 44 m (30–144 ft). Largest numbers of pink shrimp are found where shallow bays and estuaries border a broad, shallow continental shelf (Perez-Farfante 1969; Costello and Allen 1970; Williams 1984), and where habitats have daily tidal flushing with marine water and large seagrass beds with high blade densities (Costello et al. 1986). Salinity requirements or preferences vary with shrimp size and geographic area (Costello and Allen 1970). Postlarval pink shrimp have been observed in salinities ranging from 12 to 43 ppt. Juveniles have been observed in waters less than 1–47 ppt, but they seem to prefer salinities greater than 20 ppt (Costello and Allen 1970; Copeland and Bechtel 1974). Adults are generally found in 25–45 ppt, although they have been found in salinities as high as 69 ppt (Patillo et al. 1997). Adult pink shrimp generally spawn in seawater depths of 4–48 m (13–158 ft) and probably deeper waters also (Perez-Farfante 1969). In the northern Gulf of Mexico, the two principal spawning grounds are the Sanibel grounds and Tortugas grounds in depths between 15 and 48 m (49–158 ft). The height of the spawning activity occurs from April through September in the Florida Bay region (Costello and Allen 1970; Williams 1984). Spawning occurs as water temperature rises, and maximum activity occurs between 27 and 30.8 °C (Rossler et al. 1969; Jones et al. 1970). Estuarine recruitment

for pink shrimp into nursery grounds occurs during the summer months, and they remain there for 2–6 months (Costello and Allen 1970; Copeland and Bechtel 1974). Late juveniles and early adults migrate into deeper offshore waters. Although emigration occurs throughout the year, the main peak in activity occurs in the fall with a secondary peak in the spring. Decreasing water temperatures trigger the pink shrimp to move into deeper offshore waters (Costello and Allen 1970; Copeland and Bechtel 1974).

The pink shrimp fishery (see Section 8.5 for more detail) occurs almost continuously around the Gulf of Mexico, but concentrations are highest in the carbonate mud and sand areas of southwest Florida (Klima et al. 1986; Hart 2008) and southeastern Bay of Campeche. Pink shrimp, like brown shrimp, burrow in during the day and come out at night, which is when trawling activity is most intense for this species.

8.4.1.3 White Shrimp

White shrimp (*Litopenaeus setiferus* Linnaeus, 1767) (Figure 8.13) range from Fire Island, New York, to Saint Lucie Inlet, Florida; near the Dry Tortugas (rarely); and then around the Gulf of Mexico from the Ochlocknee River, Florida, to Campeche, Mexico. The centers of abundance in the Gulf occur off Louisiana, Texas, and Tabasco (Williams 1984; Klima et al. 1987), but the greatest densities occur off Louisiana (Klima et al. 1982). Adult white shrimp females reach up to 257 mm (10 in.) in size and males reach 175 mm (6.9 in.) (Carpenter 2002), and they have a translucent, bluish white body color with dusky bands and patches composed of scattered black specks (Williams 1984). Ecologically, white shrimp provide an important link in estuarine food webs by converting detritus and plankton into biomass available for fishes and other predators (Patillo et al. 1997). They are preyed upon by a large number of different estuarine and coastal finfish, and their postlarvae and juveniles tolerate lower salinities than other penaeid species. White shrimp also remain in estuaries longer and grow larger than brown shrimp (Christmas and Etzold 1977). White shrimp are omnivorous at all life stages, but they tend to rely more on plant matter than animal matter (McTigue and Zimmerman 1991). Larval stages of white shrimp are planktivorous, while adults and juveniles are scavengers. Adults combine predation with detrital feeding, including a wide variety of items such as detritus, insects, annelids, gastropods, copepods, bryozoans, sponges, corals, fish, filamentous algae, and vascular plant stems and roots (Darnell 1958; Perez-Farfante 1969; Christmas and Etzold 1977).

Habitat for white shrimp ranges from nearshore neritic to estuarine, and from pelagic to demersal, depending on life stage (Patillo et al. 1997). Eggs and early planktonic larval stages are most abundant in nearshore marine waters. Postlarvae move into shallow water estuarine habitats of soft mud or clay bottoms (sometimes sand) high in organic detritus, or abundant marsh grass in oligohaline to euhaline salinities (Patillo et al. 1997; Carpenter 2002). White

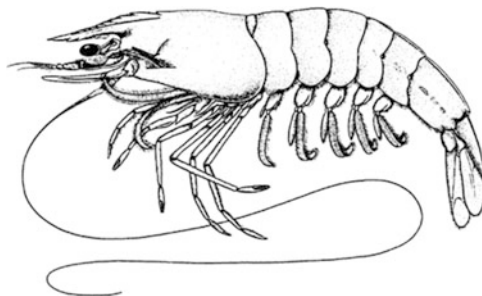


Figure 8.13. White shrimp (*Litopenaeus setiferus*) (drawing by NOAA).

shrimp are apparently more tolerant of lower salinities than brown shrimp (Gunter 1961). Postlarvae have been collected in salinities between 0.4 and 37.4 ppt, and juveniles seem to prefer salinities less than 10 ppt. Juveniles are frequently found in tidal rivers and tributaries throughout their range (Christmas and Etzold 1977). Collections of juveniles have occurred in salinities from 0.3 ppt in Florida to as high as 41.3 ppt in the Laguna Madre of Texas (Gunter 1961). Adults are generally found offshore in salinities greater than 27 ppt. Regarding depth, adults are usually found in Gulf waters less than 27 m (89 ft), and they are most abundant in waters less than 14 m (46 ft) (Perez-Farfante 1969; Renfro and Brusher 1982; Muncy 1984). Spawning takes place from spring through fall, but it peaks in summer (June–July) in offshore waters, where the eggs hatch and develop into larvae (Etzold and Christmas 1977; Klima et al. 1982). Like other penaeid shrimp, eggs are demersal and larval stages are planktonic. Postlarvae then migrate into estuarine nursery grounds through passes during May to November, with peaks in June, and a secondary one in September for the northwestern Gulf (Baxter and Renfro 1966). Juveniles migrate further up the estuary than brown or pink shrimp into less saline waters (Perez-Farfante 1969). As shrimp grow and mature, they leave the marsh habitat for open waters of the estuary and higher salinities. Emigration of juveniles and subadults from the estuaries into the open Gulf occurs in late August and September. Adults predominate in offshore, continental shelf waters during the fall and winter months and then move back nearshore in April and May (Patillo et al. 1997).

The white shrimp fishery (see Section 8.5 for more detail) is widely distributed throughout the nearshore Gulf of Mexico, but maximum catches occur along the Louisiana coast west of the Mississippi Delta (Christmas and Etzold 1977). White shrimp do not burrow into the bottom like brown and pink shrimp during the day, so the largest catches are predominantly made during daylight hours (Osborn et al. 1969). Most bays have a large bait shrimp fishery for white shrimp, and a wide variety of different kinds of nets are used for capture both commercially and recreationally (Patillo et al. 1997).

8.4.2 Eastern Oyster

The Eastern oyster (*Crassostrea virginica* Gmelin, 1791; also called American oyster) is by far the most important commercial mollusk landed in the Gulf of Mexico from Florida through Texas (Dugas et al. 1997), and it is perhaps the single most studied marine species in the entire Gulf of Mexico (see Galtsoff 1964; Berrigan et al. 1991, and VanderKooy 2012, for summaries) (Figure 8.14). Furthermore, oysters are considered to be a significantly important species in most estuaries along the Atlantic and Gulf of Mexico coasts, and self-sustaining populations

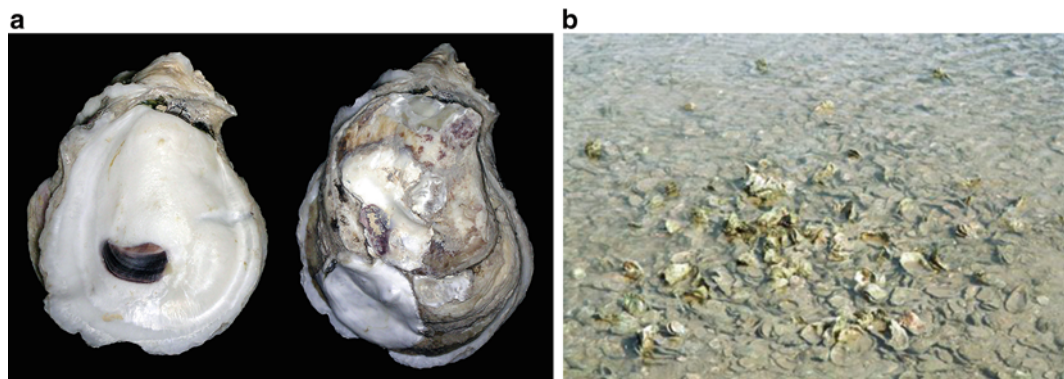


Figure 8.14. (a) Eastern oyster (*Crassostrea virginica*) and (b) an exposed intertidal oyster reef (photo 8.14a by John Wiley (used with permission of the Harte Research Institute, Texas A&M University - Corpus Christi) and 8.14b by J. W. Tunnell).

play an essential role in the ecology of these estuaries (NOAA 2007a). The Eastern oyster is easily recognized and distinguished from other species by the deep purple muscle scar, centrally located, on the interior of each valve.

Eastern oysters are bivalve mollusks in the family Ostreidae, and there are six total species found in this family within the Gulf of Mexico (Turgeon et al. 2009). The range of this species is from the Gulf of St. Lawrence in Canada through the Gulf of Mexico to the Yucatán Peninsula in Mexico (Galtsoff 1964) and perhaps further south (Carriker and Gaffney 1996). Gaffney later (2005 in NOAA 2007a) communicated that the Eastern oyster might only be confirmed genetically to the northern Yucatán Peninsula and that other distinct *Crassostrea* species may exist to the south. Although size and growth rate is highly dependent on salinity, temperature, food supply, and other environmental factors (Kennedy 1996; VanderKooy 2012), oysters generally grow rapidly during the first 6 months of life (up to 10 mm or 0.4 in. per month) and then slow down (Quast et al. 1988). Oysters may reach approximately 15 cm (5.9 in.) in 5 or 6 years (Hofstetter 1962; Berrigan et al. 1991), but a maximum size of 30 cm (11.8 in.) has been recorded in oysters living 25–30 years in Texas (Martin 1987). Harvest size (7.6–9.0 cm, 3–3.5 in.) is reached in the Gulf of Mexico within 18–24 months after setting (Hofstetter 1977; Berrigan et al. 1991). Oysters exposed to salinities that fluctuate within normal ranges (14–28 ppt; Quast et al. 1988; Shumway 1996) grow faster than those found in relatively constant salinity, but growth is stunted at 7.5 ppt and ceases below 5 ppt.

Ecologically, oysters are important in providing reef habitats that serve as areas of concentration for many other organisms (Wells 1961; Bahr and Lanier 1981), and they serve as a food source for a variety of estuarine fish and invertebrates (Burrell 1986; Eggleston 1990). Although oyster reefs have long been known as important ecological structures that participate in benthic-pelagic coupling via filtering vast quantities of water for feeding and then depositing rich organic material to the benthos, recent studies promote their importance as EFH with numerous important ecosystem services (Coen et al. 1999, 2007; Peterson et al. 2003; Grabowski and Peterson 2007). See more on this topic in Section 8.7.

Oysters are capable of surviving in a wide range of environmental conditions in coastal bays and estuaries (NOAA 2007a). However, their preferred or optimum habitat is on hard substrates in mid-salinity ranges (15–30 ppt) from intertidal to shallow subtidal. They prefer oyster shell for settlement but will settle on any available hard substrate, such as wooden pilings, concrete bulkheads, riprap shoreline, and boat hulls. In the Gulf of Mexico, depth ranges include 0.0–4.0 m (0.0–13 ft) (MacKenzie and Wakida-Kusunoki 1997; Dugas et al. 1997) and salinity optima of 10–27.5 ppt for larvae and about 5–40 ppt for adults (NOAA 2007a). Survival rate is better for adult oysters in the lower salinity range, as oyster diseases and predators are common at higher salinity. Increased water temperature reduces the ability of oysters to tolerate high salinities, while lower water temperatures allow oysters to tolerate lower salinity for longer periods (Berrigan 1988; Quast et al. 1988; Hofstetter 1990). However, prolonged exposure to freshwater during flood events, often referred to as *freshets*, can result in severe oyster mortalities (Galtsoff 1930; Hofstetter 1981; Marwitz and Bryan 1990; VanderKooy 2012). Temperature optima for oysters are 20.0–32.5 °C (68–90.5 °F) for larvae (Calabrese and Davis 1970) and 20–30 °C (68–86 °F) for adults (Stanley and Sellers 1986). Dissolved oxygen is 20–100 % saturation, but oysters can take low oxygen or no oxygen on a daily basis (NOAA 2007a; Berrigan et al. 1991). Water circulation is important for oysters for bringing in a constant food supply, but too much sedimentation is not good.

The Eastern oyster is a remarkably important and resilient organism within Gulf of Mexico estuaries. It is regarded as both a “colonizer” and an “ecosystem engineer” (NOAA 2007a). With favorable salinity and temperature regimes in the estuaries, successful reproduction and spawning of this highly fecund species provides widespread opportunity for settlement.

However, within the predominantly soft substrate estuaries of the Gulf of Mexico, available hard substrate habitat becomes the most limiting factor controlling oyster abundance (Berrigan et al. 1991). Where clean, hard substrate exists, oysters easily and abundantly colonize. As ecosystem engineers, they can even modify the physical environment and make it more suitable for their own long-term survival.

Eastern oysters are protandric, meaning that individuals first mature as males and then typically change to females later in life. Oysters may also change sex annually due to changes in environmental, nutritional, and physiological conditions. Although accurate fecundity is difficult to determine in oysters, estimates range from 2 to 115 million eggs per female, depending on size and geographic locality (Galtsoff 1964; NOAA 2007a). Initiation of spawning occurs with a combination of environmental factors including water temperature, salinity, and physiochemical interactions (Galtsoff 1964; Berrigan et al. 1991; NOAA 2007a). In Gulf waters, spawning occurs in all but the coldest months of the year. Generally, conditions for spawning include water temperature above 20 °C (68 °F) and salinity higher than 10 ppt.

Oysters develop through several free-swimming larval stages after fertilization, and then they attach to a suitable hard substrate and become sessile. The rate of development through the larval stages is variable and mainly dependent upon temperature (Shumway 1996). The process of settlement, metamorphosis (from veliger larva to spat with shell), and attachment normally occurs within 2–3 weeks of hatching, but it can be delayed for up to a month or more depending on environmental conditions (Kennedy 1996; NOAA 2007a).

Predation and disease is a significant factor to consider with oyster populations in the Gulf of Mexico. When oysters are young and their shells are thin, they are subject to predation by a variety of crabs and some fish species, particularly black drum, but as the oyster gets older it is more protected from many species. However, in more saline waters, the oyster drill (*Stramonita haemostoma*, a gastropod), the boring clionid sponge, and some boring polychaetes can inflict significant damage on oyster populations (Butler 1954; NOAA 2007a; VanderKooy 2012). Likewise, Dermo, which is a parasitic disease caused by the protozoan *Perkinsus marinus*, has caused extensive mortality to oyster populations in certain localities and in certain years (Ray 1987). It is most damaging in high salinities and high temperatures, particularly in times of drought (NOAA 2007a). Some harmful algal blooms are known to kill oysters (*Alexandrium monilatum*), yet others are known to only make them unfit for human consumption (red tide organism, *Karenia brevis*).

As filter feeders, oysters can bioaccumulate contaminants and microorganisms, including human pathogens and toxigenic microalgae, as noted above, when these organisms are present in the surrounding waters of oyster growing areas (Childress 1966; Calabrese et al. 1973; VanderKooy 2012). A number of commonly occurring bacteria, enterovirulents, parasites, and viruses can be contracted by eating raw or undercooked oysters. Since oysters are commonly consumed raw and whole, public health controls are now quite stringent to protect the consumer. Initially, the U.S. Public Health Service developed control measures through the National Shellfish Sanitation Program to reduce the risk of disease associated with the consumption of raw shellfish (oysters, clams, and mussels), and now many states also have similar programs (VanderKooy 2012).

The oyster fishery in the Gulf of Mexico (see Section 8.5 for more details on the fishery) has historically been a valuable fishery (Stanley and Sellers 1986). Although oyster production has been highly variable, Louisiana produces the most oysters in the commercial fishery and most of that is done via leases. Other Gulf states' oyster grounds are primarily public. Florida and Alabama allow tongs for harvesting oysters, while Mississippi, Louisiana, and Texas allow harvesting with dredges (NOAA 2007a).

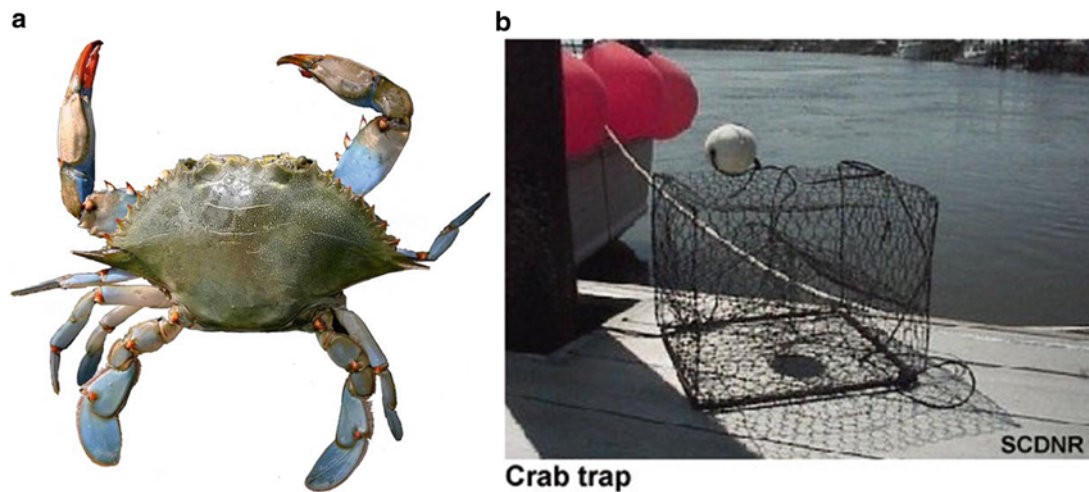


Figure 8.15. (a) Blue crab (*Callinectes sapidus*) and (b) Blue crab trap (photos by South Carolina Department of Natural Resources).

8.4.3 Blue Crab

The blue crab (*Callinectes sapidus* Rathbun, 1896) supports one of the largest commercial and recreational fisheries in the Gulf of Mexico (Figure 8.15), and it is an abundant, environmentally tolerant, estuarine-dependent organism with year-round accessibility to the fishery (Guillory et al. 2001). Since the commercial harvest of blue crabs is primarily in state, rather than federal, territorial waters, the fisheries are managed by the various state resource management agencies in cooperation with the GSMFC (Patillo et al. 1997).

Blue crabs are swimming crabs in the family Portunidae, and 29 total species in this family are found within the Gulf of Mexico (Felder et al. 2009). In addition, there are eight species within the genus *Callinectes* within the Gulf, six of which are taken as fishery species within Mexico. The range of the blue crab is from Nova Scotia, Maine, and northern Massachusetts to northern Argentina, including Bermuda and the Antilles (Williams 1984). It has also been introduced into European waters and Japan (Carpenter 2002). Maximum size of adult blue crab is reported to be 246 mm (9.7 in.) in width including spines, and average is around 150 mm (5.9 in.) (Patillo et al. 1997). Blue crab begin to reach maturity as they go over 100 mm (3.9 in.), and they are almost all mature when they reach 130 mm (5.1 in.). Estimated life span of the blue crab is 3–4 years.

Ecologically, the blue crab performs a variety of functional roles in estuaries, and it plays an important role in trophic dynamics (Patillo et al. 1997). At different stages in its life cycle, the blue crab serves as predator or prey. Numerous species of fish, mammals, and birds prey upon the blue crab (Killam et al. 1992). In turn, the blue crab is an omnivore, scavenger, detritivore, predator, and cannibal that feeds on a wide variety of plants and animals, primarily selecting whatever is most available at the time and location where it is found (Menzel and Hopkins 1956; Darnell 1959; Costlow and Sastry 1966; Laughlin 1982).

Habitat for blue crab is in coastal waters on a variety of bottom types in freshwater, estuaries, and the shallow ocean from the water's edge to usually less than 35 m (115 ft) (Williams 1984). The biology of this species is better known than any of the others within this genus. Zoea larvae are usually found in pelagic waters and megalopa larvae may be found nearshore or in higher salinity estuarine areas. Megalopae settle into seagrass or other vegetated bottoms (Killam et al. 1992). Juveniles tend to be found in greatest numbers in low to intermediate salinities, which are characteristic of upper to middle estuaries (Steele and Perry

1990). They seem to prefer seagrass habitat as a nursery area, along with salt marshes (Thomas et al. 1990; Killam et al. 1992). Both juveniles and adults tend to be demersal. Adult males spend most of their time in low salinity areas, and females move from higher to lower salinity as they approach their terminal molt in order to mate (Patillo et al. 1997).

Environmental parameters that affect the growth, survival, and distribution of blue crab vary with life stages and sex (Killam et al. 1992). As might be expected, the eggs of blue crabs are the most sensitive to changing environmental conditions such as temperature and salinity, whereas juveniles and adults have greater tolerances. Since juveniles and adults are more motile, they can also avoid or leave when conditions are not right. Juvenile and adult blue crabs have been collected at temperatures ranging between 3 and 35 °C (37–95 °F), but they stop feeding at temperatures below about 11 °C (52 °F), and they burrow in the mud at 5 °C (41 °F). Juvenile blue crabs are usually found in lower salinity waters, typically between 2 and 21 ppt. Adult males seem to prefer salinities of less than 10 ppt, and egg-bearing females (sponge) in waters usually above about 20 ppt (Patillo et al. 1997). The blue crab is very sensitive to low dissolved oxygen.

Regarding reproduction, the sexes are separate in blue crabs, fertilization is internal, and the eggs develop oviparously (Williams 1984). Mating normally occurs in the low salinity waters in the upper estuaries. Females mate while they are in the soft-shell stage in the upper estuary, but they move out to higher salinity water near the mouths or inlets of estuaries, or into the Gulf of Mexico in preparation for spawning. Spawning may occur anytime within the 2–9 months after mating, but it usually occurs in the spring by females that mated the previous fall in August to September (Williams 1984). Two spawning peaks usually occur in the northern Gulf of Mexico, one in the late spring and the other during the late summer or early fall (Stuck and Perry 1981; Patillo et al. 1997). Fecundity estimates for blue crab range from 723,500 to 2,173,300 eggs per spawning (Truitt 1939), but usually the range is between 1,750,000 and 2,000,000 (Millikin and Williams 1984). Females may spawn more than once per year.

The blue crab fishery (see Section 8.5 for more details) is found within almost all estuaries of the northern Gulf coast. Catches are highest in areas with more freshwater inflow. Hard shell crabs predominate in the catch and almost all are taken in crab pots (traps) today, although high numbers were taken in the past via trotlines and drop nets. Recreational catches are important, making up 4–20 % depending on location within the Gulf.

8.4.4 Peak Spawning, Recruitment, and Migration

Although it is difficult to give exact times for major biological activities in these three main shellfish groups of the northern Gulf of Mexico due to environmental, temporal, and geographic variation, it is instructive to see their normal and peak times of spawning, recruitment, and migration to explain or reveal the complexities of their life cycles (Table 8.4). Because of the warm temperate nature of the environment of the northern Gulf, many species reproduce almost year round, except for the coldest months, but they do have peak times when their eggs, larvae, juveniles, or adults are most abundant. This composite table is a combination of information from many sources and gives a general picture of these biological activities. Nelson et al. (1992) and Patillo et al. (1997) present detailed information and hundreds of sources in two volumes on the distribution and abundance of fishes and invertebrates in northern Gulf of Mexico estuaries, and Guillory et al. (2001) and VanderKooy (2012) analyze and present decades of blue crab and oyster data, information, and literature, respectively.

Table 8.4. Composite Display of Peak Months/Seasons of Selected Biological Activity for Shrimp (Brown, Pink, White), Eastern Oyster, and Blue Crab in the Northern Gulf of Mexico

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Shrimp												
Brown	Mainly off Texas and Louisiana											
Spawning				2nd			-----			1st		
Postlarvae to Estuary	-----											
Emigration to Gulf					-----							
Harvest Season					begins				declines through April			
White	Mainly off Louisiana west of the Mississippi Delta											
Spawning			-----				-----		-----			
Postlarvae to Estuary					1^o		-----		2^o		-----	
Emigration to Gulf							-----					
Harvest Season			adults				Young-of-year					
Pink	Mainly off Southwest Florida											
Spawning	-----			-----						-----		
Postlarvae to Estuary						-----						
Emigration to Gulf	-----			2^o			-----			1^o		
Harvest Season	-----			-----								
Blue Crab												
Spawning			-----				-----				-----	
Harvest Season	-----		-----						-----		?	
Oysters												
Spawning			-----		-----		-----		-----		-----	
Harvest Season	-----								-----			

Compiled from: Williams (1984), Gauthier and Soniat (1989), Nelson et al. (1992), Patillo et al. (1997), Guillory et al. (2001), Hart and Nance (2010), and VanderKooy (2012).

Solid line means activity occurring, bold line means peak in activity, and dashed line means probable or possible activity occurring.

8.5 SHELLFISH SPECIES STATUS AND TRENDS

Current status (in 2009) and historical trends (1960–2009) of catches of the *seafood trinity* (shrimp, oysters, and blue crabs) for the northern Gulf of Mexico are presented in this section of this chapter. Both fishery-dependent and fishery-independent data are presented and graphed. As will be noted below, annual harvests vary considerably, primarily due to annual fluctuations in environmental conditions that variously affect the eggs, larvae, and juveniles of the various species. Some fluctuations in commercial harvest are also caused by management decisions (addition of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) on shrimp trawls, limited entry programs and closures), economic conditions (fuel costs, insurance costs), loss of critical or essential habitat (seagrass beds, coastal wetlands, oyster reefs), or other environmental problems (degraded water quality, hurricanes). The latter two issues will be dealt with in the following sections after this one (Sections 8.6 and 8.7).

8.5.1 Status and Trends of Shrimp

The penaeid shrimp fishery for brown, pink, and white shrimp is the most valuable fishery in the Gulf of Mexico. These three species are all very short-lived and highly fecund, making them inherently resilient to fishing pressure (MRAG 2010). Adult brown shrimp are typically caught in less than 55 m (180 ft) and white shrimp are generally caught in less than 37 m (120 ft), and both species favor muddy or peaty bottoms, often with sand, clay, or broken shells. Primary habitat for harvesting adult pink shrimp is sand, sand-shell, or carbonate mud bottoms from the intertidal zone out to 35–65 m (115–210 ft). Catch season varies sequentially during the year: brown shrimp during May through August; white shrimp during September through November; and pink shrimp during December through April (MRAG 2010). Brown shrimp make up the majority of the Gulf catch, followed by white and then pink shrimp.

The shrimp fishery in the Gulf of Mexico has a long history, with the white shrimp fishery being the oldest, starting in the areas around New Orleans and Biloxi (Condrey and Fuller 1992). Haul seines pulled by large rowboats fitted with sails in estuaries and bays were the primary means of harvest until the trawl was introduced into the Gulf in 1917. With the use of trawls, landings continued to increase as fishermen expanded their range and depth of fishing. In the late 1940s, there was a dramatic drop in the white shrimp fishery and sudden increase in abundance and catch of the brown shrimp (Condrey and Fuller 1992). This reduction in the white shrimp fishery initiated exploration for other shrimping grounds in the Gulf and led to the discovery of other brown shrimping grounds in the western and northwestern Gulf, as well as pink shrimping grounds off southwestern Florida and southeastern Bay of Campeche (Springer 1951).

The period from 1950 to 1976 was marked by continued growth and expansion in the Gulf of Mexico shrimping fleet, as well as maximal use of U.S. Gulf shrimping grounds, and continued expansion into foreign fishing grounds in Central and South America (Condrey and Fuller 1992). An overview of the entire Gulf of Mexico shrimp fishery by Osborn et al. (1969) provided the first and only Gulf-wide maps of shrimp catch distribution (Figure 8.16). In 1976, the Magnuson-Stevens Fishery Conservation and Management Act was passed, requiring fishery management plans for all significant fisheries, and the Gulf shrimp fishery entered into a new era. This new act established regional fishery management councils and focused attention on the newly recognized EEZ off the U.S. coastline. In 1981, the GMFMC implemented the FMP for the Shrimp Fishery of the Gulf of Mexico in U.S. waters (GMFMC 1981). The Shrimp FMP for the Gulf of Mexico states its management objectives:



Figure 8.16. Historic map of all shrimp catches from the entire Gulf of Mexico (from Osborn et al. 1969).

- To optimize the yield from shrimp recruited to the fishery
- To encourage habitat protection measures to prevent undue loss of shrimp habitat
- To coordinate the development of shrimp management measures by the GMFMC with the shrimp management programs of the several states, where feasible
- To promote consistency with the Endangered Species Act and the Marine Mammal Protection Act
- To minimize the incidental capture of finfish by shrimpers, when appropriate
- To minimize conflict between shrimp and stone crab fishermen
- To minimize adverse effects of obstructions to shrimp trawling
- To provide for a statistical reporting system

The Gulf Council has been very active in the past several decades updating and amending the shrimp management plans to protect shrimp stocks from overfishing, reduce turtle drowning, reduce finfish bycatch, and protect EFH (MRAG 2010). The Gulf Shrimp FMP has been amended 14 times, and a 15th amendment is under development and consideration. To limit effort in the fishery NMFS established a moratorium on issuing more fishing permits in 2005. All federally permitted commercial vessels must be fitted with certified TEDs and BRDs (MRAG 2010).

The Galveston Laboratory of NOAA's NMFS Southeast Science Center has been a focal point for shrimp research since the late 1950s (Klima 1981, 1989). Extensive research on the biology and distribution of various shrimp species, shrimp management issues, stock assessments, and critical habitat issues has been a hallmark of this laboratory. Decades of important shrimp research are credited to the scientists of that laboratory: C. W. Caillouet, R. A. Hart, E. F. Klima, J. H. Kutkuhn, M. J. Lindner, T. J. Minello, J. M. Nance, L. P. Rozas, and R. J. Zimmerman to name a few.

Fishery-dependent data in the following sections come from the NOAA Fisheries Office of Science and Technology, Fisheries Statistics Division web site. Fishery-independent data comes from SEAMAP housed at the web site of the GSMFC. SEAMAP is a state/federal/university program for the collection, management, and dissemination of fishery-independent data (information collected without reliance on data reported by commercial or recreational fishermen) in U.S. waters of the Gulf of Mexico (Rester 2011). Annual reports, or SEAMAP Environmental and Biological Atlases, have been published annually since the data set began in 1983. A major objective of SEAMAP is to provide a large, standardized database needed by state and federal management agencies, industry, and scientists to make sound management decisions about Gulf fisheries (Rester 2011). SEAMAP data, as well as all NOAA Fisheries data are recorded in the Gulf of Mexico by shrimp statistical subareas (Nance 1992; Nance et al. 2006), which extend from the Florida Keys (subarea no. 1) to the Rio Grande in South Texas (no. 21). SEAMAP shrimp data comes from shrimp trawls collected on the continental shelves of the northern Gulf during summer and fall surveys. Inshore fisheries-independent data for shrimp within this section comes from the LDWF 16-foot trawl sampling program, which collects data year around.

Figure 8.17 shows the variable, long-term trend in total shrimp landings from fishery-dependent NOAA Fisheries data for the northern Gulf of Mexico during 1960 to 2009. The variability in the landings line reflects both annual fluctuations in fishery effort and natural population fluctuations of the three species through time governed by varying environmental conditions (Osborn et al. 1969; Condrey and Fuller 1992; MRAG 2010; Nance 2011). The gradual increase in landings and effort during the first three decades from 1960 to the late 1980s most

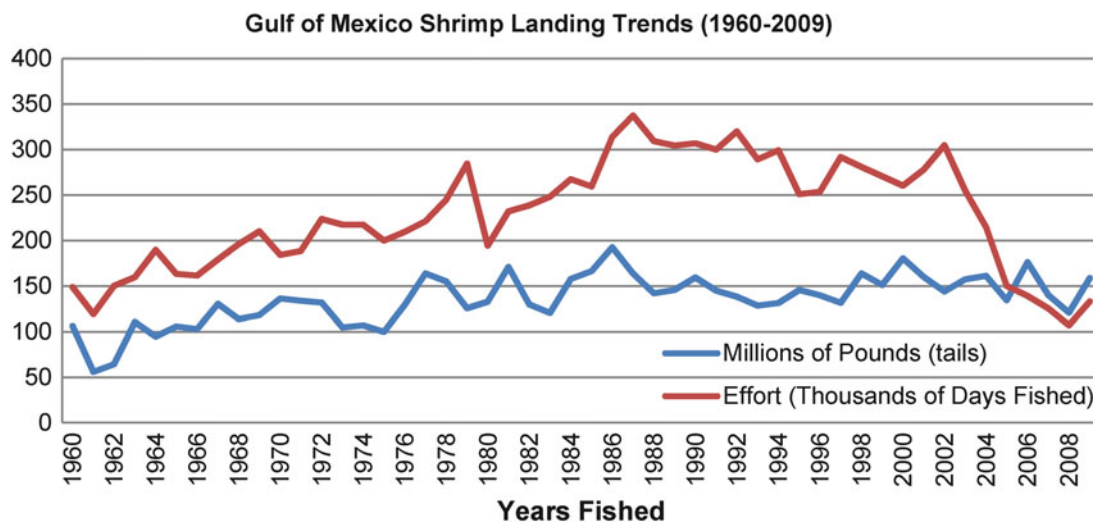


Figure 8.17. Fishery-dependent total Gulf of Mexico (United States) shrimp landing trends from 1960 to 2009 using NOAA Fisheries fishery-dependent data (from NOAA Fisheries).

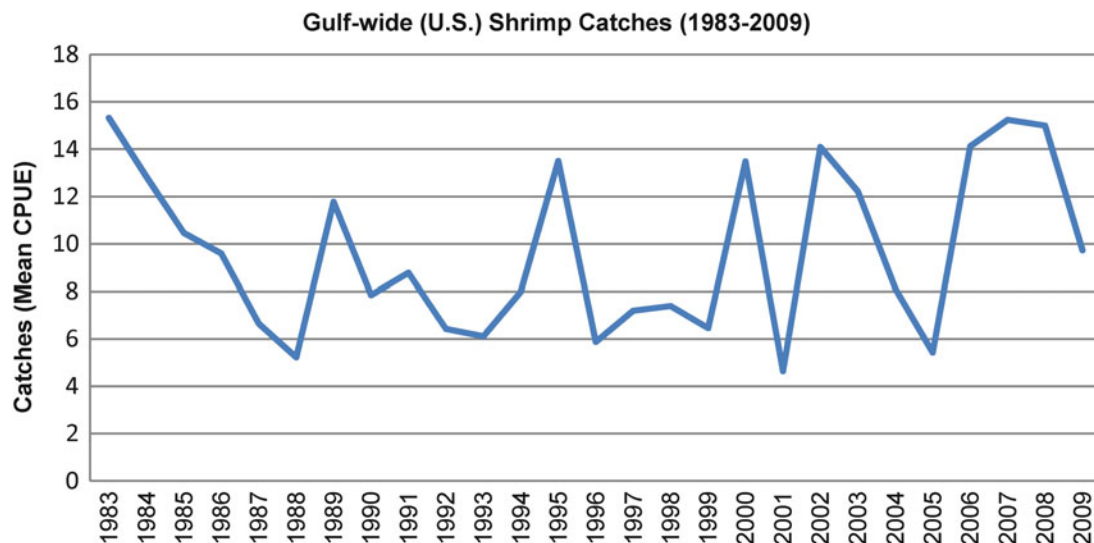


Figure 8.18. Fishery-independent mean catch per unit effort (CPUE mean count of shrimp caught per minute of fishing effort out of all sampled stations) in U.S. Gulf of Mexico shrimp trawl catches during 1983–2009 (from SEAMAP).

likely reflects the expanding shrimp fishery fleet and therefore increasing catch (Nance 2011). The precipitous drop in effort in the early 2000s primarily represents exogenous factors, such as rising fuel costs, competition from imported shrimp, damage to the fleet by recent hurricanes, and other issues (Caillouet et al. 2008; Hart 2008). Figure 8.18 shows the catch per unit effort (CPUE) of total offshore shrimp across the northern Gulf of Mexico as reported by SEAMAP using fishery-independent data, and it also clearly shows the natural fluctuations in annual populations mentioned above.

8.5.1.1 Brown Shrimp

The brown shrimp fishery is located primarily off Texas and Louisiana, but it extends from Texas to the westernmost part of Florida (shrimp statistical areas 10–21; Caillouet et al. 2008, 2011). Figures 8.19 and 8.20 reveal the trends in brown shrimp in the northern Gulf of Mexico by state and total catch from 1980 and 1983 to 2009, respectively, showing fishery-dependent and fishery-independent catches. Figure 8.19 clearly demonstrates the predominance of the catch off Texas and Louisiana.

Brown shrimp usually have the largest landings of northern Gulf shrimp (Figure 8.21). Brown shrimp reached an apex in 1990 at 103.4 million pounds (tails) followed by a low of 66.3 million pounds in 1997, a high of 96.8 million pounds in 2000, a low of 58.0 million pounds in 2005, and another high of 76.9 million pounds in 2009. The long-term average is 73.0 million pounds (Nance 2011).

Fishing effort (measured in thousands of 24-h days fished) for brown shrimp increased steadily from 1960 through 1989 but then dropped off in 1991 and remained almost level for about 7 years (Figure 8.22). Effort then fluctuated over the next several years, reaching 100 thousand days fished in 2004, which is similar to days fished in the 1970s. Effort then dropped to the upper 60 thousand days fished for 2005 to 2007 and further dropped to 61 thousand days in 2008, the lowest since the 1960s. In 2009, brown shrimp effort increased to 82 thousand days fished (Nance 2011).

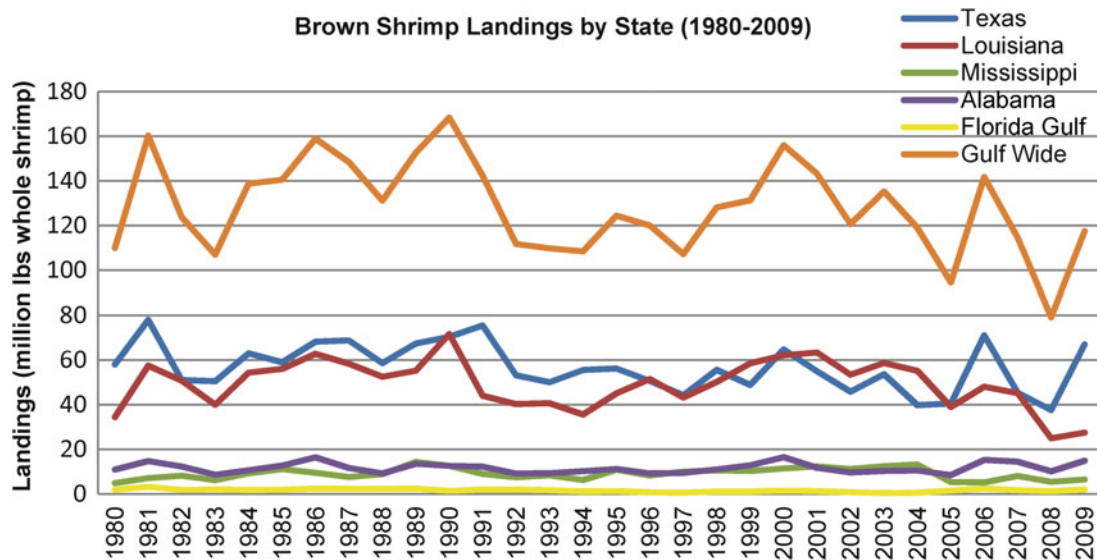


Figure 8.19. Fishery-dependent catches of brown shrimp in the northern Gulf of Mexico by state and Gulf-wide from 1980 to 2009 (from NOAA Fisheries).

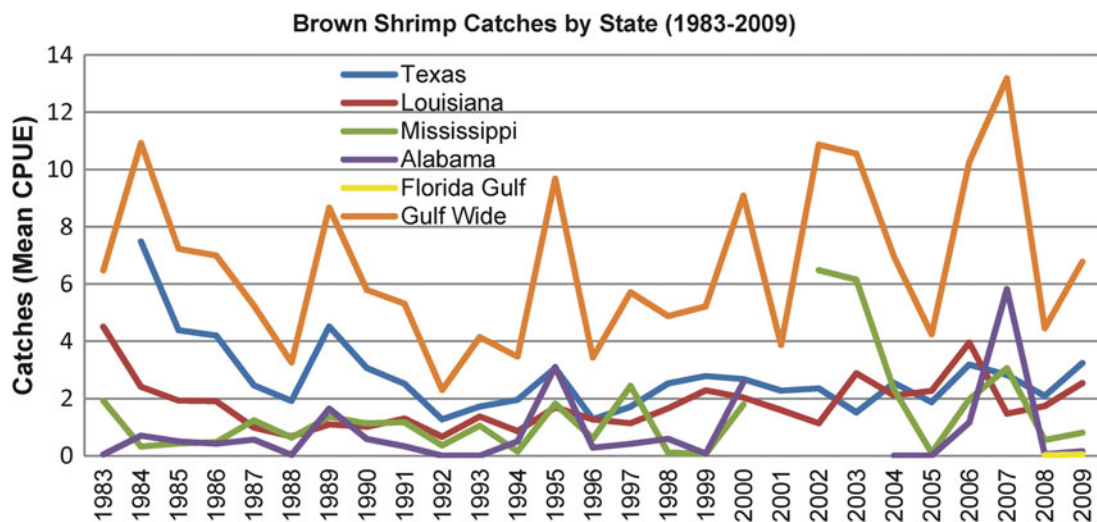


Figure 8.20. Fishery-independent mean catch per unit effort (CPUE mean count of shrimp caught per minute of fishing effort out of all sampled stations) of brown shrimp in the Northern Gulf of Mexico by state and Gulf-wide during 1983–2009 (from SEAMAP).

There are great fluctuations in CPUE fishery-dependent data, but generally there was a slow decline from 1960 to the late 1980s (Figure 8.23) (Nance 2011). Then, a general slow fluctuating increase was observed for 16–17 years. The brown shrimp CPUE value was 638 lb per day fished in 1998 and the best value since 1985. After fluctuation for several years, an upward trend in CPUE began in 2002 and reached an all-time record high value of 1,244 lb per day fished in 2006. In 2008, CPUE for brown shrimp dropped to 821 lb per day fished, but that is still above the long-term average of 643 lb per day fished. In 2009, the CPUE was 932 lb per day fished.

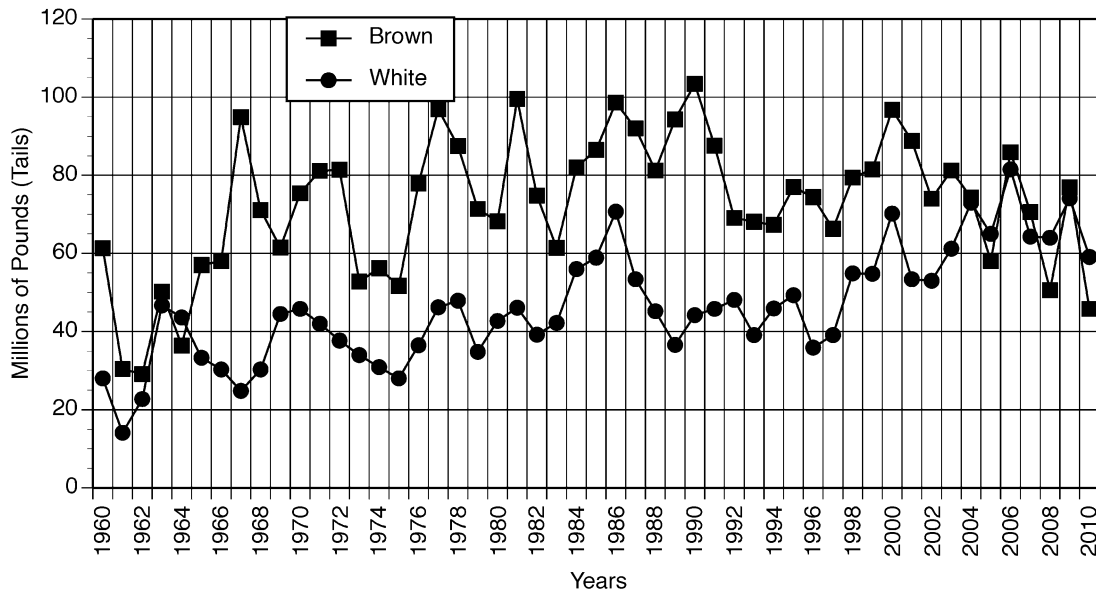


Figure 8.21. Annual catch data for northern Gulf of Mexico brown and white shrimp fisheries (from Nance 2011).

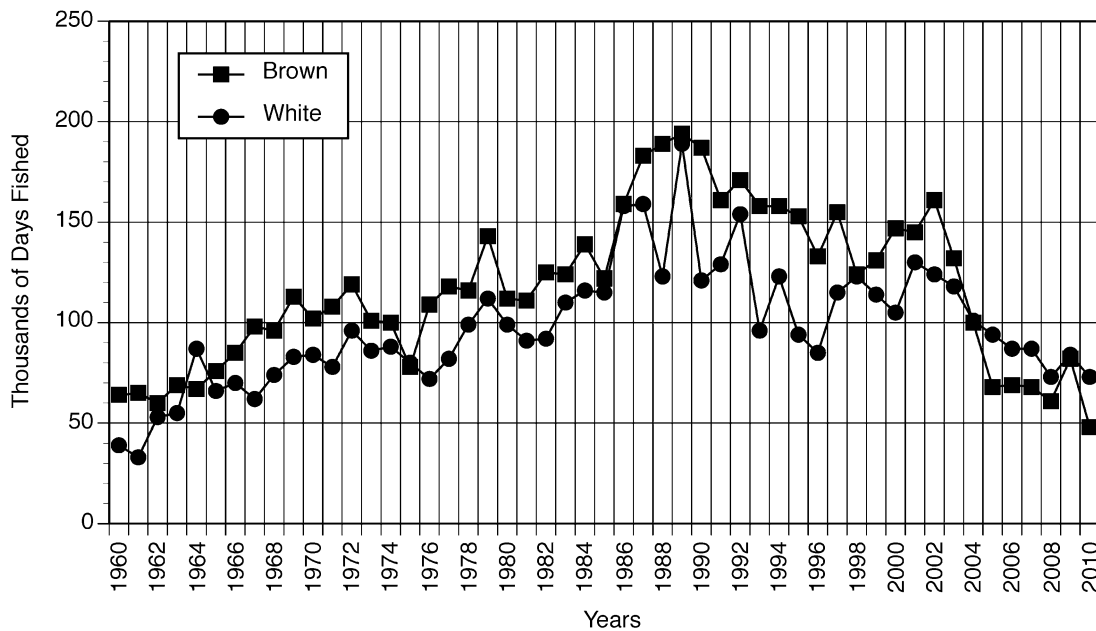


Figure 8.22. Annual effort data for northern Gulf of Mexico brown and white shrimp fisheries (from Nance 2011).

One important issue related to the brown shrimp fishery is the “Texas Closure.” This became a tool implemented in 1981 as a primary objective of the Gulf of Mexico Shrimp FMP to increase the yield of brown shrimp harvested from Texas offshore waters (Jones et al. 1982; Nance 1996). This closure of the shrimp fishery from mid-May to mid-July each year allows the smaller shrimp to grow larger, thereby increasing the size of brown shrimp and subsequently getting a higher market value (Nance 1996).

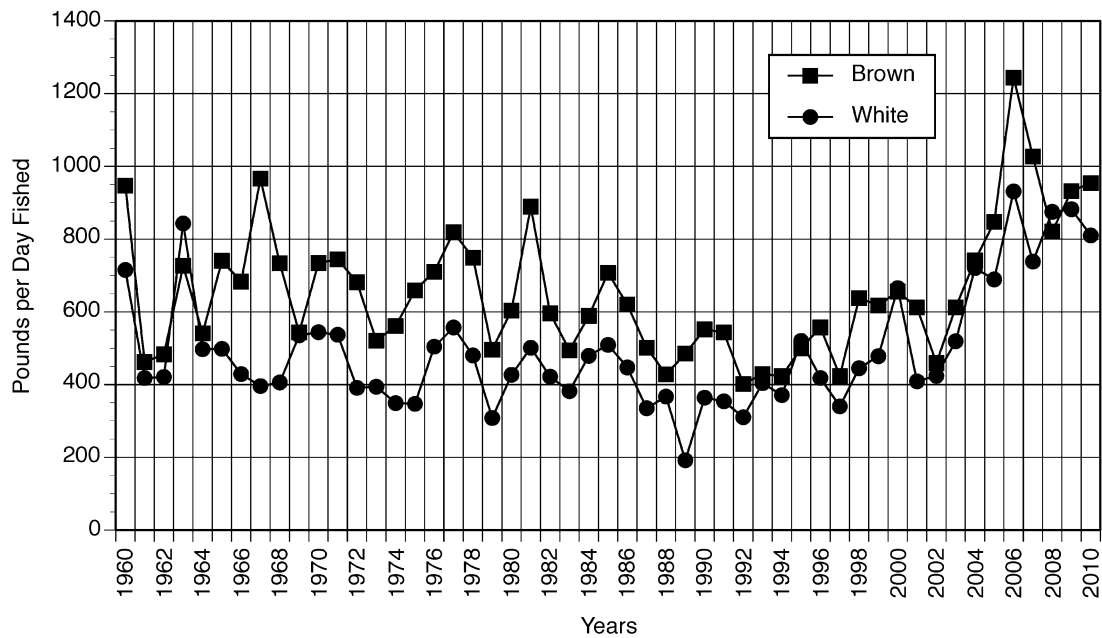


Figure 8.23. Annual CPUE data for the northern Gulf of Mexico brown and white shrimp fisheries (from Nance 2011).

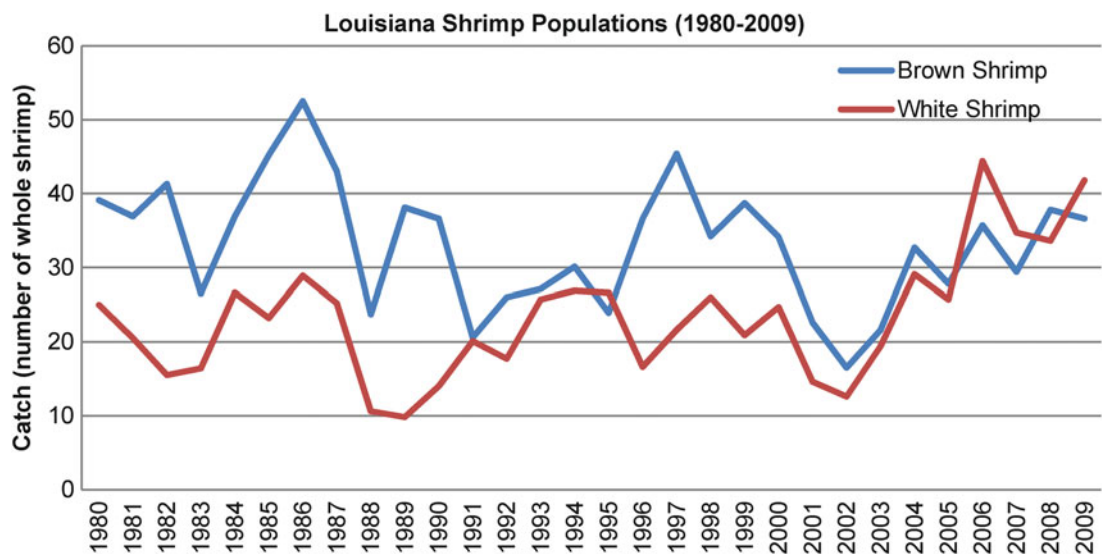


Figure 8.24. Annual fishery-independent CPUE (catch per 10-min 16-ft shrimp trawl) of brown and white shrimp caught in all Louisiana state waters during 1980–2009 (data from LDWF).

Examination of fishery-independent data gathered by Louisiana state biologists with the LDWF reveals natural population abundance variation and trends during 1980–2009 for brown and white shrimp in Louisiana state waters (Figure 8.24). Although demonstrated to fluctuate greatly over the past 30 years, these CPUE data (catch of whole shrimp per 10-min trawl) show a general upward trend in brown shrimp populations since 2002.

Historical and modern brown shrimp catch distribution is shown in Figure 8.25 (Osborn et al. 1969; NOAA 2011b).

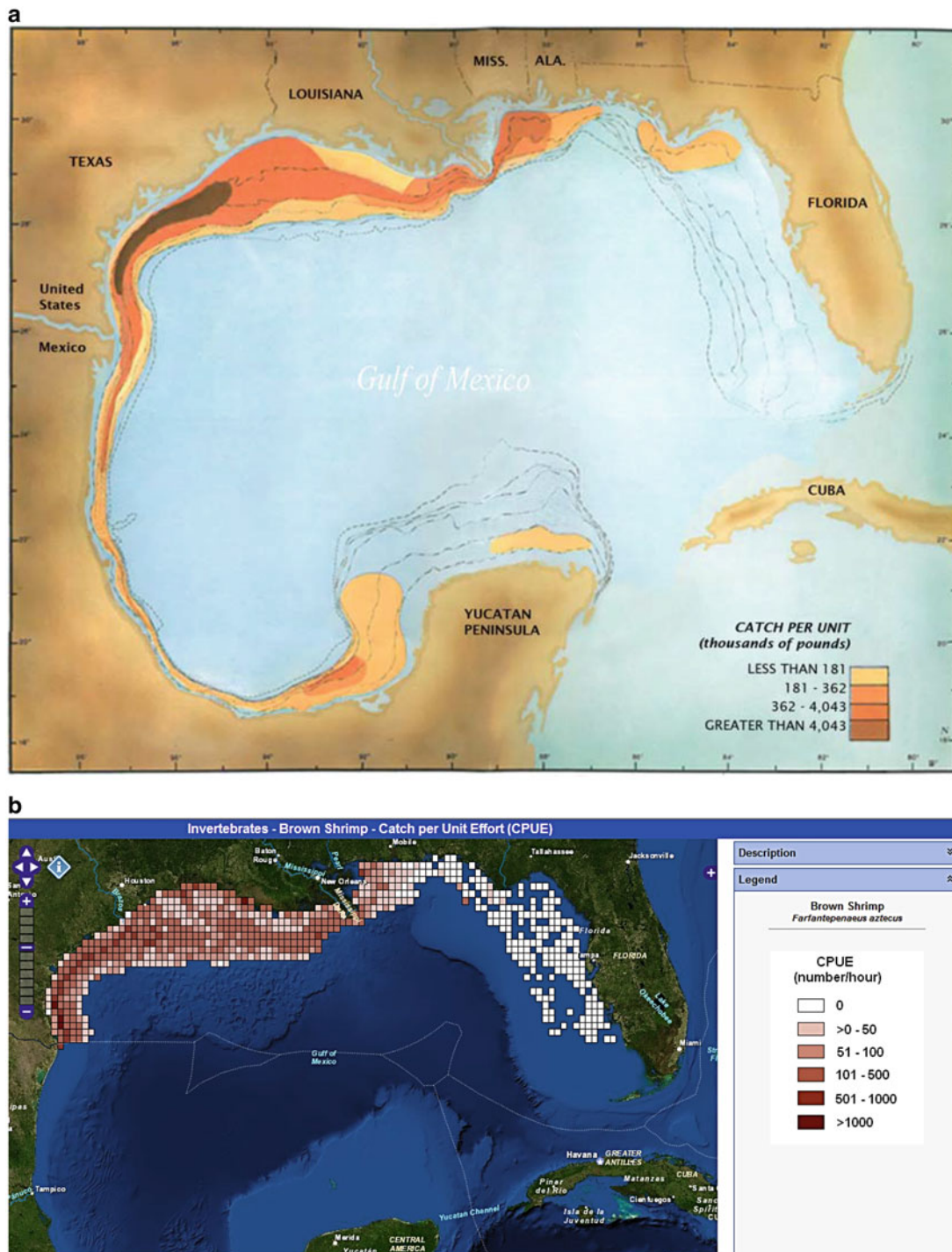


Figure 8.25. (a) Historical and (b) modern brown shrimp catch distribution in the northern Gulf of Mexico (images from (a) Osborn et al. (1969) and (b) NOAA Gulf of Mexico Data Atlas, <http://gulfatlas.noaa.gov/>).

8.5.1.2 Pink Shrimp

The pink shrimp fishery is primarily located off southwest Florida and secondarily off west Florida, but pink shrimp are also caught in all northern Gulf States (Figures 8.26 and 8.27). The main fishery encompasses statistical areas 1–9, with the Tortugas fishery in areas 1–3 and the west Florida area covering 4–9. Fishery-dependent data distinctly shows the predominance of the catch in Florida (Figure 8.26).

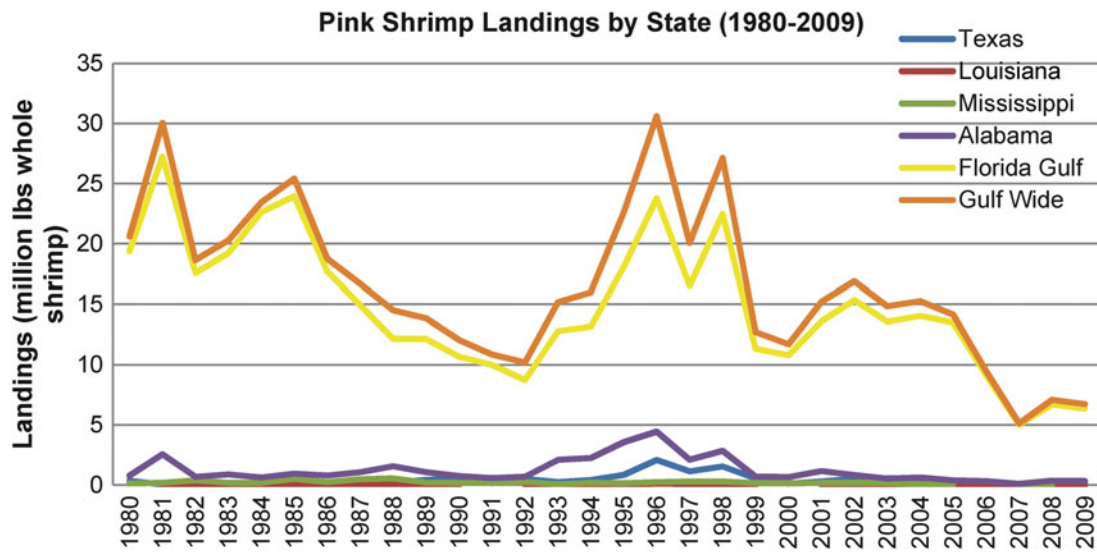


Figure 8.26. Fishery-dependent pink shrimp landings in the northern Gulf of Mexico by state and Gulf-wide during 1980–2009 (from NOAA Fisheries).

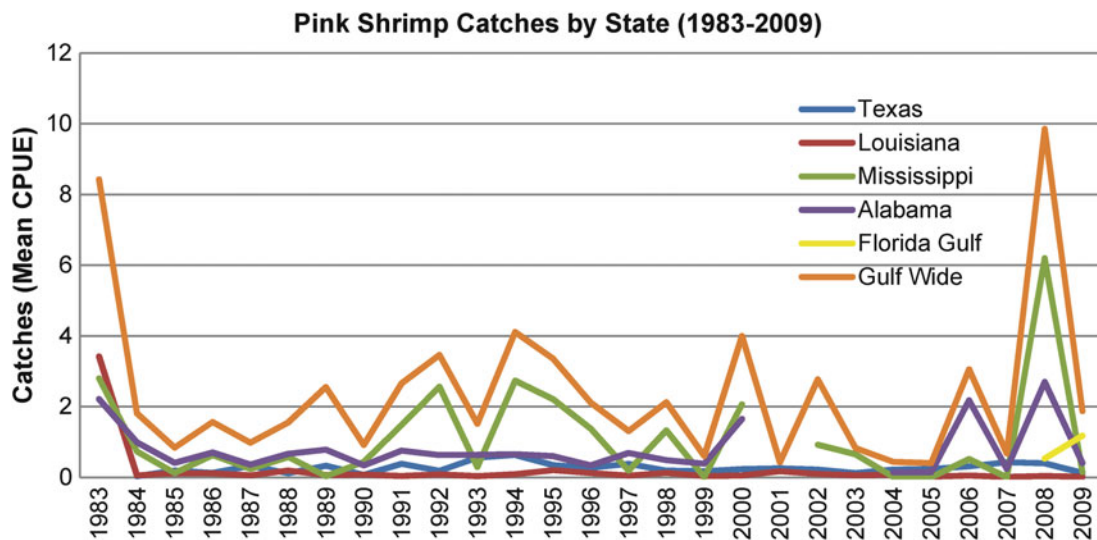


Figure 8.27. Fishery-independent mean catch per unit effort (CPUE mean count of shrimp caught per minute of fishing effort out of all sampled stations) of pink shrimp from the northern Gulf of Mexico by state and Gulf-wide during 1983–2009 (from SEAMAP).

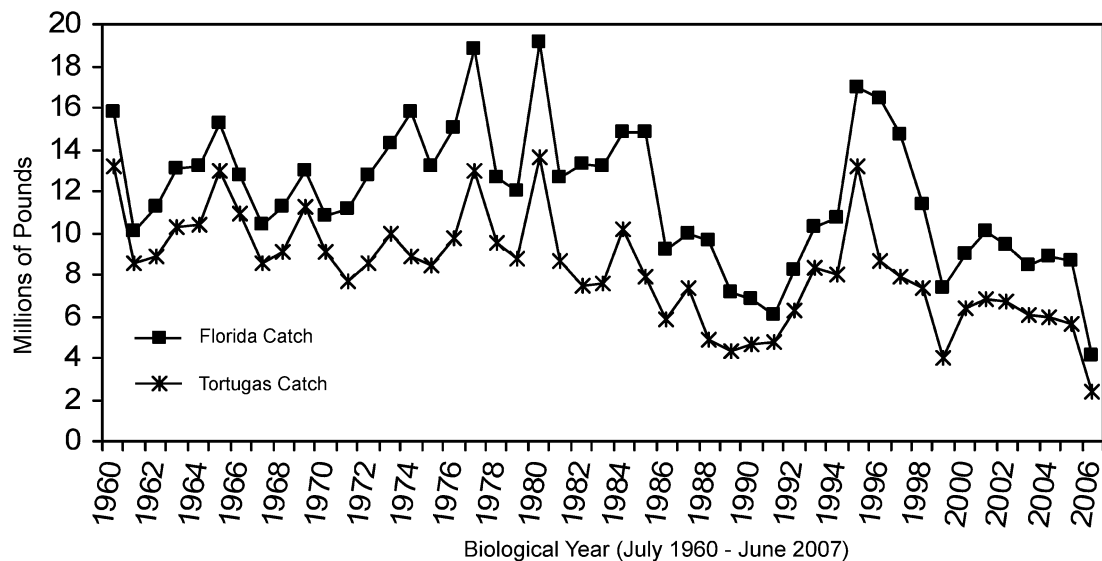


Figure 8.28. Pink shrimp catch on the Tortugas grounds (subareas 1–3) and the west coast of Florida (subareas 4–9) for biological years 1960–2006 (from Hart 2008).

Lacking an overall assessment of the entire northern Gulf pink shrimp fishery, focus herein is on the Florida pink shrimp fishery, since that is the main geographic region of the fishery and a recent overall biological review is available (Hart 2008). Annual Florida pink shrimp catch averaged 11.2 million pounds between 1960 and 2007 (Figure 8.28). Record numbers of Florida pink shrimp were landed in 1996 at 18.9 million pounds, but the catch subsequently declined and has remained near or below the long-term mean. Catches on the Tortugas grounds decreased considerably during 2005, 2006, and 2007 (Hart 2008).

Fishing effort in the Tortugas fishery was at a constant level from 1960 through the mid-1980s (average of 16.3 thousand days, Hart 2008) (Figure 8.29). Effort then dropped in the late 1980s and early 1990s but peaked in 1995 at 25 thousand days fished. Effort then fluctuated over the following years but began a continuous decline in 2002–2003 of 13 thousand days fished to 6.0 and 3.0 thousand days fished for the western coast of Florida and the Tortugas, respectively. These levels are most likely due to economic conditions in the fishery community, such as devastation caused by hurricanes Katrina and Rita in 2005, an increase in low-cost shrimp imports, and an increase in fuel prices (Haby et al. 2003).

CPUE for fishery-dependent data of Florida pink shrimp averaged 598 lb per day fished during 1960–1985 on the Tortugas grounds (Figure 8.30; Hart 2008). The CPUE was below average between 1986 and 1994 and then fluctuated a few years until 1999 when CPUE equaled 349 lb per day fished, the lowest value recorded over the entire data set on the Tortugas fishing grounds. The CPUE then began climbing to a high of 736 lb per day fished in 2005 and a drop in 2006 to 615 days, which was still one of the highest levels recorded over the past 20 years. So, as noted above, catch and effort declined, yet CPUE remained high. Thus, relative abundance of the Florida pink shrimp in the Tortugas fishery as measured by CPUE has been stable over the long-term data set for that area. This is an indication that the fishery is most likely not in decline and that the primary reason for the low harvest numbers is due to economic and not biological conditions (Hart 2008). A close examination of these latter trends and modeling efforts is provided by Hart and Nance (2010).

Historical and modern pink shrimp catch distribution is shown in Figure 8.31 (Osborn et al. 1969; NOAA 2011b).

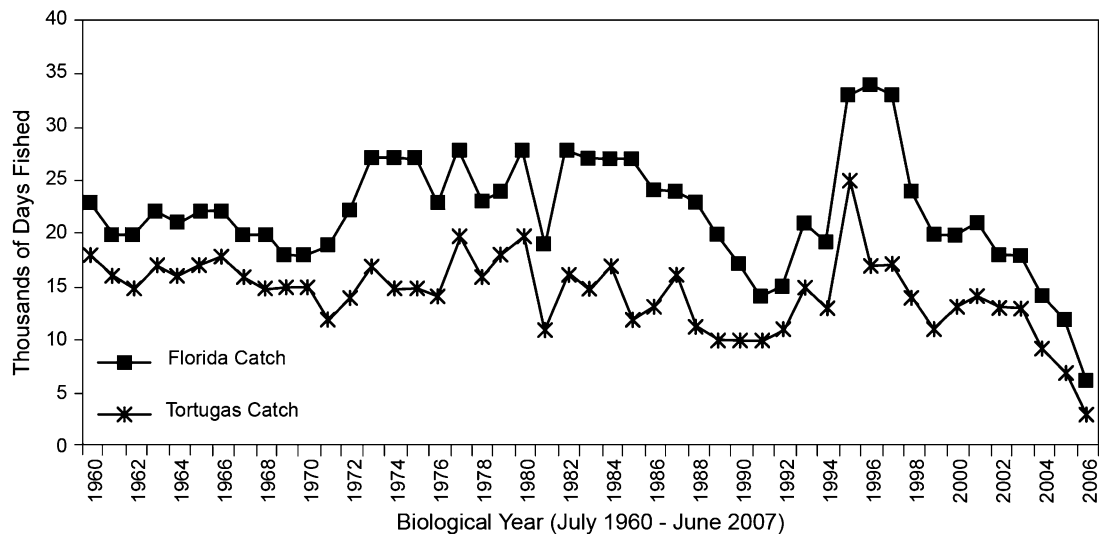


Figure 8.29. Pink shrimp fishing effort on the Tortugas grounds (subareas 1–3) and the west coast of Florida (subareas 4–9) for biological years 1960–2006 (from Hart 2008).

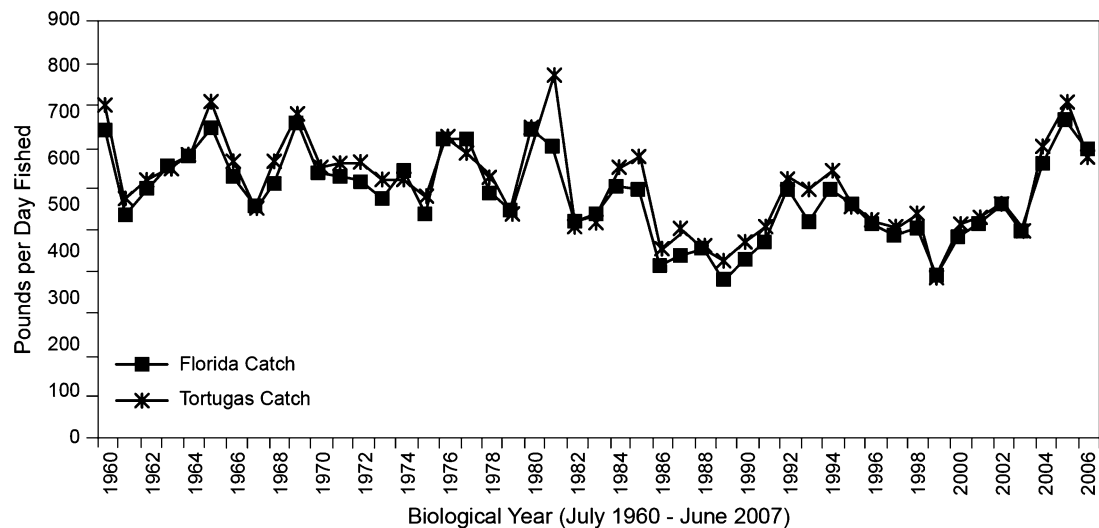


Figure 8.30. Pink shrimp catch per unit effort (CPUE) for the Tortugas grounds (subareas 1–3) and the west coast of Florida (subareas 4–9) for biological years 1960–2006 (from Hart 2008).

8.5.1.3 White Shrimp

The white shrimp fishery is located primarily off Louisiana and Texas but catches occur in all five northern Gulf States (Figures 8.32 and 8.33). Fishery-dependent data demonstrates that the catch for white shrimp is primarily off Louisiana and secondarily off Texas (Figure 8.32).

White shrimp landings in the northern Gulf of Mexico are second to brown shrimp, which is the largest catch of the three penaeid species (Nance 2011; Hart 2008) (see Figure 8.21). White shrimp reached its greatest harvest during 2006 at 81.5 million pounds (Nance 2011). Previous to that, 2004 was the highest (72.6 million pounds) followed by 1986 (70.7 million pounds). After the 1986 high catch, levels fluctuated around the long-term mean of 46.2 million pounds, but

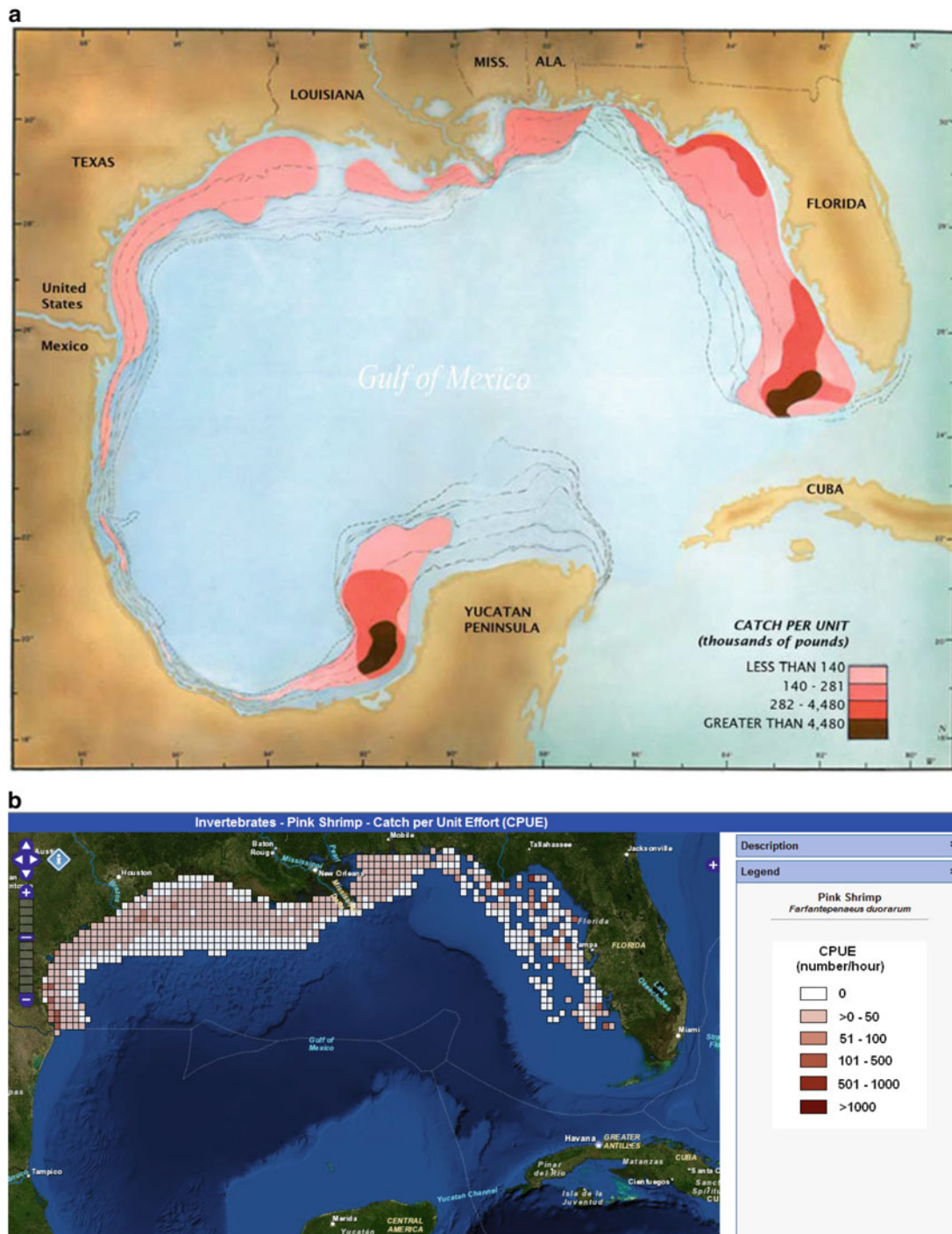


Figure 8.31. (a) Historical (image from Osborn et al. 1969) and (b) Modern pink shrimp catch distribution in the northern Gulf of Mexico (image from NOAA Gulf of Mexico Data Atlas, <http://gulfatlas.noaa.gov/>).

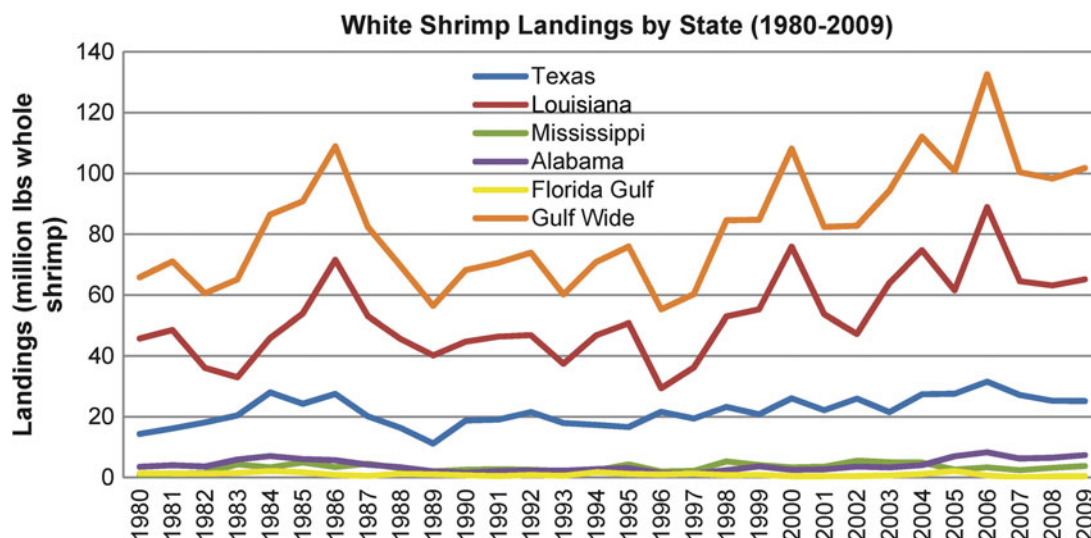


Figure 8.32. Fishery-dependent catches of white shrimp in the northern Gulf of Mexico by state and Gulf-wide from 1980 to 2009 (from NOAA Fisheries).

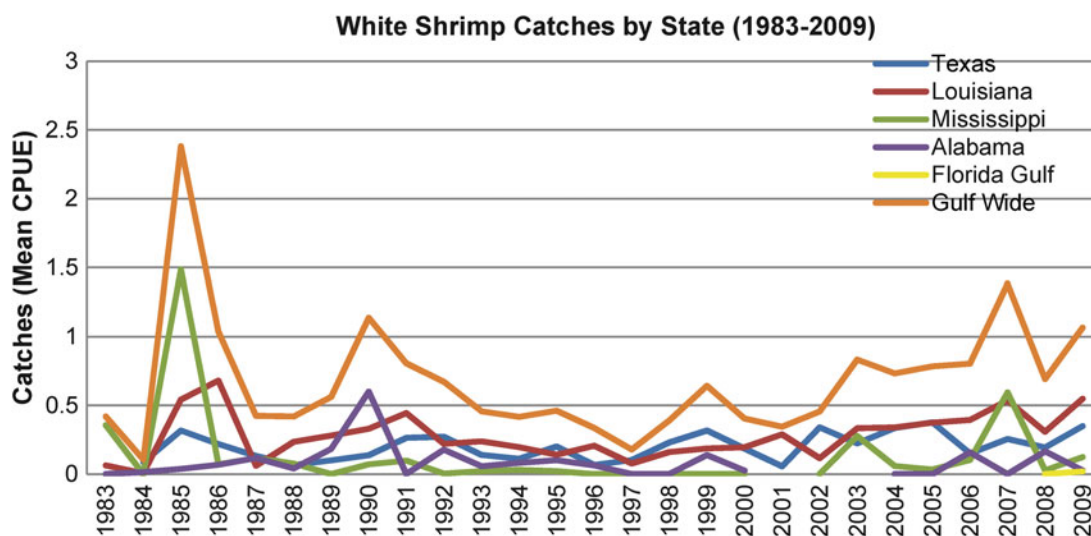


Figure 8.33. Fishery-independent mean catch per unit effort (CPUE mean count of shrimp caught per minute of fishing effort out of all sampled stations) of white shrimp in the northern Gulf of Mexico by state and Gulf-wide from 1983 to 2009 (from SEAMAP).

then in the late 1990s began increasing, but with yearly fluctuations all above the long-term mean. White shrimp landings were above brown shrimp landings for the first time in recent history (1960–2005) during 2005 and then again in 2008 (Nance 2011).

Fishing effort for white shrimp increased steadily from 1960 through 1989 (Nance 2011) (see Figure 8.22). From the 1989 high of almost 190,000 days fished, fishing effort had a fluctuating decrease to a low of 85,000 days fished in 1996, then a fluctuating increase to 130,000 days fished in 2001 when effort began declining again. Effort declined to a low of 73,000 days fished in 2008 and then had a slight increase in 2009 to 84,000 days (Nance 2011).

Catch per unit effort (CPUE; pounds per day fished) for white shrimp, as noted from fishery-dependent data, generally declined from 1960 to the late 1980s (low of 192 lb per day fished in 1989; Nance 2011) (see Figure 8.32). A slow, but fluctuating increase was then recorded to a high of 665 lb per day fished in 2000, which was the highest observed CPUE value in the previous 36 years (1964–1999). After another low in 2001 of 409 lb per day fished, CPUE increased to an all-time record high of 931 lb per day fished in 2006. White shrimp CPUE then dropped slightly in 2007 and 2008 and ended in 2009 at 882 lb per day fished. The CPUE levels since 2004 for white shrimp have increased to or above the levels of the 1960s (Nance 2011).

Like the Texas closure for increasing brown shrimp yield, pink shrimp have the Tortugas Sanctuary off south Florida, established by the Gulf of Mexico Shrimp FMP in 1981. This permanently protected sanctuary for young shrimp helps increase the yield of the Florida pink shrimp (Klima 1989).

Examination of fishery-independent data gathered by biologists with the LDWF reveals natural population abundance variation and trends during 1980–2009 for brown and white shrimp in Louisiana state waters (see Figure 8.24). Although demonstrated to fluctuate greatly over the past 30 years, these CPUE data show a general upward trend in white shrimp populations since 2002. Historical and modern white shrimp catch is shown in Figure 8.34 (Osborn et al. 1969; NOAA 2011b).

In summary, before 2009, the overall northern Gulf of Mexico shrimp stocks, as shown herein, appear to be flourishing, while the shrimp fishery appears to be in decline, primarily due to related economic and market conditions. Texas and Louisiana are the top-producing states for brown shrimp, Louisiana is the top state for white shrimp, and Florida is the top state for pink shrimp.

8.5.2 Status and Trends of Oysters

The oyster fishery in the Gulf of Mexico is the second most valuable shellfish fishery, and it has a long and diverse history. However, an evaluation of the current status and historical trends reveals a fishery in jeopardy on the U.S. east coast and beyond, according to some authors (Rothschild et al. 1994; Kirby 2004; Beck et al. 2011). Over a century of overfishing, habitat destruction, and degradation of water quality has left oyster reefs at risk globally with only 15 % remaining (Beck et al. 2011). Recognition of oyster reefs as EFH and estuarine structures with many important ecosystem services has placed significant focus on their critical role in estuaries and a need for widespread restoration (Coen et al. 1999; Peterson et al. 2003; Coen et al. 2007; Grabowski and Peterson 2007; Volety et al. 2009; Beck et al. 2011 to mention only a few). At the conclusion of their study in the mid-2000s (Beck et al. 2011), the Gulf of Mexico had some of the best remaining oyster populations in the world, and much attention began focusing on major restoration projects and programs. A more recent study analyzes changes in historic vs. present oyster habitat area (extent of coverage or distribution) and biomass (Zu Ermgassen et al. 2012). This new study suggests that biomass has declined, whereas the extent of habitat has been fairly stable in most areas.

Use of oysters as food and their shells as tools has been widely documented for prehistoric Native Americans in coastal areas of the Gulf of Mexico (Hester 1980; Ricklis 1996; Withers 2010). The first agency regulation of the oyster industry is found in the late 1800s, and many decades of oyster harvest data demonstrate the dramatic fluctuations in population levels and harvest (Berrigan et al. 1991; MacKenzie 1996; Dugas et al. 1997; NOAA 2007a).

The GSMFC published the first Regional Management Plan for the oyster fishery of the Gulf of Mexico in 1991 (Berrigan et al. 1991), and the second one was released in early 2012 (VanderKooy 2012). These comprehensive plans review all aspects of Gulf of Mexico oyster

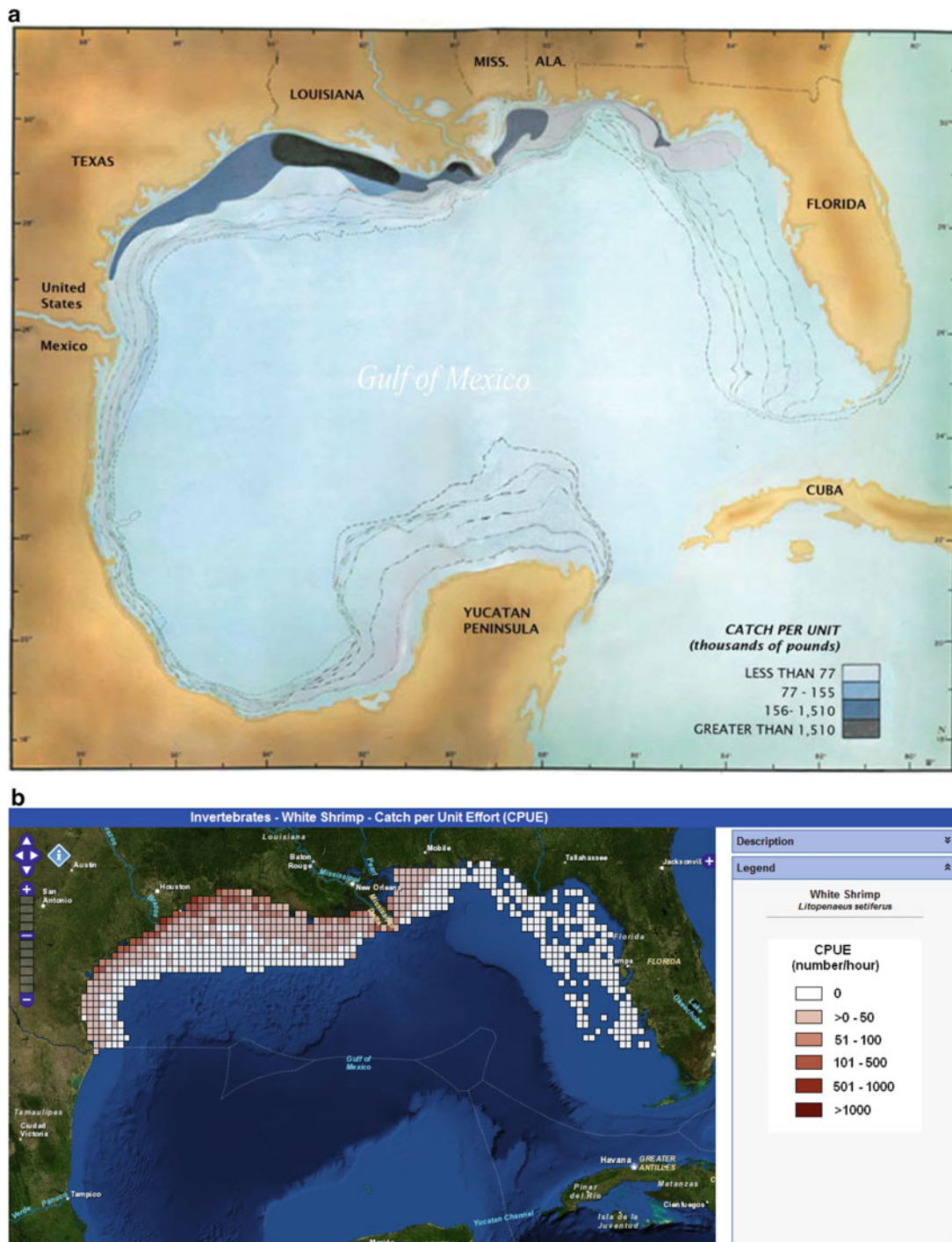


Figure 8.34. (a) Historical (image from Osborn et al. 1969) and (b) Modern white shrimp catch in the northern Gulf of Mexico (image from NOAA Gulf of Mexico Data Atlas, <http://gulfatlas.noaa.gov/>).

Table 8.5. Five-Year Average Landings (pounds of meats) of Eastern Oyster by Region 1950–2009 (from VanderKooy 2012)

Years	New England	South Atlantic	Mid Atlantic	Chesapeake	Pacific	Gulf	United States
1950–1954	2,135,820	3,751,800	16,036,900	34,500,400	19,920	12,545,120	68,989,960
1955–1959	437,400	3,030,760	6,396,360	36,639,000	12,440	13,166,120	59,682,080
1960–1964	378,478	4,063,460	1,548,720	22,983,980	9,360	20,139,800	49,123,798
1965–1969	283,628	3,139,440	1,144,700	22,610,780	13,340	20,917,340	48,109,228
1970–1974	267,280	1,766,900	2,526,980	24,943,560	8,580	17,206,040	46,719,340
1975–1979	620,220	1,940,041	2,941,240	21,152,660	2,776	18,978,066	45,635,003
1980–1984	1,245,660	2,438,736	2,228,180	17,184,700	462	23,357,919	46,455,657
1985–1989	1,162,178	1,580,296	370,520	9,030,011	32	20,294,850	32,437,887
1990–1994	5,624,089	773,492	845,210	2,356,109	2,287	15,902,540	25,503,727
1995–1999	2,465,268	507,927	825,208	1,969,435	8,408	22,760,376	28,536,622
2000–2004	433,476	588,632	832,557	1,000,412	725	25,516,329	28,372,131
2005–2009	337,167	801,178	601,069	604,004	43,020	21,017,328	23,340,168

biology, fishery, and management. All five Gulf States were represented on the Oyster Technical Task Force that developed these plans, and substantial plans and continued efforts were made to increase production yet protect the oyster populations and habitats (Arnold and Berrigan 2002; VanderKooy 2012).

Total U.S. oyster landings for the Eastern oyster have been declining steadily since the early 1950s with a peak in 1952 of 72.2 million pounds (Table 8.5) (VanderKooy 2012). Two periods had the most substantial declines: (1) New England region starting in the mid-1950s, resulting in a 32 % overall decrease, and (2) the Chesapeake Bay region, dropping first in the late 1950s and then again in the early to mid-1980s, resulting in an additional 37 % decrease in total production from the peak down to an average of 46.6 million pounds annually (Figure 8.35) (VanderKooy 2012).

In the 5-year period (2000–2004) just before the devastating hurricanes of the mid-2000s, the total U.S. landings of Eastern oyster had declined to only 28.3 million pounds, which was about a 60 % total reduction from the average harvest of the early 1950s (VanderKooy 2012). Generally, the Chesapeake Bay region was the nation's largest producer of all oyster species (four species: Eastern, Pacific, European flat, and *Olympia*) from the earliest landings records in 1880 until the mid-1970s (Figure 8.36) (VanderKooy 2012). The Gulf of Mexico generally ranked second in production, followed by the Pacific region. The remaining Eastern oyster production in other U.S. regions (South Atlantic, Mid-Atlantic, and New England) has historically represented around 10 % of the total domestic supply of oysters, with a few notable highs in the early 1950s and 1990s. However, since 2000, the combined landings for all three of these regions have totaled less than 7 % on average (VanderKooy 2012).

The Gulf of Mexico began dominating oyster production in the United States in the early 1980s when the northeastern areas began to decline. Despite the oyster reef-damaging hurricanes of 2004 and 2005, total Gulf production increased from the early 1980s to the present and has remained fairly stable (VanderKooy 2012). The Gulf of Mexico share of U.S. Eastern oyster production averaged about 40 % until 1980, but since then, it has increased from 50 % in the early 1980s to 60 % through the mid-1990s, and today represents 80–90 % of the U.S. total production (Table 8.6) (VanderKooy 2012).

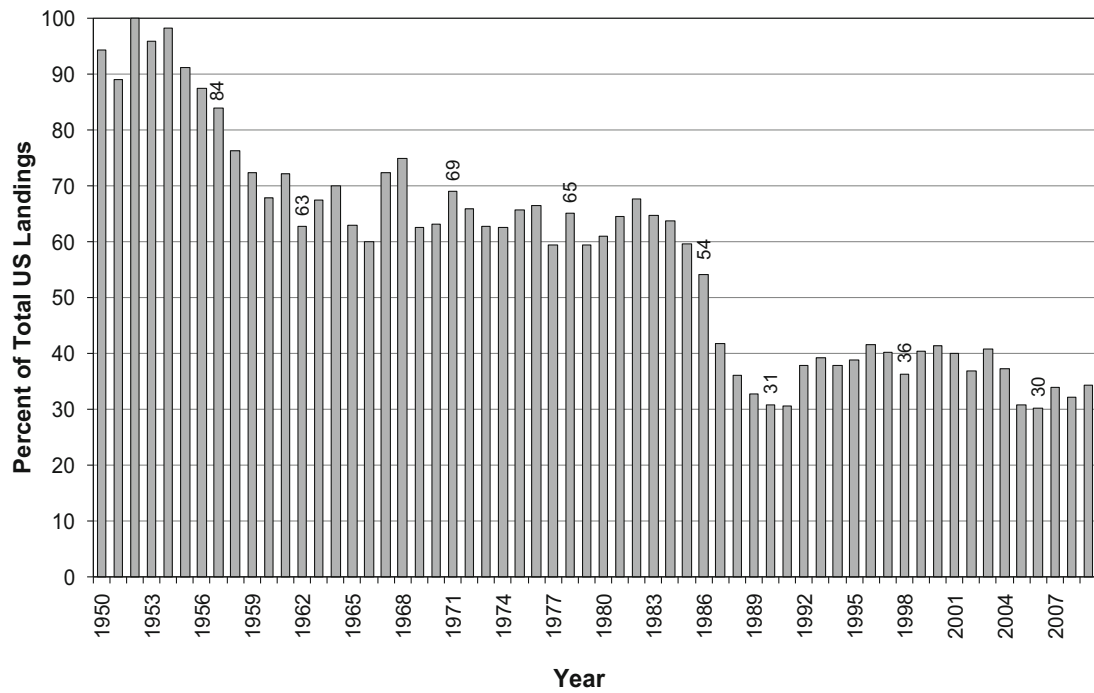


Figure 8.35. Percent decline from 1952 peak in total U.S. production of Eastern oysters from 1950 to 2009 (all regions combined). Peak production in this time period was 72.2 million pounds in 1952 (from VanderKooy 2012).

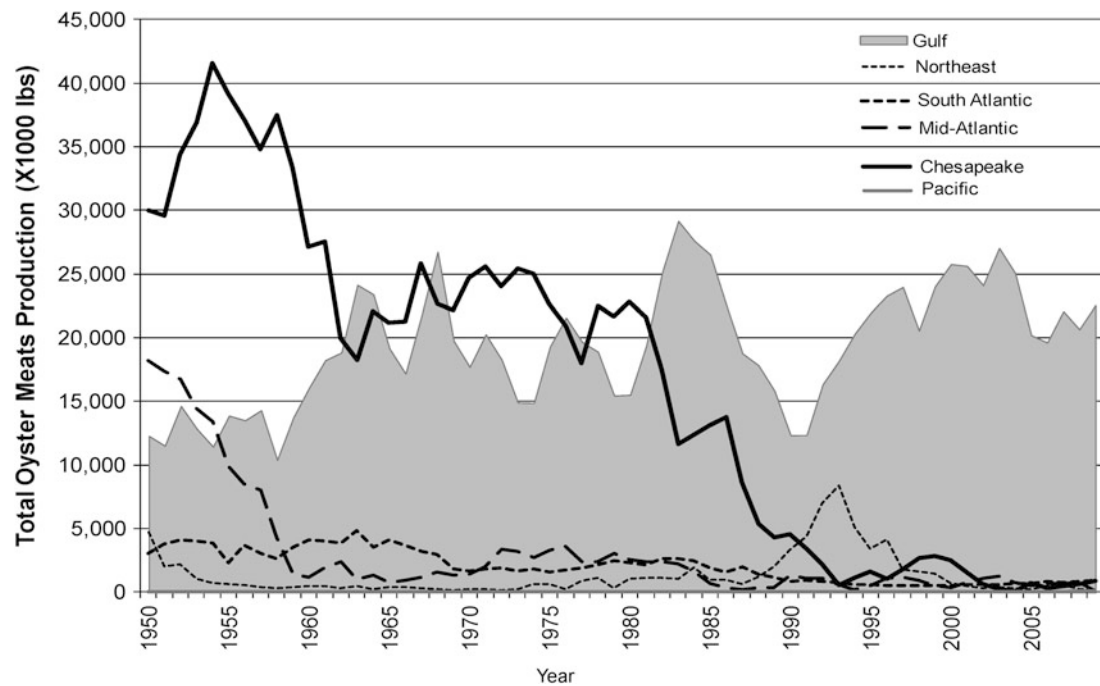


Figure 8.36. Total U.S. oyster landings for all four species (Eastern, Pacific, European flat, and Olympia) in pounds of meats by region from 1950 to 2009 (from VanderKooy 2012).

Table 8.6. Five-Year Average Percentage of Total U.S. Landings for Eastern Oyster by Region 1950–2009 (from VanderKooy 2012)

Years	New England	South Atlantic	Mid Atlantic	Chesapeake	Pacific	Gulf
1950–1954	3.1	5.4	23.2	50.0	0.0	18.2
1955–1959	0.7	5.1	10.7	61.4	0.0	22.1
1960–1964	0.8	8.3	3.2	46.8	0.0	41.0
1965–1969	0.6	6.5	2.4	47.0	0.0	43.5
1970–1974	0.6	3.8	5.4	53.4	0.0	36.8
1975–1979	1.4	4.3	6.4	46.4	0.0	41.6
1980–1984	2.7	5.2	4.8	37.0	0.0	50.3
1985–1989	3.6	4.9	1.1	27.8	0.0	62.6
1990–1994	22.1	3.0	3.3	9.2	0.0	62.4
1995–1999	8.6	1.8	2.9	6.9	0.0	79.8
2000–2004	1.5	2.1	2.9	3.5	0.0	89.9
2005–2009	1.4	3.4	2.6	2.6	0.0	90.0

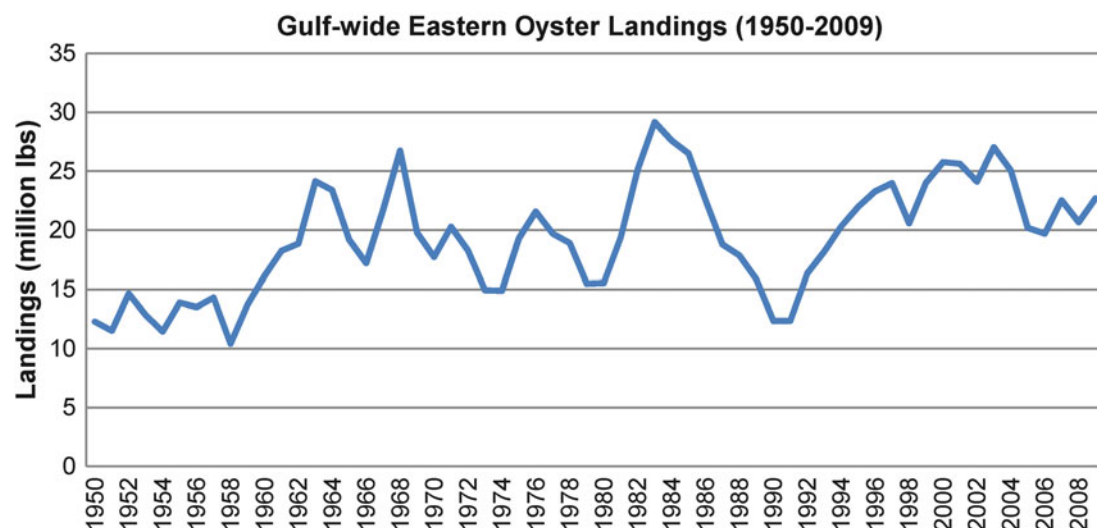


Figure 8.37. Gulf-wide Eastern oyster landings (pounds of meats) from 1950 to 2009 in the northern Gulf of Mexico (from NOAA Fisheries).

Figure 8.37 reveals the trend of oyster landings Gulf-wide from 1950 to 2009, and the fluctuating nature of catches is easily seen from this simple graph through time. Fluctuations are generally caused by changing environmental conditions (NOAA 2007a), but other species-related (diseases, parasites, harmful algal blooms) or fishery-related (market prices, fuel costs, etc.) issues can cause fluctuations also. See Sections 8.6 and 8.7 below for related environmental and habitat issues that govern oyster populations and the oyster fishery.

Louisiana is the top oyster-producing state in the northern Gulf of Mexico (Figure 8.38), as well as the entire United States, and most of its oysters are harvested from oyster leases.

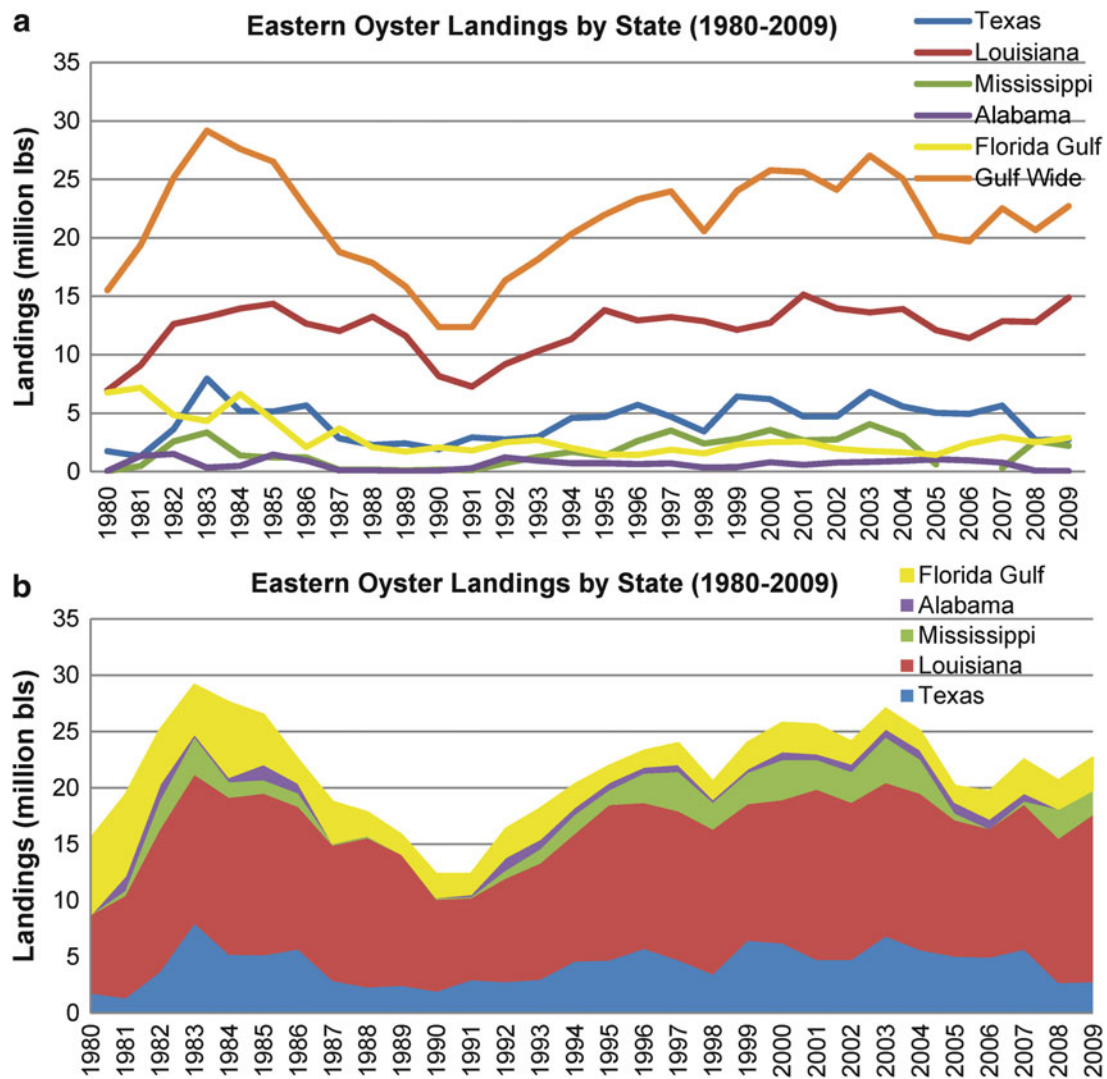


Figure 8.38. Eastern oyster landings by state in the northern Gulf of Mexico from 1980 to 2009 in two different formats: (a) line graph for ease of seeing Gulf-wide total and top-producing state Louisiana and (b) stacked graph for ease of comparing all five states together (from NOAA Fisheries).

Louisiana's average annual production of 11.9 million pounds represents nearly 60 % of the total Gulf of Mexico production during 1986–2005 (VanderKooy 2012). All other Gulf States primarily harvest oysters from public oyster grounds (NOAA 2007a). Florida and Alabama allow oysters to be harvested only with tongs on public oyster reefs. Mississippi, Louisiana, and Texas allow oysters to be harvested with dredges. Florida, Louisiana, and Texas market oysters year round, whereas Alabama and Mississippi follow seasonal harvest and marketing. Gulf of Mexico oyster reefs/resources are primarily subtidal and exhibit good sets and fast growth. In general, oyster landings increased gradually during the 1960s and 1970s then peaked in the early 1980s (NOAA 2007a). Oyster landings declined during the late 1980s due to a drought from 1986 to 1989, and a steady increase began after 1993. Confusion over the potential health risks associated with the consumption of raw oysters has eroded consumer confidence, and this may have caused an effect on oyster markets (NOAA 2007a).

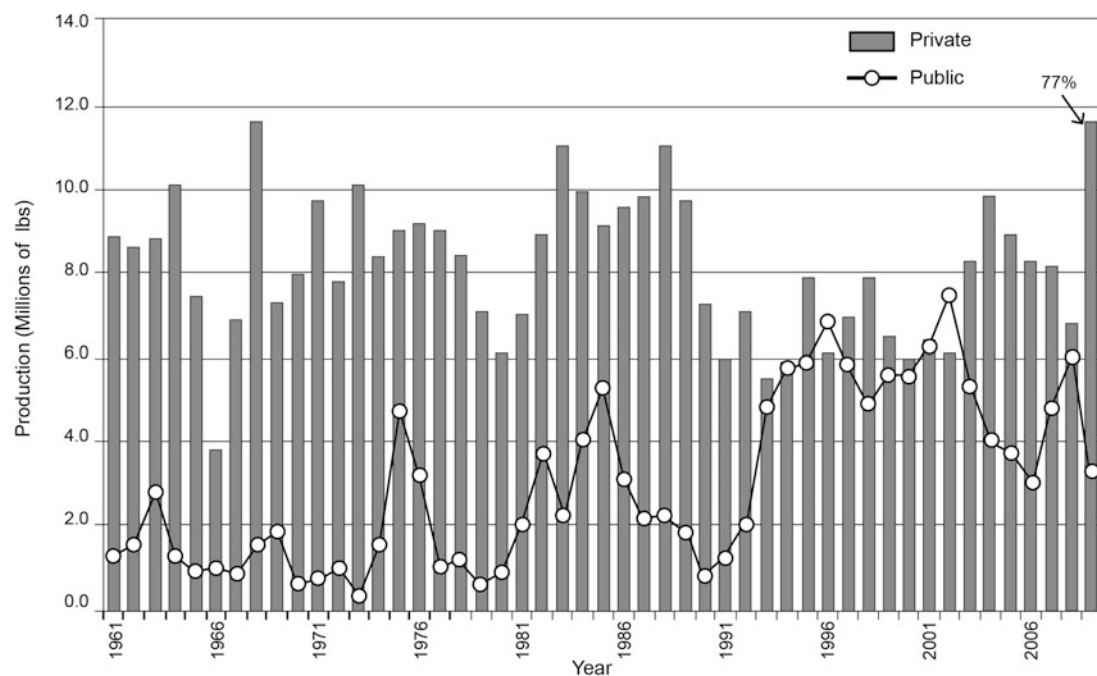


Figure 8.39. Total production of oysters from leases (private) and public grounds in Louisiana from 1961 to 2009. Long-term average for private landings is 8.007 million pounds and 3.065 million pounds for public (from VanderKooy 2012).

In Florida, oyster harvest mainly (90–95 %) comes from public oyster grounds, and the majority of that comes from Apalachicola Bay, which contains the state’s most commercially valuable oyster reefs (NOAA 2007a). Alabama and Mississippi combined produce about 12 % of the Gulf of Mexico oyster landings. Both states suffered dramatic declines in oyster production from 1987 through 1992 (Dugas et al. 1997), but Alabama returned to long-term averages and Mississippi landings increased to the highest levels in 30 years (NOAA 2007a).

Although Louisiana oyster harvests are primarily from leased bottoms (Berrigan et al. 1991), public oyster grounds increased in production during the 1990s and early 2000s (LDWF 2005). As an example of the size and growth of the fishery, lease acreage expanded from less than 50,000 acres in 1960 to 130,000 acres in the early 1970s to 230,000 acres in the early 1980s and about 394,000 acres today (VanderKooy 2012). The CPUE data do not indicate a trend in the fishery, and fishing efforts remained stable from 1961 to 1986 (Berrigan et al. 1991). Public oyster grounds in Louisiana are used as seed areas for the leased areas and for harvest of market oysters. Harvest of market oysters from these public grounds has increased since 1992, and they even exceeded lease harvest of oysters in 1996 and 2002 (Figure 8.39; LDWF 2005; LDWF 2010; VanderKooy 2012). Fishery-independent trends in long-term population abundance data from public grounds show that Louisiana oyster stock was stable at relatively low levels from 1982 to the early 1990s then increased until 2001 and declined from 2002 to 2009 (LDWF 2005, 2010; VanderKooy 2012). These meter square counts of oysters to determine stock assessment on public grounds throughout Louisiana Coastal Study Areas (CSAs) clearly reveal the cyclical trends of natural oyster populations (Figure 8.40). The Louisiana Wildlife and Fisheries Commission uses oyster stock assessment data along with the Louisiana Oyster Task Force and LDWF, Marine Fisheries Division recommendations to set oyster harvest seasons. A

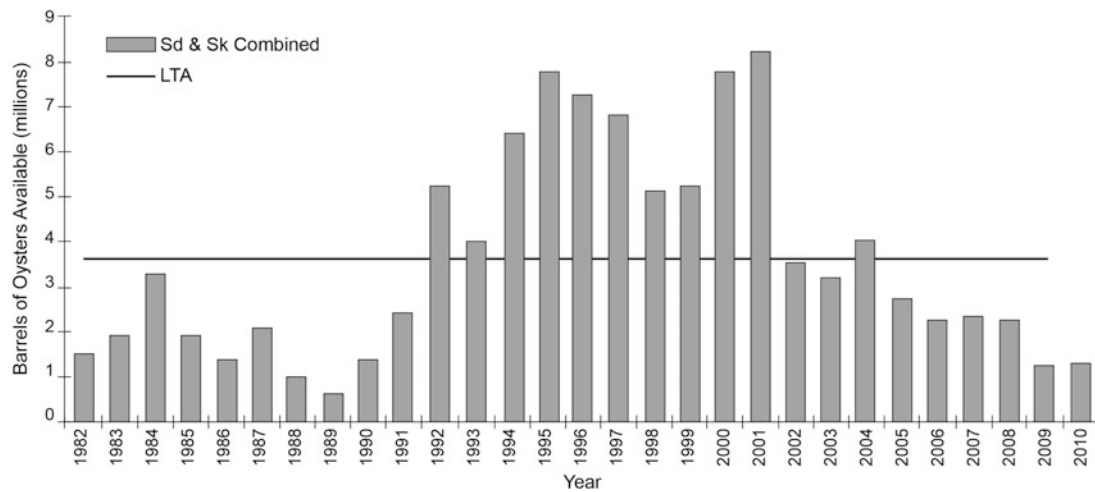


Figure 8.40. Historical estimated oyster stock size (*Sd* seed oysters; *Sk* sack or market-size oysters) on the public oyster areas of Louisiana. Meter square counts of natural populations (along with other information) are used to determine “barrels of oysters available” for the upcoming oyster season. *LTA* denotes the long-term average of 1982 to 2009 (from LDWF 2010).

lower stock availability of oysters generally results in a shorter Louisiana harvest season (NOAA 2007a).

Finally, in Texas, the Texas oyster fishery comprises two components: (1) a public reef fishery and (2) a leased bottom fishery (NOAA 2007a). Leases are only found in Galveston Bay, and they are used strictly as depuration areas for oysters transplanted from restricted waters. The lease harvest for oysters in Texas comprises between 20 and 25 % of the total commercial landings for the state. Long-term data indicate a general declining trend in oyster landings in Texas from 1956 to 1981, followed by an extremely large increase in 1982 and another decline in landings until 1987 (Quast et al. 1988). Since that time, landings have increased to more than 5.5 million pounds of meats harvested in 2004 (NOAA 2007a). More than half of Texas’s public oyster reefs are found in Galveston Bay, and those account for 80 % or more of the Texas annual commercial oyster harvest.

In summary, through 2009, the northern Gulf of Mexico oyster fishery appears to be stable, but with observed annual, multiyear, or decadal fluctuations caused primarily by variable environmental conditions, but also at times by economic/market conditions. Louisiana is the top oyster-producing state in the northern Gulf, as well as in the United States.

8.5.3 Status and Trends of Blue Crabs

The blue crab fishery is the third most valuable shellfish fishery in the northern Gulf of Mexico, and it represents one of the largest commercial and recreational fisheries in the Gulf of Mexico (Guillory et al. 2001). Blue crabs are estuarine-dependent species that are highly productive, short-lived, and fast growing. All of these unique characteristics are important when considering the fishery and its management. Hard crabs are generally harvested almost exclusively in crab traps. During the 1990s (the last full decade of analysis), annual Gulf hard shell crab commercial landings averaged 61.6 million pounds, and the contribution of Gulf landings to the total U.S. landings ranged between 21.6 and 35.4 % (Guillory et al. 2001). Average contributions for each Gulf state included the following: Louisiana, 60.9 %; Florida, 17.7 %; Texas 14.3 %; Alabama, 4.9 %; and Mississippi, 1.9 % (Adkins 1972; Perry 1975; Guillory

and Perret 1998; Hammerschmidt et al. 1998; Steele and Bert 1998). The recreational fishery equaled 4–20 % of the commercial catch in different areas of the Gulf (Guillory 1998), and there is a high-value fishery for soft-shell crabs, which averaged 188,000 lb annually during the 1990s (Perry and Malone 1985, 1989; Caffey et al. 1993; Guillory et al. 2001).

Significant changes have taken place in the Gulf of Mexico blue crab fishery since the publication of the first regional management plan (Steele and Perry 1990) and earlier descriptions of the fishery (Moss 1982; Perry et al. 1984; Perry and McIlwain 1986). Fishing effort has increased significantly, while harvests of blue crabs have stabilized or declined, and new management regulations have been implemented. The problems identified in the fishery by the first regional management plan (Steele and Perry 1990), including economic overcapitalization, habitat loss and/or degradation, as well as competition from imported crab products still persist in the fishery. The increase in count of number of crab fishermen and number of crab traps (Guillory et al. 1998, 2001) has also led to a decline in catch per fisherman, and a general overall increase in the number of traps in most Gulf states.

Although not much is known about the early history of the commercial blue crab fishery in the Gulf of Mexico, it is known that commercial landing statistics were first collected in the 1880s (Steele and Perry 1990). Long-handled dip nets were first used, and then drop nets and trotlines were employed. The first commercial fishery for blue crabs in the Gulf developed near New Orleans to supply the French Market and local restaurants (Perry et al. 1984). The first crab processing plant for Louisiana crabmeat was built at Morgan City in 1924, and others followed in Louisiana and other Gulf states. Hard crab fishing to be used for commercial processing did not become significant until World War II, and landings then increased gradually but erratically through the 1950s, 1960s, and 1970s, followed by a dramatic increase in the 1980s (Guillory et al. 2001). Although a very wide variety of fishing gears have been used to harvest blue crabs, today they are harvested almost exclusively with wire traps.

Figure 8.41 presents fishery-dependent blue crab catch Gulf-wide between 1950 and 2009, and Figure 8.42 presents fishery-dependent blue crab data for all five Gulf states from 1980 to 2009. Gulf-wide there is a fluctuating but continual increase in landings from 1950 until the late 1980s, followed by fluctuating but stable, or slightly declining, catches to 2009. Total reported

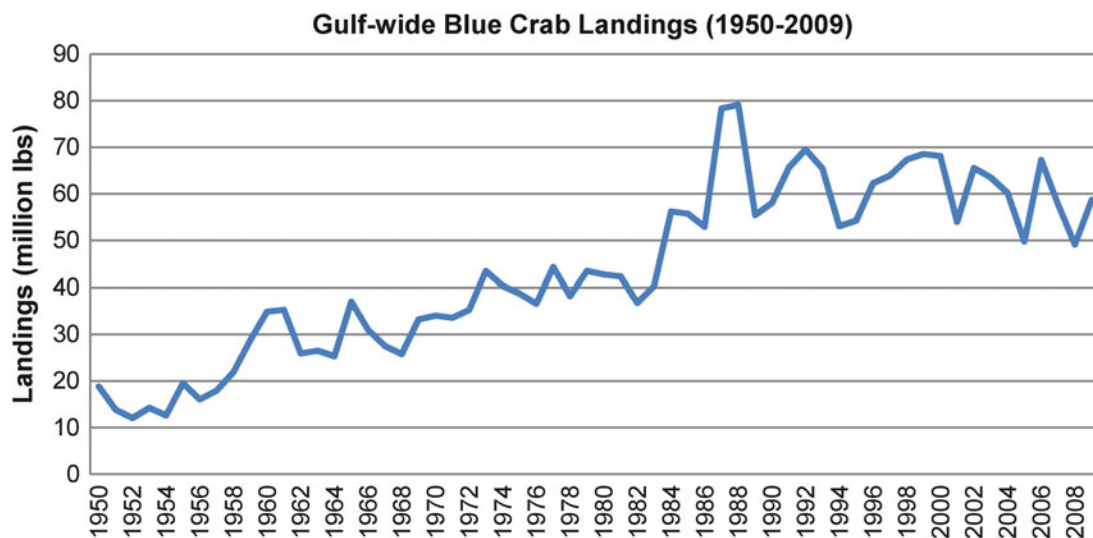


Figure 8.41. Fishery-dependent Gulf-wide blue crab landings in the northern Gulf of Mexico between 1950 and 2009 (from NOAA Fisheries).

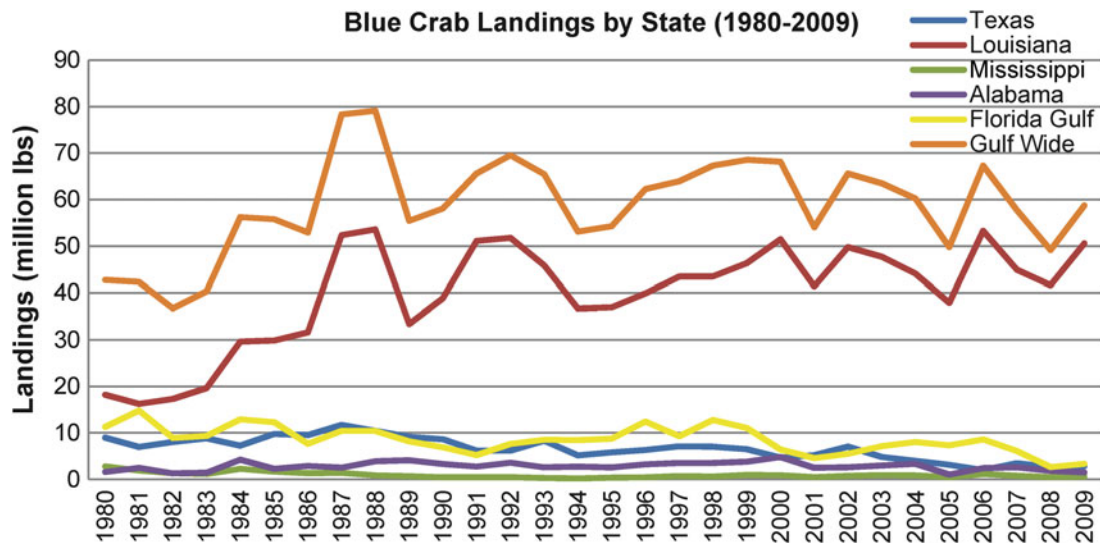


Figure 8.42. Fishery-dependent blue crab landings in the northern Gulf of Mexico by state between 1980 and 2009 (from NOAA Fisheries).

landings for blue crabs in the Gulf of Mexico increased from less than one million pounds in the late 1880s to approximately 18 million pounds before World War II. Landings then increased markedly in the late 1950s with the introduction of wire traps followed by increased processing capacity and market development (Guillory et al. 2001). Landings continued to rise in the 1980s with record landings of 78 and 79 million pounds occurring in 1987 and 1988, respectively. Landings of blue crab declined slightly after 1988 and then continued to fluctuate within the 50–70 million pound range. On the state graph (Figure 8.42), Louisiana clearly has the highest catch with a fluctuating but increasing trend since the mid-1980s. Florida and Texas both have a fluctuating but decreasing trend over the past three decades.

Stock assessment of Gulf of Mexico blue crab is limited by an absence of reliable fishery-dependent data (Guillory et al. 2001), and since there are no credible CPUE data available and no information on population age structure, many assumptions have to be made in modeling stock size. Fishery-independent data, however, gathered by the five Gulf States, does allow a better picture of blue crab status and trends.

Examination of Louisiana fishery-independent data gathered by biologists with the LDWF reveals natural population abundance variation and trends during 1980–2009 for blue crab in Louisiana state waters (Figure 8.43). Although demonstrated to fluctuate greatly over the past 30 years, these CPUE data show a general decline in crab populations with the trawl gear since the early 1990s extending to the present. Blue crab seine data (1986–2009) shows similar fluctuations over the past 25 years, and indicates a lower population level since the late 1990s.

In Texas, the blue crab fishery is shown to have matured as a fishery in the 1980s and moved into a senescent phase in the 1990s and 2000s (Sutton and Wagner 2007). Fishery-independent data show distinctive decreasing trends over the past three decades for bay bag seine, bay trawls, bay gill nets, and offshore trawls, and CPUE of Texas crab fishermen peaked in the mid-1980s with a continuing, but fluctuating, decrease since then (Sutton and Wagner 2007).

The blue crab fishery is characterized by seasonal, annual, and geographic fluctuations in landings (Guillory et al. 2001). Fluctuations have become more pronounced in recent years and

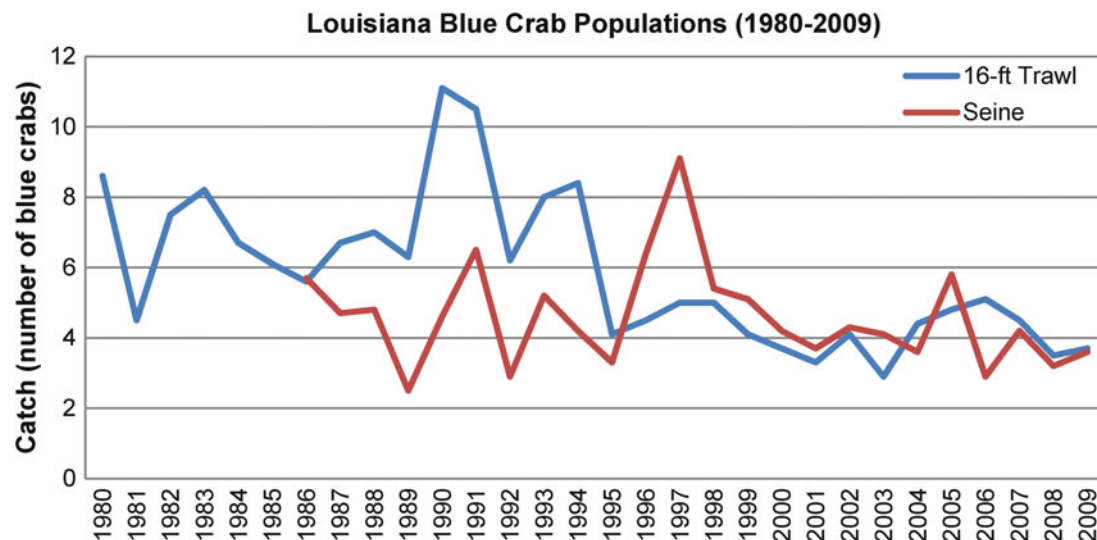


Figure 8.43. Fishery-independent annual CPUE (number of blue crabs per 10-min 16-ft trawl; average number of blue crabs per seine haul) in all Louisiana State waters during 1980/1986–2009 (data from LDWF).

include the following suggested causes: economic factors related to market demand and processing capacity (Moss 1982); economic interdependency with other kinds of fisheries (Steele and Perry 1990); changes in blue crab fishing effort (Guillory et al. 1996); and variability in year-class strength of blue crabs (Steele and Perry 1990).

In summary, through 2009, in the northern Gulf of Mexico, the blue crab fishery appears stable but is characterized by seasonal, annual, and geographic fluctuations in landings, which have become more pronounced in recent years due to various economic and other conditions. Louisiana is the top blue crab-producing state in the northern Gulf, whereas both fishery-dependent and fishery-independent data in Texas show long-term declines for blue crabs.

8.6 INFLUENCES ON SHELLFISH POPULATIONS AND THE FISHERY

Numerous factors are reported in the literature that influence or control natural populations of shellfish and their commercial landings. Environmental factors include natural variations in environmental parameters (salinity and temperature primarily), droughts, floods, hurricanes, anthropogenic impacts (e.g., degradation of water quality, habitat degradation, and loss) and outbreaks of diseases and parasites. Economic or market conditions include increased fuel costs, competition from imported shrimp causing reduced market prices for domestic shrimp, fishery overcapitalization, rising insurance costs, and loss of coastal habitat due to coastal development. After fishery management plans are developed for each fishery species, continued monitoring of the species and fishery, as well as periodic stock assessments, allow fishery managers to make management decisions about catch size, catch quota, or catch season, or in some cases, amend the fishery management plan. Important habitat issues are covered separately in Section 8.7 below.

8.6.1 Environmental Conditions

Natural fluctuations in environmental parameters, such as salinity and temperature, are known widely to cause fluctuations in animal populations and fisheries from year to year (Hofmann and Powell 1998). Many of the annual fluctuations seen on the graphs in Section 8.5 of this chapter are due to the annual variability in environmental conditions. Recent studies, however, have shown alarming negative changes and downward trends in marine species and habitats, especially in the coastal zone (Lotze et al. 2006; Halpern et al. 2008; Jackson 2008). Synergistic effects of habitat loss and destruction, overfishing, introduced species, global warming, ocean acidification, toxins and other pollutants, and massive runoff of nutrients are transforming once complex ecosystems, such as coral reefs and kelp forests, into monotonous level bottoms, transforming clear and productive coastal areas into anoxic dead zones, and transforming complex food webs formerly topped by large predators into simplified, microbial-dominated ecosystems with boom and bust cycles of toxic algal blooms, jellyfish, and disease (Jackson 2008). Globally, oysters were the first shellfish/invertebrate species to suffer extreme depletion, losing 85–90 % of populations in coastal bays and estuaries (Kirby 2004; Lotze et al. 2006; Jackson 2008; Beck et al. 2011). Many of the depleted areas are considered permanently depleted because of eutrophication, disease, and habitat loss not allowing recolonization (Jackson 2008). Fortunately, the Gulf of Mexico harbors some of the best remaining oyster reefs worldwide, and there is great opportunity in the Gulf for conservation and restoration (Beck et al. 2011).

Global climate change, including the issues of rising sea surface temperature, sea-level rise, and ocean acidification are all considered something like a large uncontrolled experiment with unknown, but potentially predictable, consequences. Some consider these to be the greatest challenge of humanity today (Jackson 2008). Some of the most obvious concerns for shellfish populations, which are dependent on estuarine conditions, are alterations to freshwater inflow and sea-level rise impacts to coastal marshes, the nursery grounds of shrimp and crabs (Montagna et al. 2007). Tolan (2007) demonstrated the impact of El Niño-Southern Oscillation translated to the watershed scale on salinity in all Texas estuaries along the Texas coast, showing significant correlations between global climate signals and local salinity patterns. These salinity patterns in turn affect the reproduction, recruitment, and survival of shellfish populations in this region of the northwestern Gulf of Mexico. Stenseth et al. (2002) and Hare and Able (2007) have likewise linked climate fluctuations or changes to ecological effects and fisheries.

Large-scale hypoxia in the northern Gulf of Mexico off Louisiana and Texas overlaps with the habitat and fishing grounds of brown and white shrimp (Zimmerman and Nance 2001). Adult brown shrimp are more affected than white shrimp due to their predominance further offshore where the hypoxic zone persists in the summer. When the hypoxic zone is widespread and persistent on the Louisiana shelf, the shrimp catch is always low (Zimmerman and Nance 2001). If the hypoxic zone blocks shrimp migration offshore, shrimp distributions and densities may be modified. White shrimp that are concentrated closer to shore and in bays and estuaries are not as affected by the hypoxic zone.

Hurricanes and tropical storms have the potential of affecting both the targeted shellfish species and the shellfish industry. In 2005, a large segment of the fishing and fishing-related businesses of the northern Gulf of Mexico and southwest Florida were devastated by Hurricanes Katrina, Rita, and Wilma. With the exception of oysters, an extensive study and report after these hurricanes revealed that Gulf coast living marine resources were not significantly impacted (NOAA 2007b). Commercial and recreational landings declined dramatically immediately after the storms, but they appeared to rebound to previous levels the following year.

However, the fishermen and fishing communities that were impacted by the storms were less resilient and did not rebound. Millions of tons of fishing-related debris were strewn across the land and shallow waters after the storms. Oysters are typically the shellfish species most severely impacted by hurricanes in the northern Gulf, as they are subject to direct physical damage or burial by mud and sand, or even hurricane-related debris, and freshets (Berrigan 1988; Haby et al. 2009). Fishery-independent surveys conducted by NOAA Fisheries after the storms indicated that none of the shrimp or crab stocks were significantly impacted and that most observed changes were within the normal, past interannual variation of CPUE (NOAA 2007b).

8.6.2 Parasites, Predators, and Diseases

Although parasites and diseases have generally not been a widespread issue in wild populations of shrimp, blue crabs are occasionally affected by diseases and parasites (Couch and Martin 1982; Davis and Sizemore 1982; Overstreet 1982; Overstreet and Rebarchik 1995; Messick 1998). Oysters, on the other hand, can be significantly impacted by parasites, pests, competitors, and diseases (White and Wilson 1996; NOAA 2007a). These impacts come from a wide variety of organisms including gastropods, crabs, flatworms, polychaetes, bivalves, sponges, bryozoans, and fish. Generally, young oyster spat is far more susceptible to predation than mature, market size oysters, as their thick calcium carbonate shell protects them against most intruders. Likewise, mortalities of oysters are much less in lower salinities (5–15 ppt) since most of the predators prefer higher salinities.

The main marine predator of adult oysters in the Gulf of Mexico is the oyster drill (*Stramonita haemastoma*, formerly *Thais haemastoma*), a gastropod with the ability to bore through the shell, kill, and then eat the oyster. Juvenile oysters are subject to predation by a number of crab species (stone crab, *Menippe* spp.; mud crab, *Panopeus herbstii*; blue crab, *Callinectes sapidus*). Polyclad flatworms in the genus *Stylochus* spp. can also predate oysters by slipping into the gaping shell and feeding on the oyster. Certain fishes are also known to feed upon oyster, such as sheepshead (*Archosargus probatocephalus*), skates (*Raja* spp.), and black drum (*Pagónias cromis*). Most fish feed only on thin-shelled juveniles, but the black drum can eat adult shells up to 8 cm (White and Wilson 1996).

Oyster pests detract from the health of the oyster by either weakening the shell or body, or by competing for food (White and Wilson 1996). Extensive damage rarely occurs, as pests are often small or uncommon. Well-known pests include the boring sponge (*Cliona* spp.), boring polychaetes (*Polydora* spp.), pea crabs (*Pinnotheres ostreum*), an ecoparasitic gastropod (*Boonea impressa*), and several bivalves that bore into the oyster shell (*Diplothyra smithi*, *Lithophaga bisulcata*, and *B. aristata*).

Oyster competitors can reduce the success of oyster populations by competing for food or space. Typical competitors include algae, arthropods, anemones, bryozoans, sponges, polychaetes, annelids, and mollusks.

There are two oyster diseases reported from Gulf of Mexico oysters: (1) Dermo and (2) MSX. Dermo is a parasitic disease caused by a protozoan *Perkinsus marinus* (Mackin et al. 1950). This is the first major oyster pathogen to be identified, and it was originally in the genus *Dermocystidium*, hence the shorten nickname Dermo. This parasite infects oysters during their first year of life and continues to proliferate causing up to 50 % mortalities in oysters living to their second year, and 80–90 % mortalities by the third year (NOAA 2007a). The parasite inhibits and affects the immune system of oysters, and it continues to cause significant mortalities along the Gulf coast. High salinity and high temperatures elevate the disease level in oysters, particularly during times of drought. MSX is also a protozoan disease, and it is caused by *Haplosporidium nelsoni*. This second lethal disease of oysters was first

reported from Delaware Bay, where it was dubbed MSX for multinucleate sphere X (unknown) at first discovery during 1957 and 1958 with massive mortalities in oysters. Although MSX continues to be a problem on mid-Atlantic oyster reefs, it has not caused major mortalities in the Gulf (NOAA 2007a).

8.6.3 Economic Conditions

Economic conditions regarding shellfish fisheries in the Gulf of Mexico can cause fluctuations or trends in landings equivalent to major swings seen in environmental condition variations and subsequent animal population levels. Economic conditions affecting the shrimp industry include: rising costs (fuel, insurance, etc.), poor market prices for domestic shrimp, competition from imports, damage from hurricanes, overcapitalization of the fishery industry, erosion, and conversion of waterfront property in some areas from fishing industry use to tourism-based and alternative uses (Nance et al. 2006; NOAA 2007b; Caillouet et al. 2008). As an example, Caillouet et al. (2008) and Nance et al. (2010) showed that numbers and sizes of shrimp, as well as landings per unit effort, were increasing through 2006 and forecast that such trends would continue if shrimping effort continued to decline. Nance (2011) confirmed those forecasts. However, while shrimp stocks have been increasing, annual yields have been decreasing most recently because of a decline in shrimping effort driven by economic conditions. Figure 8.17 clearly shows the declining effort when plotted with landings. Economic conditions are only briefly mentioned here with a few examples as an influence on shellfish fisheries. For a fuller, more detailed coverage on the economics of the fishing industry, please see Chapter 10 in this series dealing with the economics of Commercial and Recreational Fisheries of the Gulf of Mexico.

8.6.4 Management Decisions

Management decisions made by state and federal fishery management agencies can also affect landings and trends in shellfish species within the Gulf of Mexico. As noted in Section 8.2 above, these agencies include the GMFMC and NOAA Fisheries for federal waters relating to shrimp, and all five state fish and wildlife, or natural resource agencies, along with the GSMFC, for oyster and blue crab, as well as inshore shrimp catches. The Gulf of Mexico FMP for Shrimp was established in 1981 (GMFMC 1981) and now has 14 amendments (and number 15 under consideration) adjusting the fishery according to sustainable management needs to keep the fishery and habitats healthy. Oyster and blue crab both have a regional management plan coordinated and published by the GSMFC in cooperation with all five states (oyster regional management plan, VanderKooy 2012; blue crab regional management plan, Guillory et al. 2001). These plans are usually updated about every 10 years or so, and the various state agencies make adjustments, as needed, within their state. Examples of fishery management tools that can affect landings within the fishery include: limits on catch size and number (or quota), establishment of fishing seasons, regulations on fishery gear (e.g., use of TEDs and BRDs in shrimp nets), and licensing or permits for fishery vessels.

8.7 IMPORTANCE OF ESTUARIES AND SELECTED HABITATS TO SHELLFISH SPECIES

Since healthy estuaries are critically important in the life cycles of all three primary groups covered in this white paper (shrimp, oyster, and blue crab), it is important to understand the status of several critical habitats on the populations of the commercial shellfish covered. EFH is

now a critical element of all fishery management plans. Since two other chapters in this series deal with habitats (Chapter 6 and 7) and their importance to all species, only an overview is given here.

8.7.1 Estuaries and Delta/Coastal Marshes

Estuaries and coastal delta salt marshes develop at the mouths of rivers and coastal streams, and therefore are the sites where freshwater mixes with seawater and dilutes it. Both of these ecosystems exhibit very high levels of primary production and support multiple and important active food webs (Odum 1980; Teal 1986; Ross 1997). Of the commercially and recreationally important finfish and shellfish, over 80 % of species along the Atlantic coast, and nearly all species in the Gulf, are dependent on the estuaries and delta marshes at some stage of their life cycle (Arnett 1983; Gosselink 1984). The most valuable fisheries are dependent on functional coastal habitats for sustained productivity (Jordan et al. 2009).

As noted repeatedly in earlier portions of this chapter, shellfisheries are highly variable based on environmental fluctuations and population dynamics. Positive correlations are seen between fishery yields and intertidal vegetation (Turner 1977, 1986), yet negative correlations are seen between fish catch and nutrient enrichment (Deegan 2002) and habitat degradation, such as seagrass depletion and algal growth (Deegan et al. 2000; Deegan 2002). Humans have congregated in coastal areas from the beginnings of humanity, and the cumulative effects of exploitation, habitat destruction, and pollution are more severe in estuaries and the coastal zone than anywhere else in the ocean, except for coral reefs (Jackson 2008). Human impacts have depleted over 90 % of formerly important finfish and shellfish species, destroyed over 65 % of seagrass beds and wetland habitats, degraded water quality, and accelerated the invasion of multitudes of introduced species (Lotze et al. 2006). The sustainability of estuaries and delta/coastal marshes and their productivity are of concern with these conditions (Pauly 2010; Baltz and Yáñez-Arancibia 2011).

8.7.2 Seagrass Meadows, Mangrove Forests, Oyster Reefs, and Salt Marshes

Coastal ecosystems provide many vital ecological and economic services, including highly productive commercial and recreational fisheries (Beck et al. 2001, 2003). Key inshore habitats, such as seagrass beds, coastal marshes, and mangrove forests, are highly valued due to their very high productivity, which supports great abundances and diversity of fish and invertebrates, including shrimp, oyster, and blue crab. Because of the great abundance of juveniles found in these habitats, they are often referred to as nurseries where young organisms seek food and shelter (Beck et al. 2001, 2003). Strong evidence is available showing the linkages of penaeid shrimp, blue crabs, and other fishery species to these vital coastal habitats (Sheridan 1992; Heck et al. 1997; Zimmerman et al. 2000; Minello et al. 2003; Rozas and Minello 2010, and many more).

The reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 1996 included a new explicit goal to protect, restore, and enhance all “essential fish habitats.” The law defined EFH as “those waters and substrate necessary to fish for spawning, breeding, feeding, and or growth to maturity,” and “fish” was defined to include all forms of fish, invertebrates, and plants but not birds and mammals. Most of the above discussed, vegetated habitats all fit within the definition of EFH. In addition, oyster reefs also fit within that definition, and great attention has recently focused on oyster reefs as EFH and their importance in providing various ecosystem services and their need for restoration (Coen et al. 1999, 2007;

Peterson et al. 2003; Grabowski and Peterson 2007; Volety et al. 2009; Beck et al. 2011). Indeed, the conservation, restoration, and management of healthy coastal ecosystems are the requirements for healthy and productive shellfisheries in the Gulf of Mexico.

8.8 SUMMARY

There are at least 49 recognized species of shellfish taken in commercial or artisanal fisheries in the Gulf of Mexico. Of these 49 species, 28 are mollusks, 18 are crustaceans, and three are echinoderms. The greatest diversity of species is found in the tropical waters of the southern Gulf of Mexico, but the largest abundances and value are found in the northern Gulf of Mexico. Regarding the three countries that surround the Gulf of Mexico, 16 species are taken within U.S. waters, 46 from Mexico, and six from Cuba. For purposes of this chapter shellfish species are broken into three categories: (1) major (five species); (2) moderate, but important (six species); and (3) minor (38 species) (see Table 8.3). Major species (brown, pink, and white shrimp, Eastern oyster, and blue crab) are the main focus of this document, providing biological, ecological, and fishery status and trends; moderate species are briefly covered in the text; minor species are not covered in the text but are listed in Table 8.1, along with all Gulf shellfish species by scientific name, common name (English and Spanish), distribution, remarks, and a key citation. Jurisdictional boundaries and governing agencies for fishery management in all three Gulf countries are presented and compared.

The current status and historical trends of penaeid shrimp, Eastern oyster, and blue crab all show natural population fluctuations over the past several decades due to varying environmental conditions. In addition, some fisheries, like shrimp, have been greatly affected in recent years by exogenous factors, such as rising fuel costs, market competition from imported shrimp, and fleet damage from hurricanes. Overall, shrimp populations seem to be flourishing, while the shrimp fishery is in decline due to these, and other, factors. Unlike other parts of the United States, Gulf oyster populations seem to be fairly stable, but they show variable annual and multiyear fluctuations, the result mainly of environmental conditions, but also sometimes due to economic/market conditions. As the lead oyster-producing state in the Gulf, Louisiana oyster populations have declined in the past decade when compared to the 1990s, but levels are still above what they were in the 1980s (LDWF 2010). There is considerable concern over the continued loss of oyster reef habitat. The blue crab fishery is quite variable from state to state with Louisiana showing a continued growth and the largest fishery over the past two decades, while Texas shows a decrease in not only the fishery but also species populations statewide during the same time frame. Gulf-wide there is agreement that healthy bays and estuaries lead to more productive fisheries, and therefore the need for conservation of some habitats and restoration of others.

REFERENCES

- Adams C, Sanchez-Vega P, Garcia-Alvarez A (2000) An overview of the Cuban commercial fishing industry and recent changes in management structure and objectives. In: Proceedings, International Institute of Fisheries Economics and Trade, Corvallis, OR, USA, 10–14 July 2000. 7 p
- Adkins G (1972) Study of the blue crab fishery in Louisiana. Technical Bulletin 3. Louisiana Wildlife and Fisheries Commission, Baton Rouge, LA, USA. 57 p
- Appeldoorn RS, Meyers S (1993) Part Z: Puerto Rico and Hispaniola. Marine fishery resources of the Antilles, FAO fisheries technical paper 326 Rome. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy, pp 99–158

- Arenas F, Diaz de Leon CA (eds) (1999) Sustentabilidad y pesca responsable en Mexico: evaluacion y manejo 1997-1998. Instituto Nacional de la Pesca, SAGARPA, Delegación Benito Juárez, Mexico, Federal District. 1112 p
- Arenas-Fuentes V, Jimenez-Badillo L (2004) Fishing in the Gulf of Mexico: Towards greater biomass in exploitation. In: Caso M, Pisanty I, Excurra E (eds) Environmental analysis of the Gulf of Mexico. Instituto Nacional de Ecologia (English translation edited by Withers K, Nipper M (2007) Harte Research Institute for Gulf of Mexico studies. Texas A&M University—Corpus Christi, TX, USA, pp 468–477
- Arnett GR (1983) Introduction to the session—user group demands on the environment. In: Reintjes JW (ed) Improving multiple use of coastal and marine resources. American Fisheries Society, Bethesda, MD, USA, pp 11–13
- Arnold WS, Berrigan ME (2002) A summary of the oyster (*Crassostrea virginica*) fishery in Florida. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA
- Arreguin-Sanchez F, Solis-Ramirez MJ, Gonzalez de la Rosa ME (2000) Population dynamics and stock assessment for *Octopus maya* (Cephalopoda: Octopodidae) fishery in the Campeche Bank, Gulf of Mexico. *Rev Biol Trop* 48:323–331
- Bahr M, Lanier WP (1981) The ecology of intertidal oyster reefs of the South Atlantic coast: A community profile. U.S. Fish and Wildlife Service Biological Report, FWS/OBS-81/15. U.S. Geological Survey, Reston, VA, USA. 105 p
- Baisre JA (2000) Chronicle of Cuban marine fisheries (1935–1995): Trend analysis and fisheries potential. Fisheries Technical Paper 394. FAO, Rome, Italy. 26 p
- Baisre JA (2006) Cuban Fisheries Management Regime: Current state and future prospects. The United Nations University-Fisheries Training Programme, Reykjavik, Iceland. 33 p
- Baisre JA, Booth S, Zeller D (2003) Cuban fisheries catches within FAO area 31 (Western Central Atlantic): 1950-1999. *Fish Cent Res Rep* 11:133–139
- Baltz DM, Yáñez-Arancibia A (2011) Ecosystem-based management of coastal fisheries in the Gulf of Mexico: Environmental and anthropogenic impacts and essential habitat protection (Chapter 19). In: Day JW, Yáñez-Arancibia A (eds) The Gulf of Mexico: Ecosystem-based management, vol 4, Harte Research Institute for Gulf of Mexico studies. Texas A&M University Press, College Station, TX, USA
- Baqueiro ER (2004) Current state of molluscan resources of the Gulf of Mexico. In: Caso M, Pisanty I, Excurra E (eds) Instituto Nacional de Ecologia (English translation edited by Withers K, Nipper M (2007) Harte Research Institute for Gulf of Mexico studies. Texas A&M University—Corpus Christi, TX, USA, pp 195–220
- Baxter KN, Renfro WC (1966) Seasonal distribution and size distribution of post larval brown and white shrimp near Galveston, Texas, with notes on species identification. *U.S. Fish Bull* 66:149–158
- Beck MW, Heck KL Jr, Able K, Childers D, Eggleston D, Gillanders BM, Halpern B, Hays C, Hoshino K, Minello T, Orth R, Sheridan P, Weinstein M (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience* 51:633–641
- Beck MW, Heck KL, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MR (2003) The role of nearshore ecosystems as fish and shellfish nurseries. *Issues Ecol* 11:1–12
- Beck WM, Brumbaugh RD, Airoidi L, Carranza A, Coen LD, Crawford C, Defeo O, Edgar GJ, Hancock B, Kay MC, Lenihan HS, Luckenbach MW, Toropova CL, Zhang G, Guo X (2011) Oyster reefs at risk and recommendations for conservation, restoration, and management. *BioScience* 61:107–116

- Berrigan ME (1988) Management of oyster resources in Apalachicola Bay following Hurricane Elena. *J Shellfish Res* 7:281–288
- Berrigan M, Candies T, Cirino J, Dugas R, Dyer C, Gray J, Herrington T, Keithly W, Leard R, Nelson JR, Van Hoose M (1991) The oyster fishery of the Gulf of Mexico, United States: A regional management plan. Publication 24, March. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA
- Briggs JC (1974) Marine zoogeography. McGraw-Hill, New York, NY, USA
- Brownell WN, Stevely JM (1981) The biology, fisheries, and management of the queen conch, *Strombus gigas*. *Mar Fish Rev* 43:1–12
- Burrell VG Jr (1986) Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (south Atlantic)—American oyster. U.S. Fish and Wildlife Service Biological Report 82(11.57). U.S. Fish and Wildlife Service, Slidell, LA, USA
- Butler PA (1954) The southern oyster drill. *Proc Natl Shellfish Assoc* 44:67–75
- Caffey RH, Culley DD, Roberts KJ (1993) The Louisiana soft-shelled crab industry: A profile. Sea Grant Program Publication LSU-G-9-001. Louisiana State University, Baton Rouge, LA, USA. 46 p
- Caillouet CW Jr, Hart RA, Nance JM (2008) Growth overfishing in the brown shrimp fishery of Texas, Louisiana, and adjoining Gulf of Mexico EEZ. *Fish Res* 92:289–302
- Caillouet CW Jr, Hart RA, Nance JM (2011) Simulation of tail weight distribution in biological year 1986–2006 landings of brown shrimp, *Farfantepenaeus aztecus*, from the Northern Gulf of Mexico fishery. *Mar Fish Rev* 73:27–40
- Calabrese A, Davis HC (1970) Tolerances and requirements of embryos and larvae of bivalve molluscs. *Helgolander Meeresun* 20:553–564
- Calabrese A, Collier RS, Nelson DA, MacInnes JR (1973) The toxicity of heavy metals to embryos of the American oyster, *Crassostrea virginica*. *Mar Biol* 18:162–166
- Carpenter KE (2002) The living marine resources of the Western Central Atlantic, vol 1, Introduction, molluscs, crustaceans, hagfishes, sharks, batoid fishes, and chimaeras. FAO species identification guide for fishery purposes and American Society of Ichthyologists and Herpetologists special publication 5. FAO, Rome, Italy. 600 p
- Carriker MR, Gaffney PM (1996) A catalogue of selected species of living oysters (Ostreacea) of the world. In: Kenned VS, Newell RIE, Eble AF (eds) The eastern oyster *Crassostrea virginica*. MD Sea Grant, College Park, MD, USA, pp 1–18
- CFMC (Caribbean Fishery Management Council) (1996) Fishery Management Plan, regulatory impact review, and final environmental impact statement for the queen conch resources of Puerto Rico and the United States Virgin Islands. Caribbean Fishery Management Council, San Juan, Puerto Rico. 63 p
- Childress UR (1966) An investigation into levels of concentration, seasonal variations, and sources of pesticide toxicants in some species from selected bay areas. Project MP-R-2, Coastal Fisheries Project Technical Report. Texas Parks and Wildlife Department, Austin, TX, USA
- Christmas JY, Etzold DJ (1977) The shrimp fishery of the Gulf of Mexico United States: A regional management plan. *Gulf Coast Res Lab Tech Rep Ser* 2(1). 125 p
- Claro R, Lindeman KC, Parenti LR (2001) Ecology of the marine fishes of Cuba. Smithsonian Institution Press, Washington, DC, USA. 253 p
- Claro R, Mitcheson YS, Lindeman KC, Garcia-Cagide AR (2009) Historical analysis of Cuban commercial fishing effort and the effects of management interventions on important reef fishes from 1960–2005. *Fish Res* 99:7–16
- Cody TJ, Wagner T, Bryan CE, McEachron LW, Rayburn R, Bowling B, Mambretti J (1992) Texas blue crab fishery management plan, Fisheries management plan series 4. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Austin, TX, USA

- Coen LD, Luckenbach MW, Breitburg DL (1999) The role of oyster reefs as essential fish habitat: A review of current knowledge and some new perspectives. *Am Fish Soc Symp* 22:438–454
- Coen LD, Brumbaugh RD, Bushek D, Grizzle R, Luckenbach MW, Posey MH, Powers SP, Tolley SG (2007) Ecosystem services related to oyster restoration. *Mar Ecol Prog Ser* 341:303–307
- Condrey R, Fuller D (1992) The U.S. Gulf shrimp fishery. In: Giantz MH (ed) *Climate variability, climate change and fisheries*. Cambridge University Press, Cambridge, UK, pp 89–119
- Cook HL, Lindner MJ (1970) Synopsis of biological data on the brown shrimp *Penaeus aztecus* Ives, 1891. *FAO Fish Rep* 57:1471–1497
- Cook HL, Murphy MA (1966) Rearing penaeid shrimp from eggs to post larvae. *Proc Conf SE Assoc Game Comm* 19:283–288
- Copeland BJ (1965) Fauna of the Aransas pass inlet, Texas. I. Emigration shown by tide trap collections. *Inst Mar Sci Univ Tex Publ* 10:9–21
- Copeland BJ, Bechtel TJ (1974) Some environmental limits of six gulf coast estuarine organisms. *Contrib Mar Sci* 18:169–204
- Copeland BJ, Truitt MV (1966) Fauna of Aransas pass inlet, Texas. II. Penaeid shrimp post larvae. *Tex J Sci* 18:65–74
- Costello TJ, Allen DM (1970) Synopsis of biological data on the pink shrimp *Penaeus duorarum* Burkenroad, 1939. *FAO Fish Rep* 57:1499–1537
- Costello TJ, Bert TM, Cartano DG, Davis G, Lyon G, Rockwood C, Stevely J, Tashiro J, Trent WL, Turgeon D, Zuboy J (1979) Fishery management plan for the stone crab fishery of the Gulf of Mexico. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 188 p
- Costello TJ, Allen DM, Hudson JH (1986) Distribution, seasonal abundance, and ecology of juvenile northern pink shrimp, *Penaeus duorarum*. The Florida Bay area, NOAA Tech Memo NMFS-SEFC-161. National Oceanic and Atmospheric Administration, Silver Spring, MD, USA. 84 p
- Costlow JD, Sastry AN (1966) Free amino acids in developing stages of two crabs, *Callinectes sapidus* and *Rhithropanopeus harrisi* Gould. *Acta Embryol Morphol Exp* 9:44–55
- Couch JA, Martin S (1982) Protozoan symbionts and related diseases of the blue crab, *Callinectes sapidus* Rathbun from the Atlantic and gulf coasts of the United States. In: Perry HM, Van Engel WA (eds) *Proceedings, blue crab colloquium*, Publication 7. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA, pp 71–80
- Darnell RM (1958) Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community. *Inst Mar Sci Univ Tex Publ* 5:353–416
- Darnell RM (1959) Studies of the life history of the blue crab *Callinectes sapidus* Rathbun in Louisiana waters. *Trans Am Fish Soc* 88:294–304
- Davis JW, Sizemore RK (1982) Incidence of *Vibrio* species associated with blue crabs (*Callinectes sapidus*) collected from Galveston Bay, Texas. *Appl Environ Microbiol* 43:1092–1097
- Deegan LA (2002) Lesson learned: The effects of nutrient enrichment on the support of nekton by seagrass and salt marsh ecosystems. *Estuaries* 25:727–742
- Deegan LA, Hughes JE, Rountree RA (2000) Salt marsh ecosystem support of marine transient species. In: Weinstein MP, Kreeger DA (eds) *Concepts and controversies in tidal marsh ecology*. Kluwer, Dordrecht, The Netherlands, pp 333–365
- Diario Oficial (2010) Carta Nacional Pequera. Segunda Seccion: Secretaria del agricultura, ganaderia, desarrollo rural, pesca y alimentacion. Mexico City, Mexico. 102 p

- Diaz-de-Leon A, Fernandez JI, Alvarez-Torres P, Ramirez-Flores O, Lopez-Lumes LG (2004) The sustainability of the Gulf of Mexico's fishing grounds. In: Caso M, Pisanty I, Excurra E (eds) Instituto Nacional de Ecologia (English translation edited by Withers K, Nipper M (2007) Harte Research Institute for Gulf of Mexico Studies, Texas A&M University—Corpus Christi, TX, USA, pp 457–467
- Dugas RJ, Joyce EA, Berrigan MA (1997) History and status of the oyster, *Crassostrea virginica*, and other molluscan fisheries of the Gulf of Mexico. In: MacKenzie CL Jr, Burrell VG Jr, Rosenfield A, Hobart WL (eds) The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, NOAA Technical Report NMFS 127. NOAA, Silver Spring, MD, USA, pp 187–210
- Eggleston DB (1990) Foraging behavior of the blue crab, *Callinectes sapidus*, on juvenile oysters, *Crassostrea virginica*: Effects of prey density and size. Bull Mar Sci 46:62–82
- Ekman S (1953) Zoogeography of the sea. Sidgwick and Jackson, London, UK. 417 p
- ELI and CMDA (Environmental Law Institute and Centro Mexicano de Derecho Ambiental) (2011) Gulf of Mexico habitat conservation and restoration: Comparing the Mexican and United States legal and institutional frameworks. Gulf of Mexico Foundation, Corpus Christi, TX, USA. 99 p
- Etzold DJ, Christmas JY (1977) A comprehensive summary of the shrimp fishery for the Gulf of Mexico United States: A regional management plan. Gulf Coast Res Lab Tech Rep Ser 2(2). 20 p
- FAO (2011) Food and Agriculture Organization of the United Nations. <http://www.fao.org>. Accessed 2 Feb 2013
- Felder DL, Camp DK (2009) Gulf of Mexico origin, waters, and biota, vol 1, Biodiversity. Texas A&M University Press, College Station, TX, USA. 1393 p
- Felder DL, Alvarez F, Goy JW, Lemaitre R (2009) Decapoda (Crustacea) of the Gulf of Mexico, with comments on the Amphionidacea. In: Felder DL, Camp DK (eds) Gulf of Mexico origin, waters, and biota, vol 1, Biodiversity. Texas A&M University Press, College Station, TX, USA, pp 1019–1104
- Galtsoff PS (1930) Destruction of oyster bottoms in Mobile Bay by the flood of 1929. U.S. Bureau of Fisheries, Rep. Commission Fisheries for 1929 (Doc 1069). U.S. Government Printing Office, Washington, DC, USA, pp 741–758
- Galtsoff PS (1964) The American oyster *Crassostrea virginica* Gmelin. Fish Bull 64:1–480
- Gauthier JD, Soniat TM (1989) Changes in the gonadal state of Louisiana oysters during their autumn spawning season. J Shellfish Res 8:83–86
- GMFMC (Gulf of Mexico Fishery Management Council) (1979) Fishery management plan for the stone crab fishery of the Gulf of Mexico. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 188 p
- GMFMC (1981) Fishery management plan for the shrimp fishery of the Gulf of Mexico, United States waters. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 246 p
- GMSAFMC (Gulf of Mexico and South Atlantic Fishery Management Councils) (1982) Fishery management plan environmental impact statement and regulatory review for spiny lobster in the Gulf of Mexico and South Atlantic. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 247 p
- Gosselink JG (1984) The ecology of delta marshes of coastal Louisiana: A community profile. U.S. Fish and Wildlife Service FWS/OBS-84/09. U.S. Geological Survey, Reston, VA, USA
- Grabowski JH, Peterson CH (2007) Restoring oyster reefs to recover ecosystem services. In: Cuddington K, Byers J, Wilson W, Hastings A (eds) Ecosystem engineers: Plants to protists. Academic Press, Burlington, MA, USA, pp 281–298

- GSMFC (Gulf States Marine Fisheries Commission) (2011) Gulf States Marine Fisheries Commission. <http://www.gsmfc.org>. Accessed 2 Feb 2013
- Guillory V (1996) A management profile of Louisiana blue crab, *Callinectes sapidus*, Fisheries management plan series 8, Part 2. Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA, USA. 34 p
- Guillory V (1998) A survey of the recreational blue crab fishery in Terrebonne Parish, Louisiana. *J Shellfish Res* 17:4543–4550
- Guillory V, Perret WE (1998) Management, history, and status and trends in the Louisiana blue crab fishery. *J Shellfish Res* 17:413–424
- Guillory V, Bourgeois M, Prejean P, Burdon J, Merrell J (1996) A biological and fisheries profile of Louisiana blue crab, *Callinectes sapidus*, Part 1, Fisheries management plan series 5. Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA, USA
- Guillory V, Perry H, Steele P, Wagner T, Hammerschmidt P, Heath S, Moss C (1998) The Gulf of Mexico blue crab fishery: Historical trends, status, management, and recommendations. *J Shellfish Res* 17:395–403
- Guillory V, Perry H, Steele P, Wagner T, Keithly W, Pellegrin B, Petterson J, Floyd T, Buckson B, Hartman L, Holder E, Moss C (2001) The blue crab fishery of the Gulf of Mexico, United States: A regional management plan, Publication 96. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA
- Gunter G (1961) Habitat of juvenile shrimp (family Penaeidae). *Ecology* 42:598–600
- Gusmao J, Lazoski C, Monteiro FA, Sole-Cava AM (2006) Cryptic species and population structuring of the Atlantic and Pacific seabob shrimp species, *Xiphopenaeus kroyeri* and *Xiphopenaeus riveti*. *Mar Biol* 149:491–502
- Haby MG, Miget RJ, Falconer LL, Graham GL (2003) A review of current conditions in the Texas shrimp industry, an examination of contributing factors, and suggestions for remaining competitive in the global shrimp market, TAMU-SG-03-701. Texas Cooperative Extension Sea Grant College Program, College Station, TX, USA. 26 p
- Haby MG, Miget MJ, Falconer LL (2009) Hurricane damage sustained by the oyster industry and the oyster reefs across the Galveston Bay system with recovery recommendations, TAMU-SG-09-201. TexasAgriLife Extension Service/Sea Grant Extension Program, College Station, TX, USA. 51 p
- Halpern BS, Walbridge S, Selkoe KA et al (2008) A global map of human impact on marine ecosystems. *Science* 319:948–952
- Hammerschmidt P, Wagner T, Lewis G (1998) Status and trends in the Texas blue crab (*Callinectes sapidus*) fishery. *J Shellfish Res* 17:405–412
- Hare JA, Able KW (2007) Mechanistic links between climate and fisheries along the east coast of the United States: Explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). *Fish Oceanogr* 16:31–45
- Hart RA (2008) A biological review of the Tortugas pink shrimp fishery 1960 through 2007. NOAA Technical Memorandum NMFS-SEFSC-573. NOAA, Silver Spring, MD, USA. 28 p
- Hart, RA, Nance JM (2010) Gulf of Mexico pink shrimp assessment modeling update: From a static VPA to an integrated assessment model, stock synthesis. NOAA Technical Memorandum NMFS-SEFSC-604. NOAA, Silver Spring, MD, USA. 32 p
- Heath SR (1998) The Alabama blue crab fishery: Historical trends, status, management, and the future. *J Shellfish Res* 17:435–439
- Heck KL Jr, Nadeau DA, Thomas R (1997) The nursery role of seagrass beds. *Gulf Mexico Sci* 15:50–54

- Henley DE, Rauschuber DG (1981) Freshwater needs of fish and wildlife resources in the Nueces-Corpus Christi Bay area, Texas: A literature synthesis. Biological Report FWS/OBS-80/10. U.S. Fish and Wildlife Service, Washington, DC, USA. 410 p
- Hester TR (1980) Digging into South Texas prehistory: A guide for amateur archaeologists. Corona, San Antonio, TX, USA. 201 p
- Hildebrand HH (1954) A study of the fauna of the brown shrimp (*Penaeus aztecus* Ives) grounds in the western Gulf of Mexico. Inst Mar Sci Univ Tex Publ 3:233–366
- Hildebrand HH (1955) A study of the fauna of the pink shrimp (*Penaeus duorarum* Burkenroad) grounds in the Gulf of Campeche. Inst Mar Sci Univ Tex Publ 4:169–232
- Hofmann EE, Powell TM (1998) Environmental variability effects on marine fisheries: Four case histories. Ecol Appl 8:S23–S32
- Hofstetter RP (1962) Study of oyster growth and population structure of the public reefs in East Bay, Galveston and Trinity Bay. Coastal Fisheries Branch Project Reports. Texas Parks and Wildlife Department, Austin, TX, USA
- Hofstetter RP (1977) Trends in population levels of the American oyster, *Crassostrea virginica* Gmelin on public reefs in Galveston Bay, Texas, Technical series 10. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Austin, TX, USA. 90 p
- Hofstetter RP (1981) Rehabilitation of public oyster reefs damaged or destroyed by a natural disaster, Management data series 21. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Austin, TX, USA. 9 p
- Hofstetter RP (1990) The Texas oyster fishery, 3rd Rev, Bulletin 40, TPWD-BK-3400-216-2/90. Texas Parks and Wildlife Department, Coastal Fisheries, Austin, TX, USA
- Iversen ES, Jory DE (1985) Queen conch at the crossroads. Sea Front 31:151–159
- Jackson JBC (2008) Ecological extinction and evolution in the brave new ocean. Proc Natl Acad Sci 105:11458–11465
- Jennings S, Kaiser MJ, Reynolds JD (2001) Marine fisheries ecology. Blackwell Publishing, London, UK. 417 p
- Jones AC, Dimitriou DE, Ewald JJ, Tweedy JH (1970) Distribution of early developmental stages of pink shrimp, *Penaeus duorarum*, in Florida waters. Bull Mar Sci 20:634–661
- Jones A, Klima EF, Poffenberger J (1982) The effects of the 1981 closure on the Texas shrimp fishery. Mar Fish Rev 44:1–4
- Jordan SJ, Smith LM, Nestlerode JA (2009) Cumulative effects of coastal habitat alterations on fishery resources: Toward prediction at regional scales. Ecol Soc 14:16, <http://www.ecologyandsociety.org/vol14/iss1/art16/>. Accessed 2 Feb 2013
- Kennedy VS (1996) Biology of larvae and spat. In: Kennedy VS, Newell RIE, Eble AF (eds) The eastern oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, MD, USA, pp 371–421
- Kilgour MJ, Shirley TC (2008) Distribution of red deepsea crab (*Chaceon quiquedens*) by size and sex in the Gulf of Mexico. Fish Bull 106:317–320
- Killam KA, Hochberg RJ, Rzemien EC (1992) Synthesis of basic life histories of Tampa Bay species, Technical publication 10-92. Tampa Bay National Estuary Program, St. Petersburg, FL, USA. 155 p
- King BD III (1971) Study of migratory patterns of fish and shellfish through a natural pass, Technical series 9. Texas Parks and Wildlife Department, Austin, TX, USA. 54 p
- Kirby MX (2004) Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. Proc Natl Acad Sci 101:13096–13099
- Klima EF (1981) The National Marine Fisheries shrimp research program in the Gulf of Mexico. Kuwait Bull Mar Sci 2:185–207

- Klima EF (1989) Approaches to research and management of U.S. Fisheries for penaeid shrimp in the Gulf of Mexico, 99. In: Caddy JF (ed) Marine invertebrate fisheries: Their assessment and management. FOA, Rome, Italy, pp 87–113
- Klima EF, Baxter KN, Patella FJ (1982) A review of the offshore shrimp fishery and the 1981 Texas closure. *Mar Fish Rev* 44:16–30
- Klima EF, Matthews GA, Patella FJ (1986) Synopsis of the Tortugas pink shrimp fishery, 1960–1983, and the impact of the Tortugas Sanctuary. *N Am J Fish Manag* 6:301–310
- Klima EF, Castro Melendez RG, Baxter N, Patella FJ, Cody TJ, Sullivan LF (1987) MEXUS-Gulf shrimp research, 1978–84. *Mar Fish Rev* 49:21–30
- Laughlin RA (1982) Feeding habits of the blue crab *Callinectes sapidus* Rathbun, in the Apalachicola Estuary, Florida. *Bull Mar Sci* 32:807–822
- LDWF (Louisiana Department of Wildlife and Fisheries) (2005) Oyster stock assessment report of the public oyster areas in Louisiana, Oyster data report series 11. Baton Rouge, LA, USA
- LDWF (2010) Oyster stock assessment report of the public oyster areas in Louisiana, Oyster data report series 16. LA, USA
- Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312:1806–1809
- MacKenzie CL (1996) History of oystering in the United States and Canada, featuring North America's greatest oyster estuaries. *Mar Fish Rev* 58:1–78
- MacKenzie CL Jr, Wakida-Kusunoki AT (1997) The oyster industry of Eastern Mexico. *Mar Fish Rev* 59:1–13
- Mackin JG, Owen HM, Collier A (1950) Preliminary note on the occurrence of a new protistan parasite, *Dermocystidium marinum* n. sp. in *Crassostrea virginica* (Gmelin). *Science* 111:32–329
- Martin N (1987) Raw deals. *Tex Shores* 20:4–8
- Marwitz SR, Bryan CE (1990) Rehabilitation of public oyster reefs damaged by a natural disaster in San Antonio Bay, Management data series 32. Texas Parks and Wildlife Department, Austin, TX, USA. 10 p
- McLaughlin PA, Camp DK, Angel MV, Bousfield EL, Brunel P et al (2005) Common and scientific names of aquatic invertebrates from the United States and Canada: Crustaceans, vol 31, American Fisheries Society special publication. American Fisheries Society, Bethesda, MD, USA. 533 p
- McTigue TA, Zimmerman RJ (1991) Carnivory vs. herbivory in juvenile *Penaeus setiferus* (Linnaeus) and *Penaeus aztecus* (Ives). *J Exp Mar Biol Ecol* 151:1–16
- Menzel RW, Hopkins SH (1956) Crabs as predators of oysters in Louisiana. *Proc Natl Shellfish Assoc* 46:177–184
- Messick GA (1998) Diseases, parasites, and symbionts of blue crabs (*Callinectes sapidus*) dredged from Chesapeake Bay. *J Crustac Biol* 18:533–548
- Mexicano-Cintora G, Leonce-Valencia C, Salas S, Vega-Cendejas ME (2007) Recursos pesqueros de Yucatán: Fichas técnicas y referencias bibliográficas. Centro de Investigación y Estudios Avanzados del I.P.N. (CINVESTAV) Unidad Merida. 1a. Edición. Merida, Yucatán, Mexico. 150 p
- Millikin MR, Williams AB (1984) Synopsis of biological data on the blue crab, *Callinectes sapidus*. FAO Fish Synop 138, NOAA Technical Report NMFS 1. NOAA/National Marine Fisheries Service, Silver Spring, MD, USA
- Minello TJ, Zimmerman RJ, Martinez EX (1989) Mortality of young brown shrimp *Penaeus aztecus* in estuarine nurseries. *Trans Am Fish Soc* 118:693–708

- Minello TJ, Able KW, Weinstein MP, Hayes CG (2003) Salt marshes as nurseries for nekton: Testing hypotheses on density, growth and survival through meta-analysis. *Mar Ecol Prog Ser* 246:39–59
- Montagna PA, Gibeaut JC, Tunnell JW Jr (2007) South Texas climate 2100: Coastal impacts. In: Norwine J, John K (eds) *The changing climate of South Texas 1900-2100: Problems and prospects, impacts and implications*. Texas A&M University-Kingsville, Kingsville, TX, USA, pp 57–77
- Moss CG (1982) The blue crab fishery of the Gulf of Mexico. In: Perry HM, VanEngel WA (eds) *Proceedings of the blue crab colloquium*, Gulf States Marine Fisheries Commission Publication 7, Ocean Springs, MS, USA, pp 93–104
- MRAG (MRAG Americas Inc.) (2010) *Pre-assessment of the Gulf of Mexico Shrimp fishery. Sustainable Fisheries Partnership*, St. Petersburg, FL, USA. 7 p
- Muncy RJ (1984) Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)—white shrimp. *Biological Report FWS/OBS-82/11.20*. U.S. Fish and Wildlife Services, Washington, DC, USA. 19 p
- Nance JM (1992) Estimation of effort for the Gulf of Mexico shrimp fishery. NOAA Technical Memorandum NMFS-SEFSC-300. NOAA, Silver Spring, MD, USA
- Nance JM (1996) Biological review of the 1995 Texas closure. NOAA Tech Mem NMFS-SEFSC-379. NOAA, Silver Spring, MD, USA. 7 p
- Nance JM (2011) Stock assessment report 2010 Gulf of Mexico shrimp fishery. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 16 p
- Nance JM, Keithly W Jr, Caillouet C Jr, Cole J, Gaidry W, Gallaway B, Griffin W, Hart R, Travis M (2006) Estimation of effort, maximum sustainable yield, and maximum economic yield in the shrimp fishery of the Gulf of Mexico. Gulf of Mexico Fishery Management Council, Tampa, FL, USA. 85 p
- Nance JM, Caillouet CW Jr, Hart RA (2010) Size-composition of annual landings in the white shrimp fishery of the northern Gulf of Mexico, 1960–2006: Its trend and relationships with other fishery-dependent variables. *Mar Fish Rev* 72:1–13
- Nelson DM, Monaco ME, Williams CD, Czaplá TE, Patillo ME, Coston-Clements L, Settle LR, Irlandi EA (1992) Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, vol 1, Data summaries, ELMR Report 10. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, USA. 273 p
- NMFS (National Marine Fisheries Service) (2010) *Fisheries of the United States 2009*, Silver Spring, MD, USA. 103 p
- NMFS (2011) *Fisheries of the United States 2010*, Silver Spring, MD, USA. 103 p
- NOAA (National Oceanic and Atmospheric Administration) (2007a) Status review of the Eastern Oyster (*Crassostrea virginica*). NOAA Tech Mem NMFS-F/SPO-88, Silver Spring, MD, USA. 105 p
- NOAA (2007b) Report to congress on the impacts of hurricanes Katrina, Rita, and Wilma on Alabama, Louisiana, Florida, Mississippi, and Texas fisheries, Silver Spring, MD, USA. 133 p
- NOAA (2011a) NOAA Fisheries: Office of Service and Technology, Fisheries Statistics Division (ST1). <http://www.st.nmfs.noaa.gov/st1/>. Accessed 2 Feb 2013
- NOAA (2011b) NOAA Gulf of Mexico Data Atlas. <http://gulfatlas.noaa.gov/>. Accessed 2 Feb 2013
- NOS (National Ocean Service) (2011) *The Gulf of Mexico at a glance: A second glance*. U.S. Department of Commerce, Washington, DC, USA. 51 p
- Odum EP (1980) The status of three ecosystem-level hypotheses regarding salt marsh estuaries: Tidal subsidy, outwelling, and detritus-based food chains. In: Kennedy VS (ed) *Estuarine perspectives*. Academic Press, New York, NY, USA, pp 485–495

- Orensanz JM, Jaimieson GS (1998) The assessment and management of spatially structured stocks: An overview of the North Pacific symposium on invertebrate stock assessment and management. *Can Spec Publ Fish Aquat Sci* 125:441–459
- Osborn KW, Maghan BW, Drummond SB (1969) Gulf of Mexico shrimp atlas. U.S. Department of the Interior, Bureau of Commercial Fisheries Circular 312. 20 p
- Overstreet RM (1982) Metazoan symbionts of the blue crab. In: Perry HM, Van Engel WA (eds) Proceedings of the blue crab colloquium, Publication 7. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA, pp 129–136
- Overstreet RM, Rebarchik D (1995) Assessment of infections of the blue crab in Pensacola Bay. Final Report. U.S. Environmental Protection Agency, Washington, DC, USA. 76 p
- Patillo ME, Czaplá TE, Nelson DM, Monaco ME (1997) Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, vol 2, Species life history summaries, ELMR Report 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD, USA. 377 p
- Pauly D (2010) 5 easy pieces: The impact of fisheries on marine ecosystems (The State of the World's Oceans), Sea around us project. Island, Washington, DC, USA. 194 p
- Perez-Farfante I (1969) Western Atlantic shrimps of the genus *Penaeus*. *Fish Bull* 67:461–591
- Perry HM (1975) The blue crab fishery in Mississippi. *Gulf Res Rep* 5:39–57
- Perry HM, Malone R (1985) Proceedings of the national symposium on the soft-shelled blue crab fishery. Gulf Coast Research Laboratory, Ocean Springs, MS, USA. 128 p
- Perry HM, Malone R (1989) Blue crabs: Soft shell production. In: Cake EW Jr, Whicker LF, Ladner CM (eds) Mississippi Aquatic Ventures Center: Aquaculture profiles and opportunities in Mississippi. Mississippi Department of Wildlife, Fisheries and Parks, Bureau of Marine Resources, Jackson, MS, USA, pp 1–32
- Perry HM, McIlwain TD (1986) Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)—blue crab. U.S. Fish Wildlife Services Biological Report 82 (11.55). U.S. Army Corp of Engineers, TR EL-82-4, Vicksburg, MS, USA. 21 p
- Perry HM, Adkins G, Condrey R, Hammerschmidt PC, Heath S, Herring JR, Moss C, Perkins G, Steele P (1984) A profile of the blue crab fishery of the Gulf of Mexico, Publication 9. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA. 80 p
- Perry HM, Warren J, Trigg C, Van Devender T (1998) The blue crab fishery of Mississippi. *J Shellfish Res* 17:425–433
- Peterson CH, Grabowski JH, Powers SP (2003) Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. *Mar Ecol Prog Ser* 264:249–264
- Pianka ER (1966) Latitudinal gradients in species diversity: A review of concepts. *Am Nat* 100:33–46
- Quast WD, Johns MA, Pitts DE Jr, Matlock GC, Clark JE (1988) Texas oyster fishery management plan, Fishery management plan series number 1. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Austin, TX, USA. 178 p
- Ray SM (1987) Salinity requirements of the American oyster, *Crassostrea virginica*. In: Muller AJ, Matthews GA (eds) Freshwater inflow needs of the Matagorda Bay system with focus on the needs of Penaeid Shrimp, NOAA Technical Memorandum NMFS-SEFC:189. NOAA, Silver Spring, MD, USA, pp E1–E28
- Renfro WC, Brusher HA (1982) Seasonal abundance, size distribution, and spawning of three shrimps (*Penaeus aztecus*, *P. setiferus*, and *P. duorarum*) in the northwestern Gulf of

- Mexico, 1961-1962. NOAA Tech Memo NMFS-SEFC-94. NOAA, Silver Spring, MD, USA. 47 p
- Rester JK (2011) SEAMAP environmental and biological atlas of the Gulf of Mexico, 2009. NOAA, Project NA11NMF4350028. NOAA, Silver Spring, MD, USA
- Restrepo VR (1992) A mortality model for a population in which harvested individuals do not necessarily die: The stone crab. *Fish Bull* 90:412–416
- Ricklis RA (1996) The Karankawa Indians of Texas: An ecological study of cultural tradition and change. University of Texas Press, Austin, TX, USA. 222 p
- Ross MR (1997) Fisheries conservation and management. Prentice Hall, Upper Saddle River, NJ, USA. 374 p
- Rossler MA, Jones AC, Munro JL (1969) Larval and postlarval pink shrimp *Penaeus duorarum* in south Florida. In: Mistakidis MN (ed) Proceedings of the world scientific conference on the biology and culture of shrimps and prawns, FAO Fish Rep 57, pp 859–866
- Rothschild BJ, Ault JS, Gouletquer P, Heral M (1994) The decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. *Mar Ecol* 111:29–39
- Rozas L, Minello T (2010) Nekton density patterns in tidal ponds and adjacent wetlands related to pond size and salinity. *Estuar Coasts* 33:652–667
- SEDAR (Southeast Data, Assessment, and Review) (2007) SEDAR 14 stock assessment report: Caribbean Queen Conch. SEDAR Stock Assessment Report 3, North Charleston, SC, USA. 171 p
- Sheridan PF (1992) Comparative habitat utilization by estuarine macro-fauna within the mangrove ecosystem of Rookery Bay, Florida. *Bull Mar Sci* 50:21–39
- Shumway SE (1996) Natural environmental factors. In: Kennedy VS, Newell RIE, Eble AF (eds) The eastern oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, MD, USA, pp 467–513
- Springer S (1951) The Oregon's fishery explorations in the Gulf of Mexico, 1950. *Commer Fish Rev* 13:1–8
- Springer S, Bullis HR (1954) Exploration shrimp fishing in the Gulf of Mexico. Summary report for 1952-54. *Commer Fish Rev* 16:1–16
- Stanley JG, Sellers MA (1986) Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)—American oyster. U.S. Fish Wildlife Service Biological Report 82(11.64), U.S. Army Corps of Engineers Report TR EL-82-4. U.S. Army Corps of Engineers, Vicksburg, MS, USA. 25 p
- Steele P, Bert T (1998) The Florida blue crab fishery. *J Shellfish Res* 17:441–450
- Steele P, Perry HM (1990) The blue crab fishery of the Gulf of Mexico, United States: A regional management plan, Publication number 21. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA
- Stenseth NC, Myserud A, Ottersen G, Hurrell JW, Chan K-S, Lima M (2002) Ecological effects of climate fluctuations. *Science* 297:1292–1296
- Stevely JM (1979) The biology and fishery of the queen conch (*Strombus gigas*); A review. In: Proceedings of the 4th annual tropical and subtropical fisheries technological conference of the Americas, TAMU-SG 80-101. Texas A&M University Sea Grant College Program, College Station, TX, USA pp 203–210
- Stiles ML, Harrould-Kolieb E, Faure R, Ylitalo-Ward H, Hirshfield MF (2007) Deep sea trawl fisheries of the southeast U.S. and Gulf of Mexico: Rock shrimp, royal red shrimp, calico scallops. Oceana, New York, NY, USA. 13 p
- Stuck KC, Perry HM (1981) Observations on the distributions and the seasonality of portunid megalopae in Mississippi coastal waters. *Gulf Res Rep* 7:93–95

- Sutton G, Wagner T (2007) Stock assessment of blue crab (*Callinectes sapidus*) in Texas coastal waters, Management data series 249. Texas Parks and Wildlife Department, Austin, TX, USA. 42 p
- Teal JM (1986) The ecology of regularly flooded salt marshes of New England: A community profile. FWS/OBS-81/01. U.S. Fish and Wildlife Service, Biological Service Program, Washington, DC, USA
- Thomas JL, Zimmerman RJ, Minello TJ (1990) Abundance patterns of juvenile blue crabs (*Callinectes sapidus*) in nursery habitats of two Texas bays. *Bull Mar Sci* 46:115–125
- Tolan JM (2007) El Nino-southern oscillation impacts translated to the watershed scale: estuarine salinity patterns along the Texas Gulf Coast, 1982 to 2004. *Estuar Coast Shelf Sci* 72:247–260
- Trigg C, Perry H, Brehm W (1997) Size and weight relationships for the golden crab, *Chaceon fenneri*, and the red crab, *Chaceon quinque-dens*, from the eastern Gulf of Mexico. *Gulf Res Rep* 9:339–343
- Truitt RV (1939) The blue crab. In: Our water resources and their conservation, Contribution 27. Chesapeake Biological Lab, Solomons, MD, USA, pp 10–38
- Tunnell JW Jr, Chavez RA, Withers K (2007) Coral reefs of the southern Gulf of Mexico. Texas A&M University Press, College Station, TX, USA. 194 p
- Tunnell JW Jr, Andrews J, Barrera NC, Moretzsohn F (2010) Encyclopedia of Texas seashells: Identification, ecology, distribution, and history. Texas A&M University Press, College Station, TX, USA. 512 p
- Turgeon DD, Quinn JF Jr, Bogan AE, Coan EV, Hockberg FG, Lyons WG, Mikkelsen PM, Neves RJ, Roper CFE, Rosenberg G, Roth B, Scheltema A, Thompson FG, Vecchione M, Williams JD (1998) Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks, 2nd edn, Special publication 26. American Fisheries Society, Bethesda, MD, USA. 509 p
- Turgeon DD, Lyons WG, Mikkelsen P, Rosenberg G, Moretzsohn F (2009) Bivalvia (Mollusca) of the Gulf of Mexico. In: Felder DL, Camp DK (eds) Gulf of Mexico origin, waters, and biota, vol 1, Biodiversity. Texas A&M University Press, College Station, TX, USA, pp 711–744
- Turner RE (1977) Intertidal vegetation and commercial yields of penaeid shrimp. *Trans Am Fish Soc* 106:411–416
- Turner RE (1986) Relationship between coastal wetlands, climate, and penaeid shrimp yields. In: Proceedings of the FAO/IOC (IREP (OSLR) workshop on recruitment in coastal demersal stocks, Ciudad del Carmen, Campeche, 21–25 April 1986, IOC workshop report 44—supplement. FOA, Rome, Italy, pp 267–275
- Upton HF (2011) The Deepwater Horizon oil spill and the Gulf of Mexico fishing industry. Service Report for Congress. Congressional Research Service, Washington, DC, USA. 14 p
- VanderKooy SJ (2012) The oyster fishery of the Gulf of Mexico, United States: A fisheries management plan. Gulf States Marine Fisheries Commission, Ocean Springs, MS, USA
- Volety AK, Savarese M, Tolley SG, Arnold WS, Sime P, Goodman P, Chamberlain RH, Doering PH (2009) Eastern oysters (*Crassostrea virginica*) as an indicator for restoration of everglades ecosystems. *Ecol Indic* 9:S120–S136
- Wakida-Kusunoki AT (2005) Seabob shrimp small-scale fishery in southeastern of Mexico. *Gulf Caribb Fish Inst* 56:573–581
- Waller R, Perry H, Trigg C, McBee J, Erdman R, Blake N (1995) Estimates of harvest potential and distribution of the deep sea red crab, *Chaceon quinque-dens*, in the north central Gulf of Mexico. *Gulf Res Rep* 9:75–84

- Wells HW (1961) The fauna of oyster beds, with special reference to the salinity factor. *Ecol Monogr* 31:239–266
- White ME, Wilson EA (1996) Predators, pests, and competitors. In: Kennedy VS, Newell RIE, Eble AF (eds) *The eastern oyster Crassostrea virginica*. Maryland Sea Grant, College Park, MD, USA, pp 559–579
- Williams AB (1984) *Shrimps, lobsters and crabs of the Atlantic Coast*. Smithsonian Institution Press, Washington, DC, USA. 550 p
- Williams AB, Felder DL (1986) Analysis of stone crabs: *Menippe mercenaria* (Say), restricted, and a previously unrecognized species described (Decapoda: Xanthidae). *Proc Biol Soc Wash* 99:517–543
- Withers K (2010) Shells in Texas coastal history. In: Tunnell JW Jr, Andrews J, Barrera NC, Moretzsohn F (eds) *Encyclopedia of Texas seashells: Identification, ecology, distribution, and history*. Texas A&M University Press, College Station, TX, USA, pp 5–20
- Zetina MC, Rios V, Hernandez C, Guevara M, Ortiz E (2002) *Catalogo de especies de pepino de mar comercializables del Estado de Yucatán*. Ediciones de la Universidad Autonoma de Yucatán, Mexico
- Zimmerman RJ, Nance JM (2001) Effects of hypoxia on the shrimp fishery of Texas and Louisiana. In: Rabalais NN, Turner RE (eds) *Coastal hypoxia: Consequences for living resources and ecosystems, coastal and estuarine studies* 58. American Geophysical Union, Washington, DC, USA, pp 293–310
- Zimmerman RJ, Minello TJ, Castiglione MC, Smith DL (1990) Utilization of marsh and assorted habitats along a salinity gradient in Galveston Bay. NOAA Technical Memorandum, NMFS-SEFC-250. NOAA, Silver Spring, MD, USA. 68 p
- Zimmerman RJ, Minello TJ, Rozas LP (2000) Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. In: Weinstein MP, Kreeger DA (eds) *Concepts and controversies in tidal marsh ecology*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 293–314
- Zu Ermgassen PSE, Spalding MD, Blake B, Coen LD, Dumbauld B, Geiger S, Grabowski JH, Grizzle R, Luckenbach M, McGraw K, Rodney W, Ruesink JL, Powers SP, Brumbaugh RD (2012) Historical ecology with real numbers: Past and present extent and biomass of an imperiled estuarine habitat. In: *Proceedings of the Royal Society B* 279:3393–3400 (Biological Sciences), Published online 13 June 2012

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