CHAPTER 1

HABITATS AND BIOTA OF THE GULF OF MEXICO: AN OVERVIEW

C. Herb Ward[1] and John W. Tunnell, Jr.[2]

[1]Rice University, Houston, TX 77005, USA; [2]Texas A&M University-Corpus Christi, Corpus Christi, TX 78412, USA
wardch@rice.edu; wes.tunnell@tamucc.edu

1.1 INTRODUCTION AND OVERVIEW OF CHAPTER TOPICS

The Gulf of Mexico is the ninth largest body of water in the world, and it is recognized as 1 of 64 Large Marine Ecosystems by the U.S. National Oceanic and Atmospheric Administration (NOAA) (Kumpf et al. 1999). Economically and ecologically the Gulf is one of the most productive and important bodies of water (Tunnell 2009; Fautin et al. 2010; NOS/NOAA 2011; Yoskowitz et al. 2013), occupying a surface area of more than 1.5 million square kilometers (km^2) (579,153 square miles [mi^2]), a maximum east–west dimension of 1,573 km (977 mi), and 900 km (559 mi) from north to south between the Mississippi Delta and Yucatán Peninsula. The shoreline, which extends counterclockwise from Cape Sable, Florida, to Cabo Catoche, Quintana Roo, Mexico, is approximately 5,696 km (3,539 mi) long, and it includes another 380 km (236 mi) of Gulf shoreline in Cuba from Cabo San Antonio in the west to Havana in the east (Tunnell 2009; Fautin et al. 2010).

The Gulf of Mexico basin resembles a bowl with a shallow rim around the edges. The shallow continental shelves, generally less than 200 meters (m) (656 feet [ft]), are narrow and terrigenous in the west, moderately broad and terrigenous in the north, and wide carbonate platforms in the east, adjacent to the Florida and Yucatán peninsulas. Approximately 32 % of the Gulf is continental shelf, 41 % is continental slope (200–3,000 m/656–9,843 ft), and 24 % is abyssal plain (more than 3,000 m/9,843 ft). The deepest area (more than 3,800 m/12,467 ft) occurs within the Sigsbee Deep (Darnell and Defenbaugh 1990; Tunnell 2009; Darnell 2015).

Warm, tropical waters enter the Gulf of Mexico from the Caribbean Sea between the Yucatán Peninsula and Cuba via the Yucatán Straits, where it forms the primary Gulf current—the Loop Current. Large eddies occasionally spin off this large current system and move westward (Sturges and Lugo-Fernandez 2005). After penetrating northward into the Gulf, the Loop Current loops eastward and then southward, then exits the Gulf via the Florida Straits between Florida and Cuba, where it forms one of the world's strongest and most important currents—the Gulf Stream.

As a large receiving basin, the Gulf of Mexico receives extensive watershed drainage from five countries (Canada, Cuba, Guatemala, Mexico, and the United States [U.S.]), including over two-thirds of the continental United States. The Mississippi River dominates the drainage systems in the north, and the Grijalva-Usumacinta River System dominates in the south. Thirty-three major river outlets and 207 bays, estuaries, and lagoons are found along the Gulf coastline (Kumpf et al. 1999).

C.H. Ward (ed.), *Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill*,
DOI 10.1007/978-1-4939-3447-8_1

Biologically, shallow waters in the northern Gulf are warm temperate (Carolinian Province); those in the south are tropical (Caribbean Province) (Briggs 1974; Fautin et al. 2010). Oyster reefs and salt marshes are the dominant habitat type in the northern Gulf. Low-salinity estuaries and shallow-water seagrass beds are common in clearer, more saline bays. In the tropical southern Gulf of Mexico, mangrove swamps line bay and lagoon shorelines with oyster reefs, some salt marshes, and seagrasses distributed in similar salinity conditions as the northern Gulf. Along the western Gulf coastline, uniquely wedged between two wet regions, the Laguna Madre of Texas and Tamaulipas exist as the most famous of only five hypersaline lagoons in the world (Tunnell and Judd 2002). This highly productive lagoon has extensive clay dunes, wind-tidal flats, and shallow seagrass beds in a semiarid region. Offshore, coral reefs are common in the Florida Keys, Cuba, and the southern Gulf off the state of Veracruz and on the Campeche Bank (Tunnell et al. 2007). The Flower Garden Banks south of the Texas-Louisiana border represent the only coral reefs in the northern Gulf, but numerous other topographic highs or hard bottoms are found on the normally flat, soft substratum of the continental shelves of the northern Gulf (Rezak and Edwards 1972; Rezak et al. 1985; Ritchie and Keller 2008; Ritchie and Kiene 2012). Unique, recently discovered, and highly diverse habitats in deeper Gulf waters include chemosynthetic communities and communities of deepwater corals (*Lophelia* reefs) (CSA International Inc. 2007; Brooks et al. 2008; Cordes et al. 2008).

The purpose of this book series is to summarize the state of knowledge of the Gulf of Mexico environment, as well as the status and trends of its biota and habitats, before the Deepwater Horizon oil spill. Few books have ever attempted to cover the entire Gulf or most of it (Galtsoff 1954; Gore 1992; Kumpf et al. 1999), although one was released in 2015 (Darnell 2015). Alternatively, some books have covered one particular topic or discipline of the entire Gulf, as in the list below:

- Economy—Cato (2009)
- History—Weddle (1985)
- Ecosystem-based management—Day and Yanez-Arancibia (2013)
- Geology/geological oceanography—Rezak and Henry (1972); Buster and Holmes 2011
- Physical oceanography—Capurro and Reid (1972), Sturges and Lugo-Fernandez (2005)
- Biology—Pequegnat and Chace (1970)
- Shore ecology—Britton and Morton (1989)
- Biodiversity—Felder and Camp (2009)
- Beaches—Davis (2014)
- Sea-level change—Davis (2011)
- Fishes—McEachran and Fechhelm (1998, 2005)
- Marine mammals—Würsig et al. (2000)

Other books have focused on multiple topics within a particular region, such as Caso et al. (2004) and Withers and Nipper (2009) which both focus on the southern Gulf of Mexico.

Thirteen white papers on selected topics of the Gulf of Mexico were commissioned by BP and appear as Chapters 2 through 14 in these volumes. The chapters focus on baseline knowledge of the Gulf of Mexico before the Deepwater Horizon accident on April 20, 2010.

Chapters on water quality, sediment contaminants, and natural oil and gas seepage help define the physical and chemical settings for the diversity of coastal and marine habitats in the Gulf of Mexico. Plankton and benthos systems are analyzed to illustrate energy capture, trophic levels, and food webs. Chapters on status and population trends of shellfish and finfish are followed by an economic analysis of Gulf recreational and commercial fisheries. The final chapters on sea turtles, resident and migratory birds, and marine mammals, as well as fish and other animal diseases, explore threatened and endangered species issues through analysis of the historical and current status of selected indicator species.

All chapters have been written by recognized experts in the subjects covered, and most of the authors have lengthy careers in Gulf of Mexico research and are now known as distinguished, regents, or emeritus professors. Each chapter is well illustrated and referenced. Some chapters have appendices with additional supporting and reference material. Author biographies are provided in the front matter of this volume.

This introductory chapter provides a brief overview of the environmental assessment chapters that follow, stressing key points in each and ending with a conclusions section for all chapters. The reader is referred to the individual chapters for further detail on each topic covered.

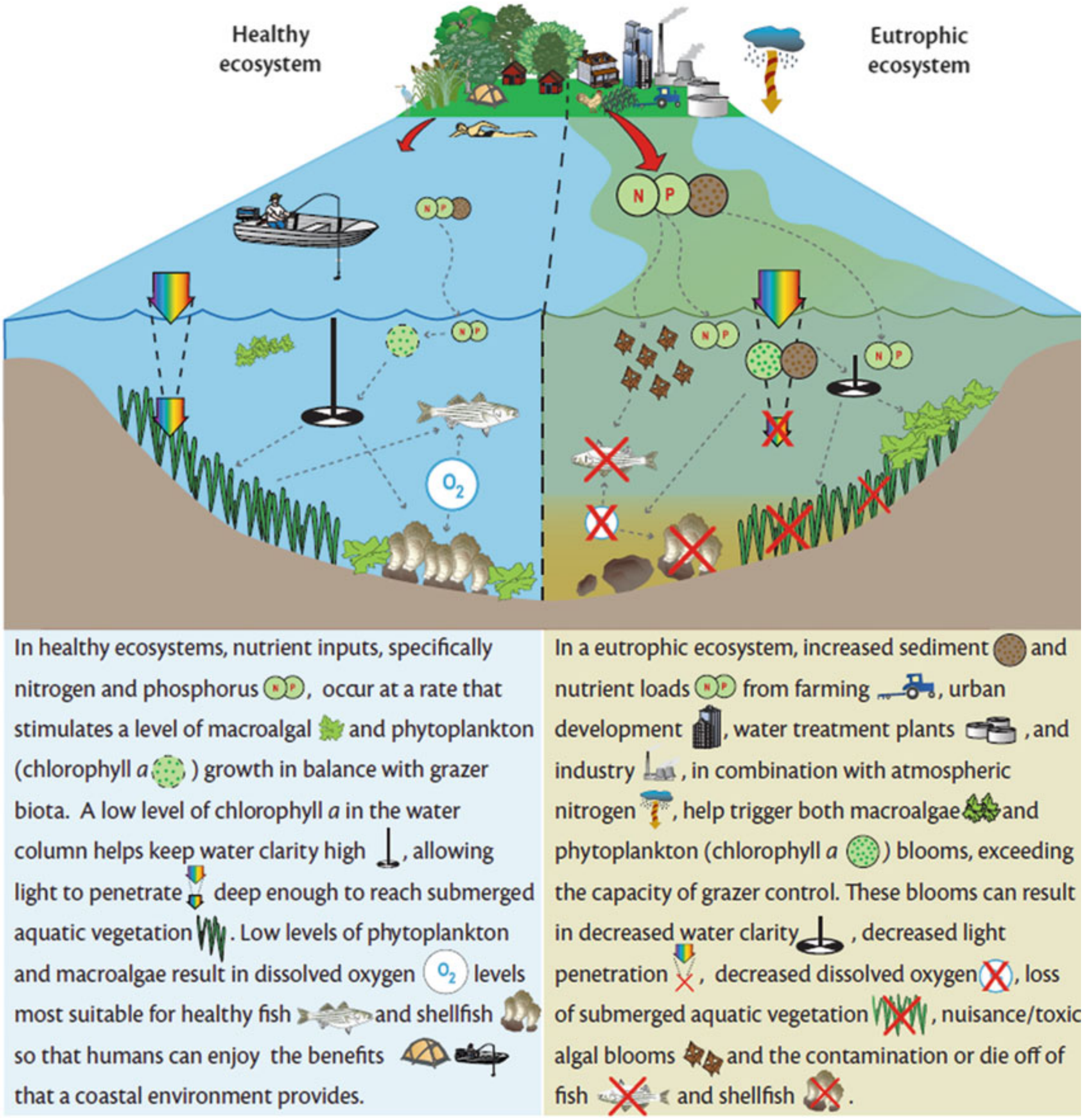
1.2 WATER QUALITY IN THE GULF OF MEXICO (CHAPTER 2)

Water quality is a measure of a water body's suitability for ecosystems and/or human use. Water quality is a vital characteristic that determines how societies and humans use and value aquatic environments and other associated natural resources. Coastal and offshore environments are some of the greatest natural assets in the United States, and much of their value is critically dependent upon good water quality. Coastal, shelf, and deepwater environments are subject to numerous processes, interactions, influences, and stresses, which in turn determine the quality of the water they contain. The determinants, current status, and historical trends in water quality in the northern Gulf of Mexico are reviewed in Chapter 2, which is authored by Mahlon C. Kennicutt II, Professor Emeritus of Chemical Oceanography at Texas A&M University and long-time oceanographic researcher in the Gulf of Mexico.

The information reviewed in Chapter 2 was drawn from periodic summaries of national coastal condition reports prepared by various federal, state, and local agencies and programs. These summaries were reviewed, but the underlying primary data that provided the basis for the reports was not reanalyzed. The assessments involved were produced by a large number of expert government and academic scientists based on a vast amount of data and information from primary sources and the peer-reviewed literature. Within this context, the synthesized data comes from hundreds of sources including national program reports; water quality reporting at the federal, state, and local levels; locally organized monitoring programs; and the published literature. The reports and data collection programs are primarily from the 1990s to the mid-2000s, and they often utilize differing metrics, indicators, and methodologies for assessing and rating water quality. These region-wide assessments in this time period of approximately 20 years are the most relevant and up-to-date means of defining the present day status and trends in water quality in the northern Gulf of Mexico.

Good water quality is a concept derived from a suite of characteristics, so there is no single definition. Two key determinants of water quality in the Gulf of Mexico are physiographic setting and human activities. Several important measures of water quality include water clarity, degree of eutrophication (excessive aquatic plant growth caused by nutrient enrichment), and chemical (petroleum and nonpetroleum pollutants) and biological (pathogens) contamination. Natural and anthropogenic effects on water quality are dynamic on many scales, and this leads to considerable variability in space and time. Impacts on water quality caused by multiple factors can be additive and/or synergistic. Thus, the cumulative effects of natural and anthropogenic influences and processes that ultimately determine overall water quality and the type and mix of components used to define water quality are highly site dependent.

The patterns, current status, and historical trends in water quality in the Gulf of Mexico are complex and variable in both space and time. Assessments performed over the past two decades lead to the conclusion that water quality in most estuaries and coastal environments of the northern Gulf of Mexico is highly influenced by human activities. One of the most prevalent causes of degraded coastal water quality in the northern Gulf is anthropogenic addition of nutrients such as nitrogen and phosphorous, which cause widespread coastal eutrophication. Multiple impacts from eutrophication include lower dissolved oxygen concentrations, increases in chlorophyll *a*, and diminished water clarity, all of which can lead to toxic/nuisance algal blooms and loss of submerged aquatic vegetation (Figure 1.1). Although variable over time,



In healthy ecosystems, nutrient inputs, specifically nitrogen and phosphorus, occur at a rate that stimulates a level of macroalgal and phytoplankton (chlorophyll *a*) growth in balance with grazer biota. A low level of chlorophyll *a* in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of phytoplankton and macroalgae result in dissolved oxygen levels most suitable for healthy fish and shellfish so that humans can enjoy the benefits that a coastal environment provides.

In a eutrophic ecosystem, increased sediment and nutrient loads from farming, urban development, water treatment plants, and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and phytoplankton (chlorophyll *a*) blooms, exceeding the capacity of grazer control. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen, loss of submerged aquatic vegetation, nuisance/toxic algal blooms and the contamination or die off of fish and shellfish.

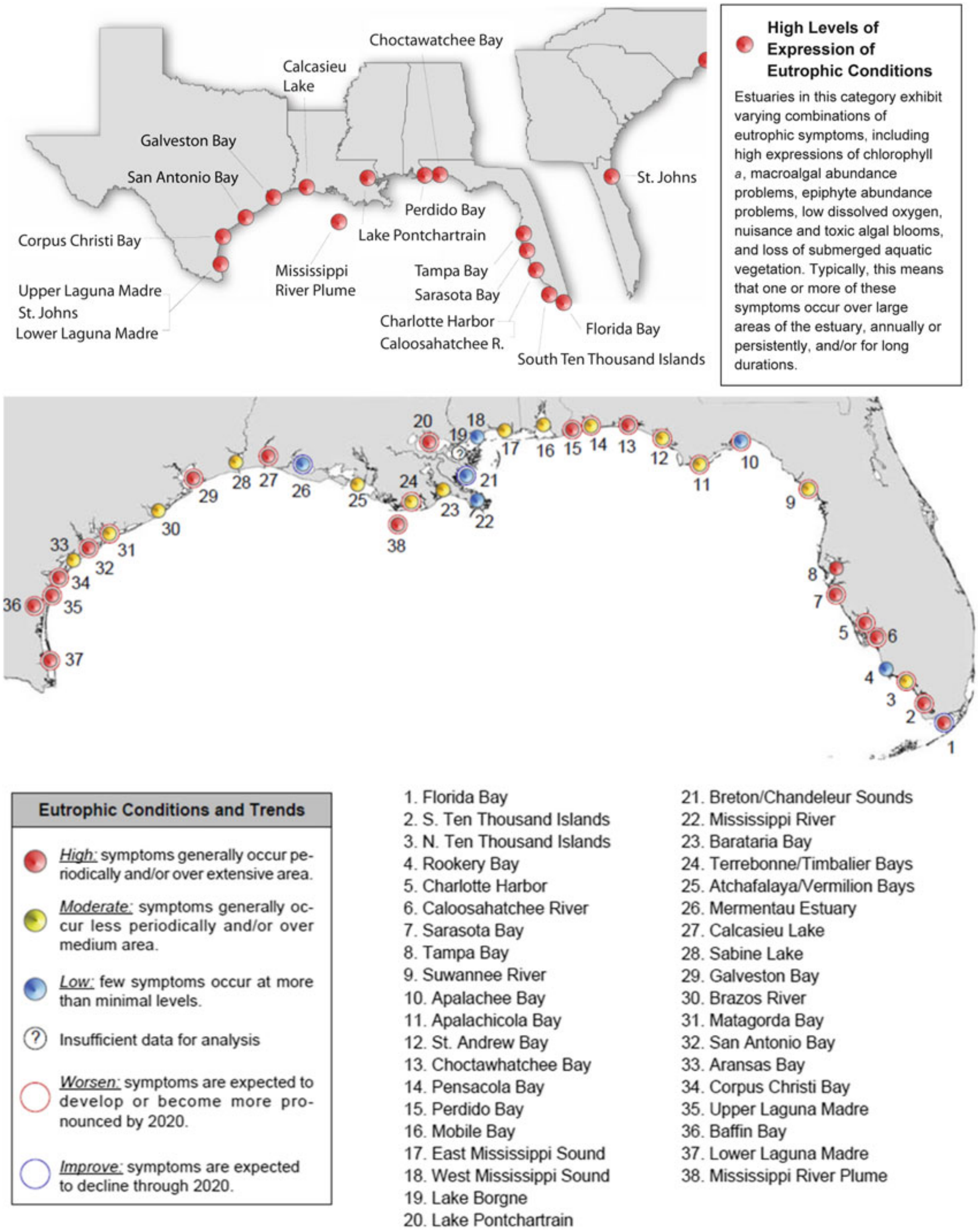
Figure 1.1. Comparison of a healthy system with no or low eutrophication to an unhealthy system exhibiting eutrophic symptoms (Figure 2.6 from Chapter 2 herein; modified from Bricker et al. 2007).

overall ecological conditions in Gulf estuaries were judged as "fair to poor," and assessments consistently concluded that water quality was "fair." At some locations, water quality appeared to be improving because of environmental regulations and controls; in other localities, conditions were continuing to deteriorate.

The current status and historical trends in water quality are highly site specific. Many Gulf of Mexico coastal environments exhibit high levels of eutrophication, and chlorophyll *a* concentrations were high, particularly along the west coast of Florida, in coastal Louisiana, and in lower coastal areas of Texas. Abundance of macroalgae and epiphytes were moderate to high in a number of locations, and low dissolved oxygen concentrations were routinely observed, particularly along coastal Florida and in the Mississippi River Plume. Loss of submerged aquatic vegetation was a consistent problem in many estuaries, and nuisance/toxic algal blooms were pervasive in many, especially in Florida, western Louisiana, and the lower Texas coast. The few improvements observed over time were attributed to better management of point and nonpoint sources of nutrients (e.g., wastewater outfalls and agricultural runoff). The intensity of human activities generally correlates with high eutrophication, although in many instances impairment of use was difficult to directly or solely relate to eutrophication or water quality. In comparing a 1999 assessment to a 2007 assessment, eutrophication conditions had worsened in one system and improved in another. A complete or comprehensive trend analysis was not possible because indicators were not always comparable. In one report, of the 38 Gulf of Mexico estuaries studied, 13 were predicted to develop worsening conditions in the future (Figure 1.2). Main factors expected to influence future trends in water quality were control and mitigation of urban runoff, wastewater treatment, industrial expansion, atmospheric deposition, animal operations, and agriculture activities. No estuaries had conditions that were expected to improve, and worsening conditions were predicted in all systems for which data were available. Trends in human population distributions, increasing development pressures, and human-associated activities were the primary factors used to predict if water quality will worsen in the future.

Direct measurements of chemical pollutants dissolved in marine waters are limited. While chemical contaminants can, and probably do, make limited contributions to water quality degradation, especially in coastal areas where concentrations are highest, impacts are masked by the overwhelmingly dominant factor of eutrophication that degrades water quality. The northwestern Gulf of Mexico has some of the highest average annual inputs of petroleum into North American marine waters, as a result of the high volume of tanker traffic, large numbers of oil and gas platforms, contaminated inflows from the Mississippi River, and the occurrence of natural oil and gas seeps. Indirect indications of possible impacts from chemical contaminants on water quality included the detection of contaminants in biological tissues and sediments. Elevated tissue concentrations of total polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), dieldrin, mercury, cadmium, and toxaphene have been detected in fish tissue. However, contaminants can accumulate in biological tissues via pathways other than uptake from water. Fish consumption advisories due to mercury contamination were reported as common along the northern Gulf of Mexico, and beaches have been routinely closed or under advisories due to elevated levels of bacteria.

Once outside the influence of coastal processes, however, water quality in the Gulf of Mexico is good and has been good for a long time. Exceptions to this are hypoxic zones on the continental shelf caused by nutrient enriched waters flowing from the Mississippi River, waters just above natural oil and gas seeps, as well as localized and ephemeral effects on water quality due to the discharge of produced waters around oil and gas platforms. However, outer continental shelf, slope, and abyssal Gulf of Mexico waters remain mostly unimpaired by



High Levels of Expression of Eutrophic Conditions

Estuaries in this category exhibit varying combinations of eutrophic symptoms, including high expressions of chlorophyll *a*, macroalgal abundance problems, epiphyte abundance problems, low dissolved oxygen, nuisance and toxic algal blooms, and loss of submerged aquatic vegetation. Typically, this means that one or more of these symptoms occur over large areas of the estuary, annually or persistently, and/or for long durations.

Eutrophic Conditions and Trends

🔴 *High:* symptoms generally occur periodically and/or over extensive area.

🟡 *Moderate:* symptoms generally occur less periodically and/or over medium area.

🔵 *Low:* few symptoms occur at more than minimal levels.

? Insufficient data for analysis

○ *Worsen:* symptoms are expected to develop or become more pronounced by 2020.

○ *Improve:* symptoms are expected to decline through 2020.

1. Florida Bay
2. S. Ten Thousand Islands
3. N. Ten Thousand Islands
4. Rookery Bay
5. Charlotte Harbor
6. Caloosahatchee River
7. Sarasota Bay
8. Tampa Bay
9. Suwannee River
10. Apalachee Bay
11. Apalachicola Bay
12. St. Andrew Bay
13. Choctawhatchee Bay
14. Pensacola Bay
15. Perdido Bay
16. Mobile Bay
17. East Mississippi Sound
18. West Mississippi Sound
19. Lake Borgne
20. Lake Pontchartrain
21. Breton/Chandeleur Sounds
22. Mississippi River
23. Barataria Bay
24. Terrebonne/Timbalier Bays
25. Atchafalaya/Vermilion Bays
26. Mermentau Estuary
27. Calcasieu Lake
28. Sabine Lake
29. Galveston Bay
30. Brazos River
31. Matagorda Bay
32. San Antonio Bay
33. Aransas Bay
34. Corpus Christi Bay
35. Upper Laguna Madre
36. Baffin Bay
37. Lower Laguna Madre
38. Mississippi River Plume

Figure 1.2. Level of expression of eutrophic conditions and future trends (Figure 2.8 from Chapter 2 herein; modified from Bricker et al. 1999).

human activities, principally because of the low levels of pollutant discharges and the large volume and mixing rates of receiving waters. Coastal Gulf of Mexico water quality is highly influenced by humans, and this will continue to be true for the foreseeable future. For the most part, future trends in water quality will be dependent on the decisions made by the populations that live, recreate, and work along the northern Gulf of Mexico coast in regard to controlling and/or mitigating those factors that degrade water quality.

Some major conclusions resulting from an extensive review of the available literature and applicable databases on water quality in the Gulf of Mexico include the following:

- Patterns and trends in Gulf of Mexico water quality are highly variable in space and through time. Water quality in Gulf of Mexico coastal environments is highly influenced by human activities, and the primary cause of degraded water quality is excess nutrients. Water quality rapidly improves with distance offshore. More than 60 % of assessed estuaries were either threatened or impaired for human use and/or aquatic life over the time period of this review—from the 1990s to the mid-2000s.
- Eutrophication has produced low dissolved oxygen and increased chlorophyll *a* concentrations, diminished water clarity, and other secondary effects including toxic/nuisance algal blooms and loss of submerged aquatic vegetation. Degraded coastal water quality was also indicated by contaminants in biological tissues and sediments, fish consumption advisories, and beach closing/advisories due to bacterial contamination.
- Gulf of Mexico continental shelf/slope and abyssal water quality was and continues to be good. Exceptions are hypoxic zones on the continental shelf, waters just above natural oil and gas seeps, and ephemeral effects due to produced water discharges during petroleum extraction. Along the northwest/central Gulf of Mexico continental shelf, the seasonal occurrence of waters with low concentrations of oxygen is geographically widespread. These “dead zones” are highly seasonal, and it has been suggested they result from water column stratification driven by weather coupled with Mississippi River outflow that delivers excess nutrients (mostly from agricultural lands) to the offshore region. It has been suggested that anthropogenic changes to the Mississippi River drainage basin and its discharges have increased the frequency and intensity of hypoxic events.

1.3 SEDIMENTS OF THE GULF OF MEXICO (CHAPTER 3)

The Gulf of Mexico is a Mediterranean-type sea with limited fetch and low tidal ranges (microtidal) throughout. The basin is somewhat like a miniature ocean in that it contains all of the main bathymetric provinces of an ocean along with a complicated coastal zone with many estuaries, barrier islands, and other features. Sediments of the Gulf of Mexico basin are the focus or emphasis of this chapter, and discussions are restricted primarily to surface sediments and only to Holocene sediments where subsurface materials are included. Richard A. Davis, who has studied the sediments and coastal geology of the Gulf of Mexico for more than 45 years, is author of this chapter. He is Distinguished Research Professor Emeritus of Coastal Geology and Sedimentology at the University of South Florida, as well as Visiting Research Associate at the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi.

A broad spectrum of depositional environments exists in the Gulf of Mexico from the coast to deep water (Figure 1.3). These sediments and the processes that distribute them vary greatly over these diverse environments. The primary mechanisms that move the sediments are waves, tides, currents, and gravity. With the exception of gravity, weather is a significant influence on all of these processes. Topography also can be a factor in how these processes distribute sediments. Most sediment has its origin from the adjacent land, primarily via fluvial (stream and river) transport. Some sediment is also produced in situ through chemical or biogenic processes. Direct precipitation of calcium carbonate and evaporite minerals takes place

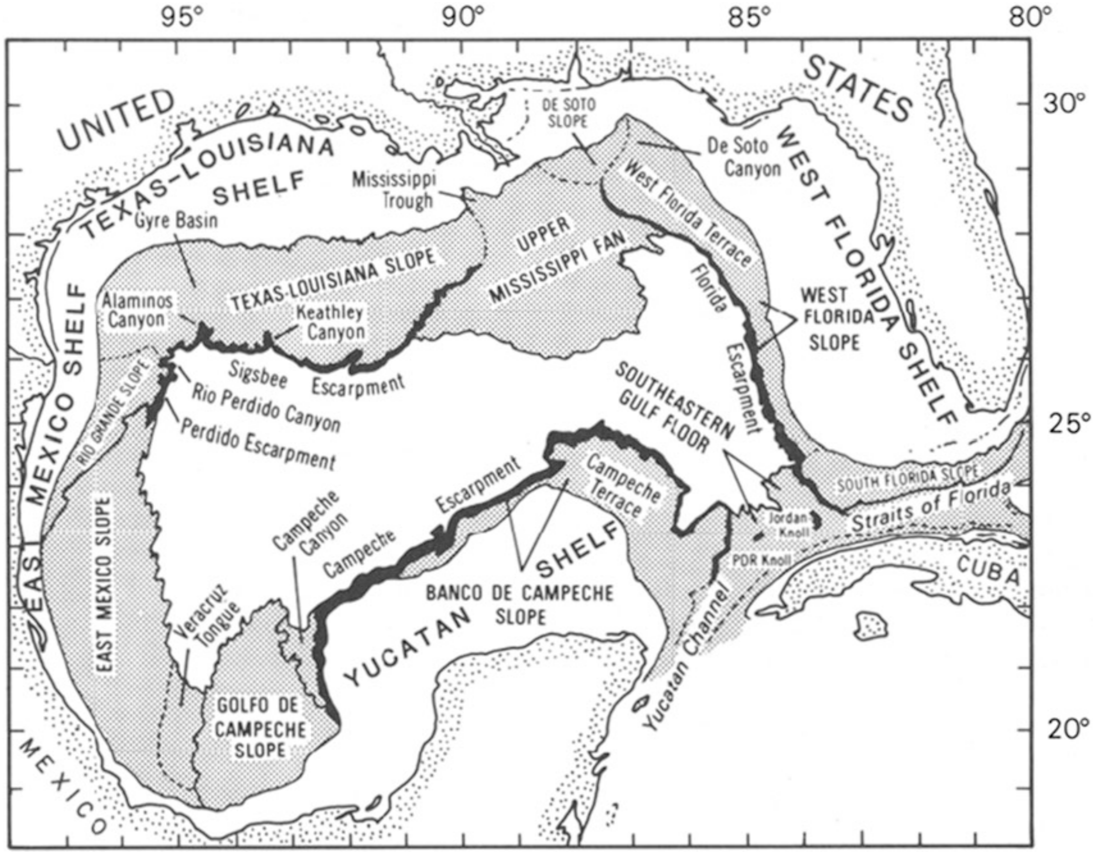


Figure 1.3. Physiographic map showing the major provinces of the Gulf of Mexico (Figure 3.2 from Chapter 3 herein; from Martin and Bouma 1978; AAPG©[1978], reprinted by permission of the AAPG whose permission is required for further use).

primarily on the Florida and Yucatán platforms, or continental shelves, but also in some coastal lagoons. Skeletal debris may comprise most of the modern bottom sediment on these two platforms, but this debris is also widely distributed in a range of varying amounts throughout all Gulf environments.

Deep Gulf environments tend to be dominated by mud in a combination of terrigenous and biogenic sediments. Biogenic components are planktonic and include coccoliths, foraminiferans, diatoms, and radiolarians. Deep terrigenous sediments are delivered by both gravity-driven processes along the continental slope and through the water column. Sedimentary gravity processes dominate the continental slope, where the sediments come to rest as deposits called turbidites. This is also a region of significant topographic relief with the steepest slopes in the Gulf of Mexico. The continental shelf is well known, and it also shows considerable variety. The carbonate platforms are shelf provinces dominated by biogenic debris and low rates of sedimentation. The remainder of the shelf is dominated by terrigenous mud and sand with varying amounts of biogenic debris. The rate of accumulation and the volume of modern sediment on the continental shelf range widely. In general, areas bounded by rivers receive the greatest volume of sediment at the highest rates of delivery. The Mississippi Delta is the extreme of this generality in that it covers almost the entire continental shelf. Some shelf areas, such as those bordering southern Texas and northern Mexico, have received little modern sediment.

Coastal sedimentary environments display the widest variety of sediments and sedimentary processes. Beaches, tidal inlets, tidal flats, wetlands, and estuaries include the full spectrum of sediments, but terrigenous sediments dominate them. The outer barrier island/inlet complexes are comprised of sediments that combine those recently delivered to the coast with the older sediments that have been reworked by rising sea level over the past 18,000 years. Sand dominates this depositional system with waves, tides, and currents being the main processes that deliver and maintain the sediments. Landward of the barrier system, sedimentary environments are much lower in physical energy. In these areas, mud is the dominant sediment texture and biogenic sediment is relatively abundant. Tidal range on the Gulf is low, meaning that tidal currents are minimal except in the inlets. Estuaries tend to be shallow, thus waves can be important in modifying sediment distribution. Sediment delivery is dominated by fluvial discharge so climate and seasons are other important factors.

In summary, the nature and distributions of sediments in the Gulf of Mexico are similar to the ocean basins. There are basically two primary provinces: terrigenous sediments carried from land to the northern and western portions of the basin and carbonate sediments that originate on the Florida and Yucatán platforms. Changes in sea level over the past several thousand years have had a major influence on sediment distributions.

The coastal systems of the Gulf of Mexico contain the most complicated sediment distributions and are dominated by terrigenous sediments. Coastal sediments are composed of mud and sand with biogenic organic debris; sand is dominating in the barrier-inlets systems and mud is the largest sediment component in the estuaries and lagoons.

1.4 SEDIMENT CONTAMINANTS OF THE GULF OF MEXICO (CHAPTER 4)

Sediments are vital components of the health of aquatic environments, but the presence of elevated concentrations of contaminants can degrade sediment quality, thereby adversely affecting organisms and ecosystems and possibly human health. The most widely found chemicals in the sediments of the northern Gulf of Mexico that have the highest likelihood of causing detrimental biological effects include polycyclic aromatic hydrocarbons (PAHs), pesticides, PCBs, and the following metals: lead, mercury, arsenic, cadmium, silver, nickel, tin, chromium, zinc, and copper (Pb, Hg, As, Cd, Ag, Ni, Sn, Cr, Zn, and Cu, respectively). The potential for harmful effects by these chemicals is multifold and includes issues related to toxicological and physicochemical properties, widespread use and release by humans, bioavailability, accumulation in sediments and lipid-rich biological tissues, and persistence in the environment. Contaminants have been released into the Gulf of Mexico for many years, and this continues today by a wide range of human activities, which are most highly concentrated in coastal areas. Accidental or intentional releases of contaminants can be traced to population centers and urban-associated discharges; agricultural practices; industrial, military, and transportation activities; and the exploration for and the production of oil and gas. The sources, current status, and historical trends of sediment contaminants in the northern Gulf of Mexico have been reviewed and summarized in this chapter by Mahlon C. Kennicutt II, Professor Emeritus of Chemical Oceanography at Texas A&M University and long-time Gulf of Mexico oceanographic researcher.

Polycyclic aromatic hydrocarbons and some of the metals have natural, as well as human-related sources. A certain amount of these chemicals ultimately end up in coastal, and to a much lesser extent, offshore sediments. Releases or inputs of these chemicals into the environment are spatially and temporally variable in both composition and concentration. Sediments are integrators of these inputs, as well as the breakdown and removal processes. The mixture of contaminants and their concentrations found in sediments at any given locale are often unique and variable over small spatial scales. Nationally sponsored regional assessments of the Gulf of Mexico are available with detailed information from the mid-1980s to the present, and these have been used extensively in this chapter. In the 1980s, the NOAA National Status and Trends Program observed that the highest concentrations of contaminants in sediments were located close to population centers. In the 1990s, the U.S. Environmental Protection Agency (USEPA) Environmental Monitoring and Assessment Program and Regional Environmental Monitoring and Assessment Program concluded that although measurable concentrations of contaminants were present in almost all estuaries of the northern Gulf of Mexico, less than 25 % of the estuarine area had contaminant concentrations that exceeded concentrations suspected of causing biological effects. USEPA's first National Coastal Condition Report (USEPA 2001) for the 1990s (1990–1997) concluded that overall coastal conditions were fair to poor with 51 % of the estuaries of the northern Gulf of Mexico in good ecological condition showing few signs of degradation due to contamination. Sediment quality at the remaining locations was judged to be poor, and contaminant concentrations exceeded concentrations suspected of causing biological effects at many locations. Most exceedances (exceeding set standards) were for pesticides and metals, while PCB and PAH exceedances occurred at <1 % of the locations. Enrichments in these sediment contaminant concentrations were directly attributed to humans. For the year 2000, the National Coastal Condition Report II (USEPA 2004) concluded that the overall condition of the northern Gulf of Mexico coast was fair. Effects range median (ERM) exceedances occurred mainly in Texas and Mobile Bay, and no exceedances were observed along the Florida Gulf Coast. Pesticides and metals exceeded concentrations suspected of causing biological effects at some locations, but only a few PCB and PAH exceedances were observed. In the National Coastal Condition Report III (USEPA 2008) covering 2001 and 2002, the sediment contaminant index was rated as fair and poor for 1 % and 2 % of coastal area, respectively, indicating that about 97 % of coastal areas had fewer than five chemicals that exceeded sediment concentrations suspected of causing biological effects. Elevated concentrations of pesticides and metals, and occasionally PCB and PAH, were observed in sediments, but only a few of them exceeded concentrations suspected of causing biological effects. In the National Coastal Condition Report IV (USEPA 2012), which covers 2003–2006, the sediment contaminants indicator was rated good, with 2 % and about 3 % of coastal area rated as fair and poor, respectively, indicating about 95 % of the coastal area had fewer than five chemicals that exceeded concentrations suspected of causing biological effects. Elevated concentrations of both metals and pesticides, as well as occasionally PCB and PAH, in sediments were observed, but few of the concentrations exceeded biological effects values. Table 1.1 is a summary of these four reports. Finer scale monitoring in selected bays revealed steep gradients in contaminant concentrations near the shore in close proximity to population centers and industrial complexes. The highest concentrations of contaminants in most coastal sediments were generally restricted to "hot spots" of limited spatial extent associated with unique contaminant sources; however, a few bays contained extensive areas of contaminated sediments.

Contaminant concentrations in sediments quickly decrease with distance offshore. Petroleum hydrocarbons found in continental shelf and slope sediments are almost exclusively due to natural oil and gas seepage. Few releases of petroleum in the offshore region that are attributable to humans reach the underlying sediments. The one exception to this is the discharge of petroleum and metal-contaminated drilling muds and cuttings from offshore oil and gas exploratory platforms. Deposits of contaminated sediments from these discharges are generally restricted to within a few hundred meters of the discharge point, and they usually occur as thin veneers less than a few meters thick, which become diluted with uncontaminated sediments with time due to the action of currents. Considering the immense area of sea bottom in the offshore region, these localized, contaminated sediment deposits are expected to have limited and local-only impact. Contaminant concentrations in these offshore areas are low, and PCBs and pesticides are generally absent. Contaminated sediments close to platforms measured

Table 1.1. Summary of Results from USEPA National Coastal Condition Reports (NCCR) I, II, III, and IV for Percent of Coastal Area Exceeding ERL (effects range low) and ERM (effects range median) Values of Chemicals in Sediments (Table 4.2 from Chapter 4 herein; from USEPA 2001, 2004, 2008, 2012)

NCCR (years of data collection)	Pesticides	Metals	PCB	PAH
I (1990–1997)	43 %	37 %	<1 %	<1 %
II (2000)	12–14 % with one pesticide or PCB exceedances	28 %	12–14 % with one pesticide or PCB exceedances	Rare
	<14 %		≪14 %	<1 %
III (2001–2002)	97 % of coastal with <5 ERL exceedances	97 % of coastal with <5 ERL exceedances	97 % of coastal with <5 ERL exceedances	97 % of coastal with <5 ERL exceedances
	<3 %	<3 %	<<3 %	<3 %
IV (2003–2006) [Note: 1 % of ERM exceedances were for silver in a Florida Bay]	95 % of coastal with <5 ERL exceedances	95 % of coastal with <5 ERL exceedances	95 % of coastal with <5 ERL exceedances	95 % of coastal with <5 ERL exceedances
	<5 %	<5 %	≪5 %	≪5 %
	<1 % exceed ERM	<1 % exceed ERM	<1 % exceed ERM	<1 % exceed ERM
	<2 % with <5 ERL exceedances	<2 % with <5 ERL exceedances	<2 % with <5 ERL exceedances	<2 % with <5 ERL exceedances

over a period of years were similar with a few exceptions, for example increases in Pb concentrations and microbial degradation of petroleum. This is most likely due to the low energy setting and slower rates of removal processes. It can be reasonably expected that offshore areas will remain relatively uncontaminated by chemicals attributable to humans for the foreseeable future.

Chemical contaminants in sediments continue to threaten environment quality in the coastal regions of the northern Gulf of Mexico, but sediment contamination is much less extensive in offshore regions. Elevated concentrations of pesticides and metals in coastal areas are of most concern; however, the mixtures of chemicals and their concentrations can be highly variable in both time and space. In coastal areas, pesticides and metals account for most exceedances of concentrations suspected of causing biological effects, but these exceedances appear to be decreasing with time. Nationally sponsored, region-wide assessments suggest a decrease in contamination of coastal sediments in the northern Gulf of Mexico, but there is a high degree of spatial and temporal variability from location to location. Use of some chemicals has been banned in the United States and/or decreased over time; for example, certain pesticides and sediment concentrations are expected to continue to decline. Continued reductions in emissions and discharges, as well as remediation of contaminated sites, can be expected to accelerate improvements in sediment contaminant levels, thereby reducing the role of sediment contaminants in degrading environmental quality in the northern Gulf of Mexico.

Summary findings on contaminants in Gulf of Mexico sediments resulting from extensive review of relevant literature and government synthesis reports include the following:

- Contaminant concentrations and distributions in Gulf of Mexico sediments are spatially and temporally heterogeneous over small scales due to variations in inputs, sediment deposition and accumulation rates, susceptibility to and rates of removal, chemical form, physicochemical properties, and the physical settings of receiving waters.

- Contaminants are found widely in Gulf of Mexico coastal sediments and coastal estuaries. Coastal sediments were judged to be in good to poor condition with concentrations of metals and pesticides in more than 40 % and concentrations of PAHs and PCBs in less than 1 % of coastal sediments exceeding levels suspected of causing biological effects. Within bay systems, steep gradients in contaminant concentrations were observed near population centers, agricultural activities, and industrial complexes. Contaminant concentrations decrease with distance offshore, since these regions are remote, with few exceptions, from most contaminant inputs. Natural petroleum seepage is the major source of hydrocarbons in northern-central Gulf of Mexico continental shelf/slope sediments.
- In general, levels of pesticides and contaminant metals appear to have decreased with time in coastal sediments in response to water pollution control regulations.

1.5 OIL AND GAS SEEPS IN THE GULF OF MEXICO (CHAPTER 5)

Hydrocarbon seepage is a prevalent, natural worldwide phenomenon that has occurred for millions of years, and it is especially widespread in the deepwater region of the Gulf of Mexico. As one of the most prolific oil and gas basins in the world, the Gulf of Mexico has abundant deep-seated supplies of oil and gas to migrate to the surface. The deepwater region of the Gulf of Mexico is an archetype for oil and gas seepage, and most of our worldwide knowledge of petroleum seeps is based on studies of this region. The essential geological conditions for seepage are met in many areas of the deepwater region of the Gulf of Mexico, including multiple, deeply buried mature source rocks and migration pathways to the surface. The northern Gulf of Mexico basin has been a depocenter for massive amounts of sediments over geologic time, and salt tectonics are prevalent, setting boundaries on the geographic patterns of petroleum seepage. Gulf of Mexico seeps are highly variable in composition and volume and include gases, volatiles, liquids, pitch, asphalt, tars, water, brines, and fluidized sediments.

These seeps occur on land and beneath the ocean, and they are biogenic, thermogenic, or mixed in origin. Oil and gas seeps are well known and widespread in the Gulf of Mexico region, but they are most prevalent in deeper water areas. These seeps release considerable amounts of oil and gas to the environment each year, and they are estimated to account for about 95 % of oil annually discharged to Gulf of Mexico waters. Biogenic gas seeps have a microbial metabolic origin, and microbial methane is pervasive in recent marine sediments throughout the world's oceans, including the Gulf of Mexico. Thermogenic hydrocarbons, on the other hand, rise to the surface from more deeply buried source rock horizons or accumulations. As a prolific petroleum basin, vast amounts of oil and gas have been generated beneath the deepwater of the Gulf Mexico, giving rise to widespread thermogenic seeps, which often comingled with wider spread biogenic gas seepage.

Geological processes control the location and intensity of thermogenic oil and gas seeps. The essential geological conditions that lead to thermogenic petroleum seepage include source rocks and migration pathways to the surface. Deeply buried source rocks underlie the deep waters of the Gulf of Mexico, and salt tectonics has created extensive fractures and faults in these subsurface strata. Buoyant hydrocarbons migrate along geological layers crossing strata via these fractures and faults. The distribution and interactions of these two phenomena control

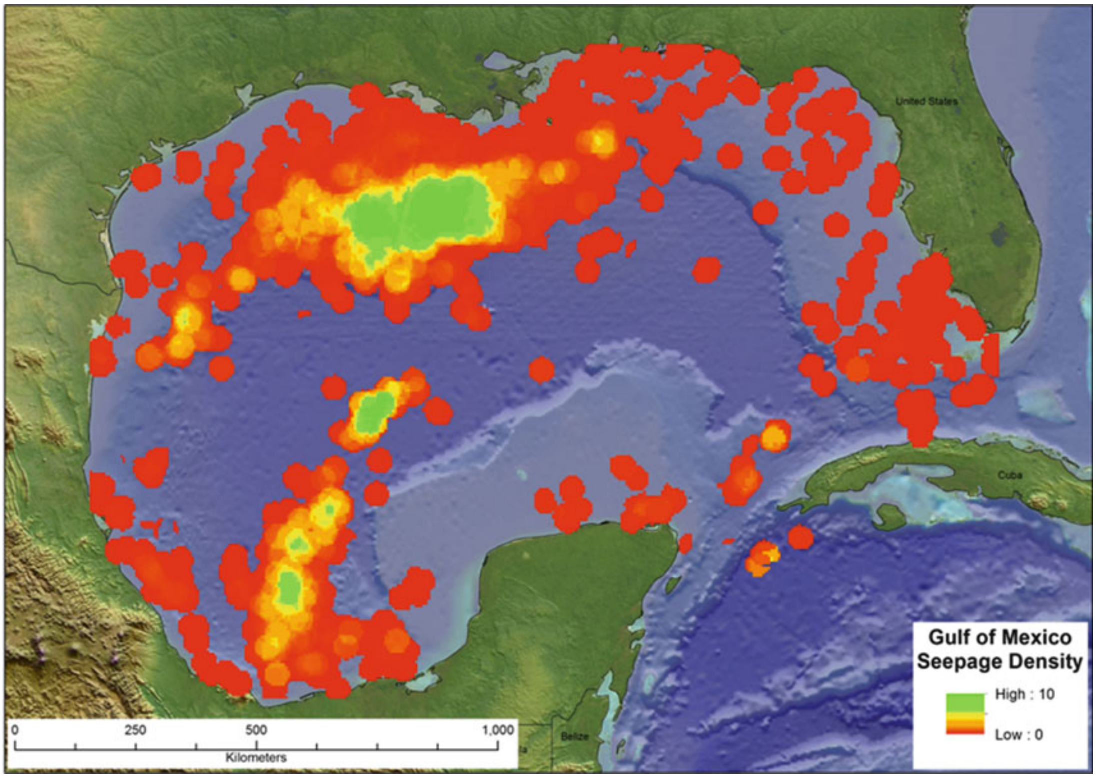


Figure 1.4. Oil and gas seepage in the Gulf of Mexico (determined from analysis of synthetic aperture radar, graphic provided by CGG's NPA Satellite Mapping, used with permission) (Figure 5.42 from Chapter 5 herein).

the amounts and spatial patterns of thermogenic oil and gas seepage with most seeps occurring in the northwestern and central deepwater region of the Gulf of Mexico (Figure 1.4). These seeps are dynamic on various timescales and can be ephemeral or persist for years. All seep compositions, whether on the land or in the sea, reflect the source of gases and liquids and postseepage alteration, or weathering, processes. Some seeps are 100 % methane, while others contain a range of petroleum hydrocarbons. Seeps interact with the surrounding environment and can range from unaltered to severely altered, mostly by microbial degradation. Seep gases can be free, adsorbed to mineral or organic surfaces, and/or entrapped in mineral inclusions.

Phenomena commonly associated with marine petroleum seeps include sea-surface slicks, water-column bubble streams and plumes, elevated hydrocarbon concentrations in sediments, seafloor mounds and pockmarks, and precipitation of authigenic minerals (Figure 1.5). The seepage of oil and gas into marine sediments initiates a complex biogeochemical cycle, and seafloor acoustic properties are altered in areas of seepage due to the presence of gases and fluids, lithification, disruption of sediment layers, and gas hydrate formation and decomposition. Gas hydrates can occur in sediments in water depths below about 500 m (1,640 ft), an upper temperature and pressure boundary for stability.

A unique ecology has evolved in association with oil and gas seeps based on chemosynthesis and symbioses. Assemblages of microbial species mediate the geological and biogeochemical processes that are essential for supporting what are commonly referred to as cold-seep communities. Cold-seep, chemosynthetic communities are common at macroseeps across the northern Gulf of Mexico continental slope, on the abyssal plain, and in the southern reaches of

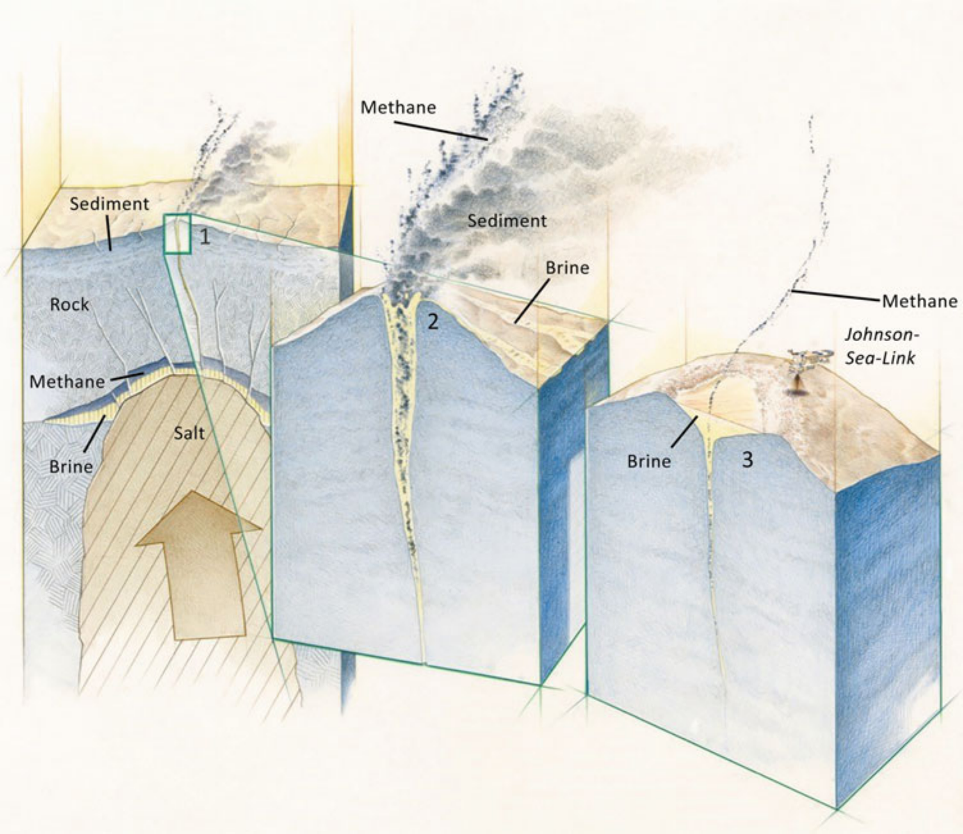


Figure 1.5. **Schematic diagram of a typical marine seep location and associated features: (1) rising pillars of salt (diapirs) fracture the overlying strata creating migration pathways from deep-seated reservoirs to the near-surface; (2) the efflux of gases and fluidscan disrupt and mix with overlying sediments creating seabed mounds and/or craters that are often associated with gas and/or liquid plumes in the overlying water column; and (3) seeping brines that are denser than sea water can accumulate in the depression forming a sea-bottom lake of high salinity water (Figure 5.1 from Chapter 5 herein. MacDonald and Fisher 1996; Bruce Morser/National Geographic Creative, used with permission). *Johnson-Sea-Link* refers to a scientific research submersible (http://oceanexplorer.noaa.gov/technology/subs/sealink/sealink.html).**

the Gulf of Mexico. At these locations, bacteria oxidize hydrocarbons to carbon dioxide or bicarbonate ions, which favor the formation of hard ground substrate in otherwise mostly muddy environments. Other bacteria reduce sulfate ions to hydrogen sulfide, an essential nutrient for many of the free-living and symbiotic bacteria. Common and distinctive macrofauna at these chemosynthetic community sites include tubeworms, mussels, and clams.

The prevalence, persistence, number, and volume of oil and gas seeps in the Gulf of Mexico have created a spectrum of biological, chemical, and physical characteristics that are typical of seep sites. The fluxes of crude oil, gas, and brine seepage vary over time, and therefore, cold-seep community assemblages evolve and can die when seepage abates or ceases. Thermogenic oil and gas seeps and biogenic gas seeps are pervasive and intrinsic features of the Gulf of Mexico, and thermogenic seeps will persist as long as oil and gas continue to migrate to the seafloor. Petroleum seepage in the Gulf of Mexico has occurred for millions of years and is widespread and active today.

1.6 COASTAL HABITATS OF THE GULF OF MEXICO (CHAPTER 6)

Vegetated coastal and marine habitats of the Gulf of Mexico provide a wealth of ecosystem services, such as food, employment, recreation, and natural system maintenance and regulation to the three countries bordering the Gulf: the United States, Mexico, and Cuba. The economic, ecologic, and aesthetic values of these habitats benefit human well-being as illustrated by the desire of humans to live on or near the coast. Ironically, the attraction of coastal shorelines and their varied habitats to people, along with associated demands on the exploitation of natural resources, have led to environmental pressures and degradation, or loss of many vegetated coastal and marine habitats in the Gulf of Mexico. Nevertheless, coastal habitats of the Gulf continue to represent vital components of the Gulf of Mexico ecosystem. This chapter has been written by a team of experts to cover the wide variety of topics included. Irving A. Mendelssohn is Professor Emeritus of Oceanography and Coastal Sciences at Louisiana State University and a coastal ecologist who has studied Louisiana coastal marshes for several decades; Mark R. Byrnes is a coastal oceanographer who specializes in analysis and modeling of coastal and estuarine processes at Applied Coastal Research and Engineering in Mashpee, Massachusetts; Ronald T. Kneib is a population and community ecologist and sole proprietor of RTK Consulting Services based in Hillsboro, New Mexico; and Barry A. Vittor is a wetlands and benthic community ecologist and owner of Barry A. Vittor & Associates in Mobile, Alabama.

The coastal habitats chapter reviews the physical and biological processes that control habitat formation, change, and ecological structure and function. The goal was to provide baseline information by which resource managers and decision makers can better understand and manage these important natural resources. Emphasis has been given to those vegetated marine habitats that occur immediately adjacent to the Gulf of Mexico, including barrier islands and beaches, salt marshes and mangroves, seagrasses, and reed marshes at the mouth of the Mississippi River. Also included are intertidal flats and subtidal soft bottom habitats because of their close spatial association with many of the dominant vegetated habitats.

Diverse coastal depositional systems evolved along the 6,077 km (3,776 mi) land–water interface in response to various patterns in upland drainage; groundwater supply; sediment availability; wind, wave, and current processes; relative sea-level rise; and physiographic characteristics of margin deposits. However, three depositional environments dominate: (1) carbonate deposits in Mexican States of Campeche (east of Laguna de Términos), Yucatán, and Quintana Roo, as well as the northwestern coast of Cuba and the southwestern coast of Florida; (2) terrigenous sediment in the northern Gulf of Mexico; and (3) terrigenous fluvial input along the Tamaulipas, Veracruz, and Tabasco coasts of Mexico, resulting in a mixture of fine-grained terrigenous clastics and carbonate sediment.

Vegetated marine habitats dominate these depositional shorelines, and although qualitatively similar throughout the Gulf, they vary in relative importance depending upon their location. Regional climate, geology, and riverine influence are key drivers of geographical habitat differences. Mangrove habitat is more prevalent in the Southern Gulf of Mexico Ecoregion, as well as the South Florida/Bahamian Atlantic and Greater Antilles Ecoregions, compared with the Northern Gulf of Mexico Ecoregion, where salt marshes dominate (Figure 1.6). Seagrasses occur throughout much of the Gulf, but areal extent is lower in the northern Gulf due to reduced water clarity and salinity associated with major riverine discharges of the Mississippi/Atchafalaya drainage basins. Arid environments resulting from low precipitation and high evapotranspiration in southern Texas-northwestern Mexico and the northern Yucatán generate hypersaline conditions and sedimentary habitats where rooted vegetation is stunted, absent, or replaced by algal assemblages. Such conditions stand in

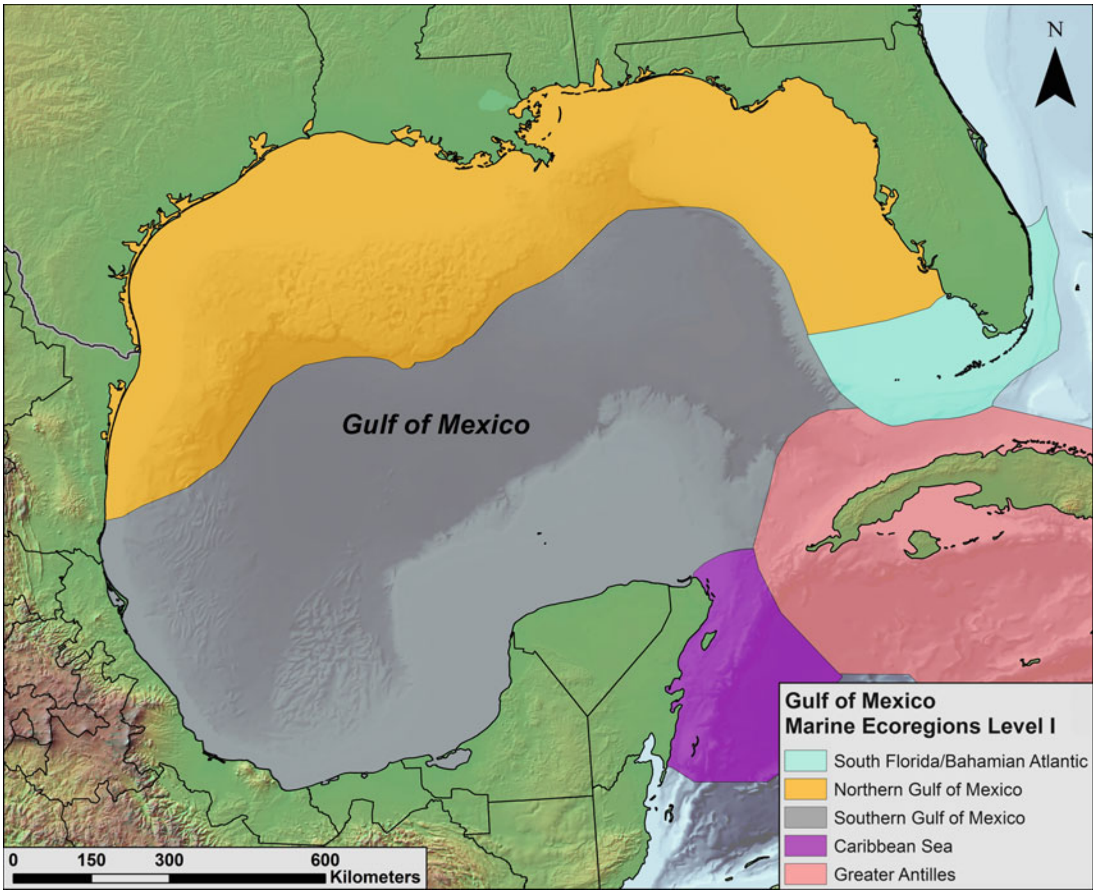


Figure 1.6. Level I marine ecoregions of the Gulf of Mexico (Figure 6.2 from Chapter 6 herein; data from Spalding et al. 2007; Wilkinson et al. 2009; and basemap from CEC 2007; French and Schenk 2005).

contrast to much of the rest of the Gulf of Mexico, where high precipitation and lush vegetated marine habitats occur. Barrier islands and beaches, as well as intertidal flats and subtidal soft bottoms, occur throughout much of the Gulf.

Vegetated habitats throughout the Gulf of Mexico play a key role in providing organic matter essential for the trophic support of coastal faunal assemblages, refugia from predation, and nursery grounds for highly valued fisheries species. For example, macroinvertebrates that live near or on the bottom (epifauna) and within the substrate (infauna) provide an important trophic base for secondary consumers. Macroinvertebrates are distributed primarily on the basis of sediment texture and quality, and vegetative cover type. Most of the numerically dominant epifaunal and infaunal taxa are found throughout the Gulf of Mexico, while others exhibit more limited geographic distributions. Species that are adapted to finer and organic-rich sediments characterize the Mississippi Estuarine and Texas Estuarine Ecoregions, while some species in the Eastern Gulf Neritic Ecoregion and South Florida/Bahamian Atlantic Ecoregion are associated primarily with biogenic sediments on the West Florida Shelf and Campeche Banks in the Southern Gulf of Mexico Ecoregion (Figure 1.7).

Coastal habitat epifauna and infauna, which play an important role in the trophic dynamics of the Gulf of Mexico ecosystems, exhibit a wide range of feeding strategies and are critical to the conversion of vegetative detritus available to higher trophic levels. Few of these taxa are

Figure 1.7. Level III marine ecoregions for the Gulf of Mexico (Figure 6.3 from Chapter 6 herein; data from Wilkinson et al. 2009 and basemap from CEC 2007; French and Schenk, 2005).

migratory as juveniles and adults, but their life histories often include a planktonic larval stage; consequently dispersal and recruitment is limited to the early life stages. Nekton, in contrast, are characterized by their mobility, and so their assemblages in the region's coastal habitats are a subset of the fishes, natant crustaceans, cephalopods, marine reptiles, and marine mammals found along the beaches, bays, lagoons, and tidal channels of the Gulf of Mexico. It is difficult to describe a characteristic nekton assemblage for individual marine habitats because the habitat of many nekton species includes multiple types of coastal wetlands; species richness and abundance are often greatest at the boundaries (i.e., edges) between subtidal (e.g., embayments) and intertidal (e.g., salt marshes) wetland habitats.

Overall, nekton assemblages connect vegetated marine habitats across the coastal landscape of the Gulf by functioning to facilitate significant energy transformations and production transfers among coastal wetland habitats and from estuaries to nearshore coastal marine environments via either diel, tidal and ontogenetic migrations (e.g., penaeid shrimps, gulf menhaden), or size-structured predator–prey interactions.

In summary, coastal habitats have experienced the greatest temporal changes in areas most susceptible to relative sea-level rise, tropical cyclones, and human disturbances. Consequently, the deltaic coast of Louisiana has the most substantial land and habitat changes in the Gulf of Mexico. Conversely, the more stable coasts of the Yucatán Peninsula, Cuba, and southwestern Florida show the least amount of change. Human disturbances are evident in areas of significant industrial activity and tourism. Human impacts are in large part tied to periodic and chronic stressors and disturbances associated with urban, agricultural, and industrial activities. Draining and filling of wetlands for human habitation, agricultural development, and industrial expansion have dramatically impacted coastal habitats throughout the Gulf. Also, overfishing and related activities have threatened important commercial fisheries in some areas of the Gulf. Other stressors such as nutrient enrichment and resulting eutrophication and hypoxia, altered hydrology from multiple causes, invasive species, and chemical pollutants including those associated with energy extraction and production have challenged the health and sustainability of vegetated marine habitats. In addition, natural disturbances driven by hurricanes, underlying geology, and floods and drought are exacerbated by human impacts. Information provided in this review should facilitate effective management and restoration of coastal habitats in the Gulf of Mexico as environmental change continues to alter their structure and function and reshape their associated biotic assemblages.

1.7 OFFSHORE PLANKTON AND BENTHOS OF THE GULF OF MEXICO (CHAPTER 7)

The plankton and benthos of the offshore Gulf of Mexico are reviewed in this chapter because of their importance as food sources for all major groups of larger organisms of economic importance to recreational or commercial fisheries (large invertebrates and finfish), or for the charismatic megafauna (mammals, birds, turtles) that are generally not subject to direct human consumption. The health and status of these groups, which can be defined by their abundance, biomass, diversity, and productivity, regulates the diversity and biomass of the larger organisms in the food web that consume them. In turn, the terminal elements of a food web are not sustainable if their food supplies fail or if their food sources are altered significantly. Finfish, commercially important invertebrates, turtles, birds, and mammals, are covered in other chapters. Gilbert T. Rowe, the author of this chapter, is Regents Professor and former Chair of the Marine Biology Interdisciplinary Degree Program in the Department of Marine Biology at Texas A&M University at Galveston.

This chapter addresses communities or assemblages of organisms in a variety of habitats. These assemblages of organisms can each be defined by their quantitative abundances and biomasses, as well as their biodiversity within volumes of water or sea-surface areas. In addition, and where useful and available, the dominant organisms of these assemblages are listed by their common and scientific names, but comprehensive species lists for these assemblages are not provided, although references in the literature cited contain such lists. The Gulf of Mexico offshore is divided into salient habitats that contain their own suites of organisms. These habitats include (1) continental shelves; (2) deep continental margins and adjacent abyssal plain; (3) methane seeps; and (4) live (hard) bottoms, partitioned according to water depths (e.g., hermatypic coral reefs in the Mexican Exclusive Economic Zone (EEZ), coral banks on salt diapirs [e.g., Flower Gardens Banks National Sanctuary off Texas], Alabama Pinnacles, Florida Middle Ground, Viosca Knolls, and Florida Lithoherms). In addition, some important exceptional habitats within these broader habitats are highlighted (continental shelf hypoxia off Louisiana, large submarine canyons [Mississippi, DeSoto, Campeche], deep iron stone sediments, and asphaltine outcroppings).

Several functional groups of organisms are reviewed: (1) phytoplankton, separated into nearshore (neritic) and open ocean assemblages; (2) zooplankton, also separated into neritic and offshore populations, with somewhat more extensive coverage of the ichthyoplankton because of its potential importance to fisheries; and (3) benthos, divided by size into the microbiota, meiofauna, macrofauna, megafauna, and demersal (near-bottom dwelling) fishes. In each case,

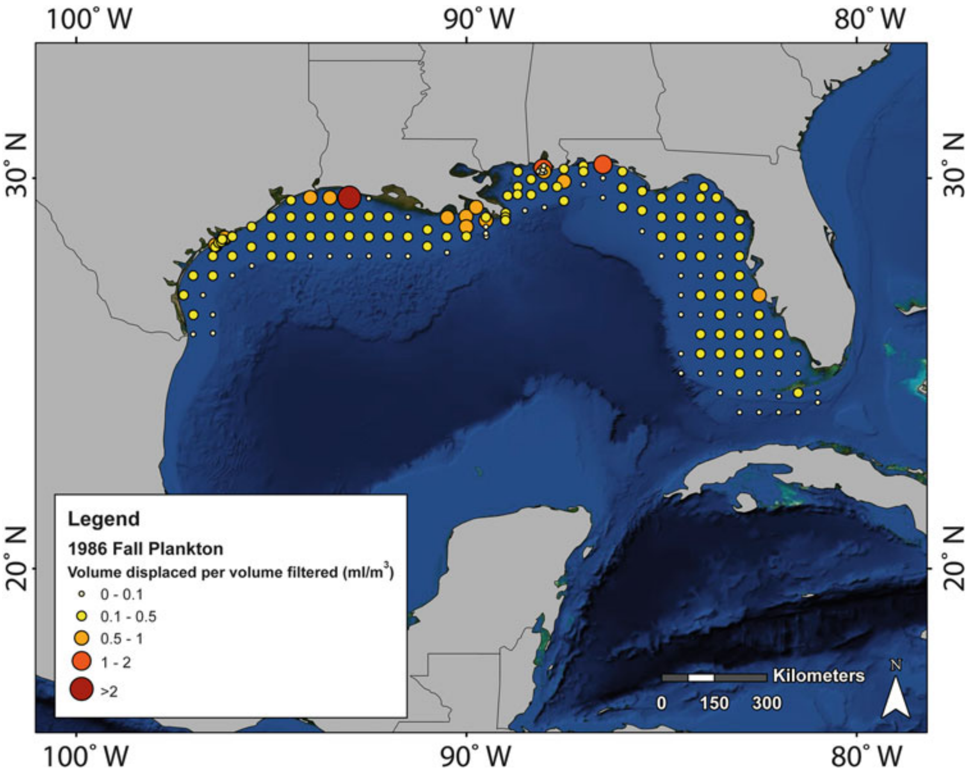


Figure 1.8. Zooplankton displacement volume in SEAMAP samples from fall sampling in the upper 200 m (656 ft) (larger than 330 μm mesh net) (data from the Southeast Area Monitoring and Assessment Program [SEAMAP], http://www.gsmfc.org/seamap.php) (Figure 7.9 from Chapter 7 herein).

brief explanations are given about what biological processes or environmental characteristics of a particular habitat control the distributions of the organisms being summarized.

Several significant generalizations can be concluded, as summarized in the baseline information referred to above. In general, low productivity and biomass of many of the larger habitats indicate that the Gulf is oligotrophic (low plant nutrients) when compared to similar habitats at higher latitudes or to continental margins characterized by tropical or equatorial upwelling. This overall generalization is based on geographically widespread assessments of phytoplankton, zooplankton, and benthic biomass. The offshore plankton and benthos are characterized by exceptional geographic variation in biomass, productivity and diversity that are controlled by physical processes and regional geology. A narrow band of highly productive habitats hug the coast around the entire circumference of the Gulf of Mexico. These biologically rich zones are fertilized regionally by rivers and, to a limited extend, upwelling. This fertilization leads to stressful seasonal hypoxia in a limited area on the continental shelf off Louisiana west of the Mississippi River. The rich nearshore productivity is in stark contrast to offshore habitats that by and large are characterized by low biomass and low productivity because the source water of the open Gulf is the nutrient-depleted Caribbean Sea (Figure 1.8). This offshore water enters the Gulf of Mexico from the Caribbean via the Yucatán Strait. This Caribbean water forms the Loop Current that curls to the right, flows back down the west coast of Florida, and then exits into the North Atlantic via the strait between Cuba and Florida. The Loop Current spins off warm eddies that create a patchwork of warm water bodies of low surface plankton productivity bounded by intermediate habitats of somewhat higher productivity. This mottling of the upper layers of the open ocean affects all levels of the food web hundreds of kilometers from shore across the entire Gulf of Mexico.

Deep benthos, regardless of its size category, declines exponentially as a function of depth and the delivery of detrital organic matter to the seafloor, and the well-established statistical regressions of these declines tend to be below similar biomass estimates on other worldwide continental margins. Likewise, the benthic biomass going down across the continental margin of the northern Gulf appears to be higher than that across the continental margin of the southern Gulf of Mexico. The deep zooplankton and the benthos species composition of the Gulf fall into depth-related zones along the continental margin of the northern Gulf of Mexico. That is, all groups of organisms appear to be zoned into discrete depth intervals, but there is substantial overlap in species composition between zones.

Several important exceptions to the oligotrophic conditions mentioned above are evident. The Louisiana continental shelf west of the Mississippi River Delta is annually subjected to seasonal hypoxia because of excessive nutrient (primarily nitrate) inflow by river water and stratification caused by fresh water. Containing or controlling this harmful and recurring condition is problematic, but improving farming practices to reduce the nitrate loading and diverting the freshwater before it reaches the Gulf of Mexico are possible helpful alternatives. In addition, much of the continental slope of the Gulf is characterized by patches of large chemosynthetic benthic organisms that are sustained by fossil hydrocarbons that seep up to the seafloor from deep deposits within the sediments. While many similar cold-seep communities have now been discovered on continental margins worldwide, the Gulf of Mexico appears to support some of the most prolific that have been described anywhere to date. Clearly, the majority of what is known today about the species composition and the chemistry, as well as physiological modes of existence, of such communities is based on studies conducted in the Gulf of Mexico.

Another exceptional habitat type with high diversity and biomass are several large submarine canyons, which are presumed to support high regional biomass by accumulating or focusing organic detritus. Likewise, such habitats provide physical complexity that enhances species richness. In addition, hard bottoms, sometimes referred to as *live* bottoms, are scattered intermittently across the entire Gulf of Mexico continental margin. These are inherently more difficult to evaluate because quantitative evaluations have to consider their three-dimensional aspects in most cases. The hard bottom also makes sampling difficult for traditional gear. Numerous sessile, large benthic organisms, both plants and animals, are attached to the seafloor in these habitats and provide a diverse physical environment that provides niches for a long list of inhabitants, from small cryptic invertebrates to large finfishes. While diversity and species lists have been compiled for these habitats utilizing cameras and direct observations with self-contained underwater breathing apparatus (SCUBA) in shallow water and submersibles and remotely operated underwater vehicles (ROV) in deeper water, quantifying biomass and rates of processes remains extremely difficult, if not impossible. Therefore, comparisons between such habitats are relative. Shallow topographic highs, or banks, on the continental shelf contain hermatypic corals that depend on light because the corals contain photosynthetic zooxanthellae (microalgae) within their tissues. Many of these banks are important to recreational fisheries, as are the many habitats formed by offshore oil and gas platforms (artificial reefs). Such complex structures are also fascinating destinations for SCUBA divers. An important example of this situation is the Flower Garden Banks natural reefs, which are surrounded by oil and gas platforms (Figure 1.9). At greater depths, such as the Alabama Pinnacles, hard bottoms on seafloor prominences have long provided popular fishing spots, but

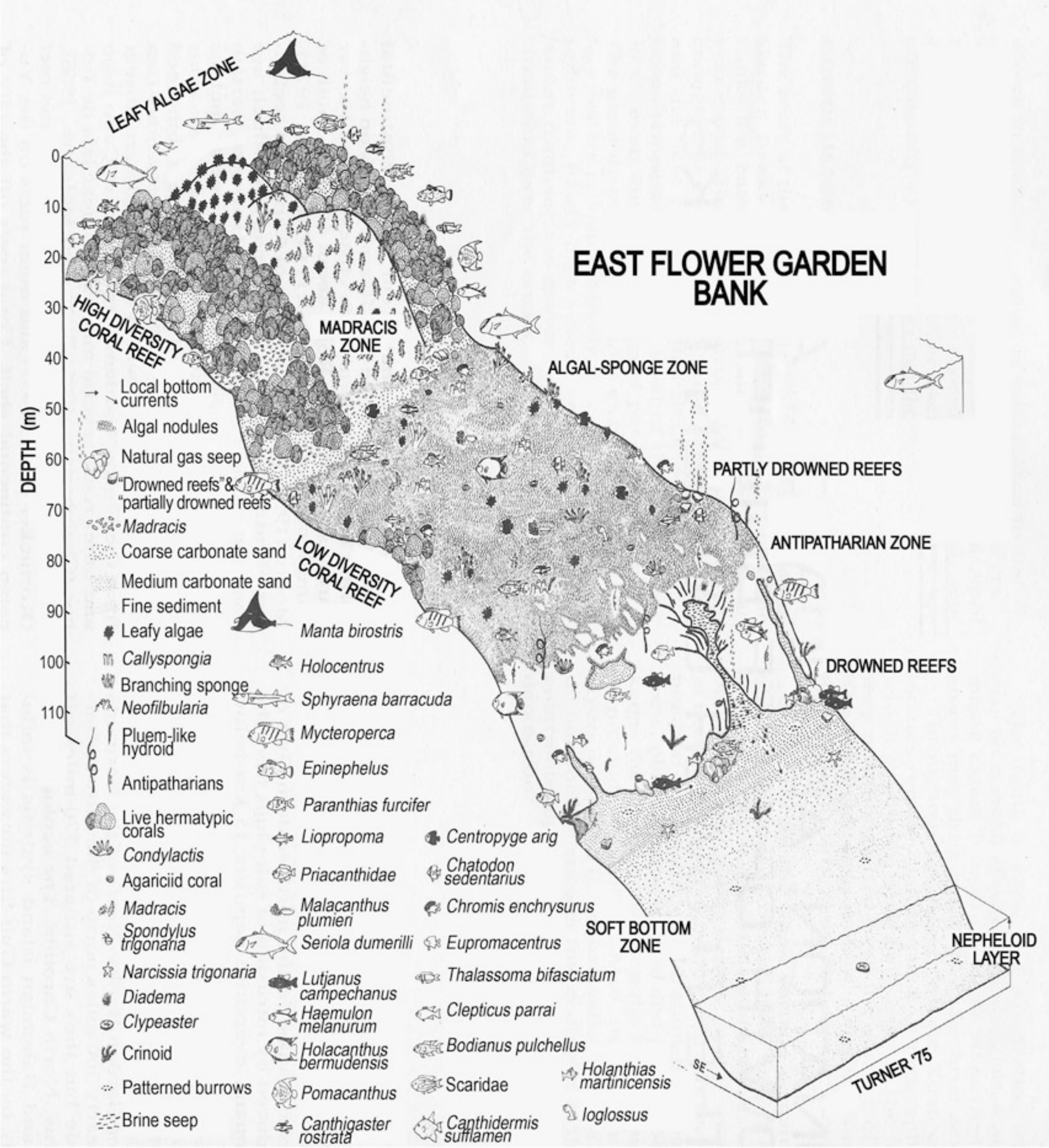


Figure 1.9. Diagram of faunal and floral zonation down the side of the East Flower Garden Bank coral reef on top of a salt diapir on the outer continental shelf off Texas. Note the salt pond and stream on the lower boundary and the bubbles appearing intermittently across the entire depth interval. Copied from Rezak et al. (1985) and based on Bright et al. (1984) (republished from Rezak et al. (1985) with permission of John Wiley and Sons Inc.; permission conveyed through Copyright Clearance Center, Inc.) (Figure 7.54 from Chapter 7 herein).

these are too deep for recreational SCUBA. Little is known about what lives on the steep, unexplored escarpments surrounding the deep Gulf of Mexico central basin.

This chapter on the plankton and benthos of the Gulf of Mexico demonstrates that the principal ecosystem components, at the lower end of the food web (phytoplankton, zooplankton, mid-water fishes, and seafloor organisms) in most habitats are characteristic of an oligotrophic ecosystem. That is, the biota is relatively low in numbers of organisms and biomass when compared to other continental margins such as upwelling regions and in temperate and polar latitudes. The principal cause of this oligotrophic condition is the source water from the Caribbean, which is depleted of nitrate in the surface to about 125 m (410 ft). The penetration of the Loop Current coming up through the Yucatán Channel spins off large, warm anticyclonic (clockwise) eddies that travel westward across the Gulf of Mexico. These features induce a counter flow in the opposite direction, which sometimes includes cyclonic (counterclockwise) eddies. Depending on location, this combination of complicated surface currents can draw nutrient-rich water off the continental shelf and into deep Gulf water, where phytoplankton production can be marginally enhanced offshore. Upwelling zones along the west coast of the Yucatán Peninsula and West Florida are also characterized by some intensification of primary production. Satellites can remotely observe most of these offshore regions of modestly enhanced productivity.

The populations in the offshore plankton represent a near-surface fauna that declines with depth as a *biocline* (the greater the distance from the surface, the more depauperate the biomass). This biocline occurs in the top 100–200 m (328–656 ft), and by a depth of 1 km (0.6 mi), the standing stocks are very limited. All size groups of multicellular organisms decline exponentially as a function of depth and distance from land, so that the abyssal plain supports only a very few seafloor organisms (fishes; zooplankton; mega-, macro-, and meiobenthos). Biodiversity of the macrobenthos follows a different pattern as a function of depth, depending on the taxon studied. In general, there is a mid-depth maximum of the macrofaunal diversity at a depth of about 1.2 km (0.8 mi). In addition, a zonation in diversity across a physical gradient is apparent with increasing depth in macrofauna, megafauna, and fishes, most likely due to the decreasing amount of food sources available. These deepwater oligotrophic (depauperate in biomass) conditions are reflected in low sediment mixing, as well as biodegradation and sediment community biomass and respiration.

The deep continental margin of the Gulf of Mexico has exceptionally complex layers of pelagic and terrigenous sediments overlying thick salt layers that are associated with fossil organic deposits (oil and gas). This oil and gas seeps up to the seafloor where it supports a distinctive and peculiar fauna. The seep-supported assemblages are very old, possibly living upwards of centuries, based on in situ growth rate experiments. Authigenic carbonate deposited at old seep areas provide substrate for deep-living, cold-water corals such as *Lophelia pertusa*, which provide habitat for deep-living demersal fishes, crustaceans, and echinoderms in a narrow depth band at the upper margin of the continental slope in the northeastern Gulf. Since the open Gulf is relatively oligotrophic, these corals would not be expected to be as abundant in the Gulf of Mexico as they are in other more productive basins or at high latitudes.

In summary, potential problems in sustaining the offshore biota (plankton, nekton, and benthos) include climate change, turbidity currents and slumps, eutrophication, oil and gas industry accidents, hypoxia, overfishing, trawling the bottom, and hurricanes. The luxuriant growths associated with topographic highs (reefs and banks) are potentially threatened by all of the above. The establishment of areas such as the Flower Gardens Banks National Sanctuary offers some protection from directly intrusive activities, but it does not provide protection from climate-induced changes that are more global. The thousands of oil and gas industry platforms in the Gulf of Mexico seem to have had a positive effect on biodiversity and fishing, but there is no uniform acceptance of these relationships. Removal of platforms on the other hand is thought to be a threat to thriving recreational fishermen and charter boat operators.

1.8 SHELLFISH OF THE GULF OF MEXICO (CHAPTER 8)

Shellfish species are highly regarded as seafood delicacies of great value. In the Gulf of Mexico, four of the five top species by value and poundage of landings are shellfish species, and therefore, great attention has been focused on their biology and fisheries. Gulf-wide, there are at least 49 officially recognized shellfish species among the three surrounding Gulf countries of the United States, Mexico, and Cuba. Of these 49 species, 28 are mollusks, 18 are crustaceans, and 3 are echinoderms. The greatest diversity of shellfish species is found in the tropical waters of the southern Gulf of Mexico, but the largest abundances and values are found in the temperate northern Gulf. Regarding the three countries surrounding the Gulf of Mexico, 16 shellfish species are taken within U.S. waters, 46 from Mexico, and 6 from Cuba. The main purpose of this chapter is to summarize the status and trends of the five major shellfish species in the northern Gulf of Mexico. The author of this chapter is John W. Tunnell, Jr. who has studied the biology and ecology of Gulf of Mexico marine life for almost 50 years. He is Associate Director and Endowed Chair of Biodiversity and Conservation Science at the Harte Research Institute for Gulf of Mexico Studies, as well as Professor Emeritus, Regent's Professor, and Fulbright Scholar, at Texas A&M University-Corpus Christi.

The waters and species of the Gulf do not recognize political boundaries. 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 first for better understanding of the species and their aquatic habitats. Within this chapter, shellfish species are broken into three separate categories: (1) major (5 species); (2) moderate, but important (6 species); and (3) minor (38 species) (Table 1.2). Although the moderate and minor species are briefly covered Gulf-wide, the major focus is on the northern Gulf species of brown, pink, and white shrimp, Eastern oyster, and blue crab.

Table 1.2. Relative Size and Importance of Gulf of Mexico Shellfish Fisheries (Table 8.3 from Chapter 8 herein)

Species	Country
Major fishery	
1. Eastern oyster	USA, MX
2. Brown shrimp	USA, MX
3. Pink shrimp	USA, MX
4. White shrimp	USA, MX
5. Blue crab	USA, MX
Moderate but important fishery	
1. Queen Conch	USA, MX, CU
2. Yucatán Octopus	MX
3. Mangrove Oyster	MX, CU
4. Atlantic Seabob	USA, MX
5. Spiny Lobster	USA, MX, CU
6. Florida Stone Crab	USA
Minor fishery	
1. Milk Conch	MX
2. West Indian Fighting Conch	MX

(continued)

Table 1.2. (continued)

Species	Country
3. Banded Tulip	MX
4. True Tulip	MX
5. Horse Conch	MX
6. Knobbed Welk	MX
7. Crown Conch	MX
8. West Indian Chank	MX
9. Squids (three species)	USA, 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	USA, 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	USA, MX
23. Royal Red Shrimp	USA
24. Spotted Lobster	MX
25. Swimming Crabs (six species)	MX
26. Gulf Stone Crab	USA, MX
27. Cuban Stone Crab	USA, MX, CU
28. Blue Land Crab	MX, CU
29. Sea Cucumbers (three species)	MX

USA United States, *MX* Mexico, *CU* Cuba

The biology and ecology of each species is presented, as well as its current status and historical trends over the past several decades. All species are known to vary widely or fluctuate in population levels in accordance with varying environmental conditions from year to year. In addition to these natural fluctuations, shrimp harvests also have been affected by exogenous factors, such as rising fuel costs, market competition from imported shrimp, and fleet damage from hurricanes. Overall, the shrimp populations—the most valuable of all Gulf shellfish species—seem to be flourishing, while the shrimp fishery is in decline due to these and other factors (Figure 1.10).

Oysters show the same annual environmental fluctuations, but the fishery appears to be fairly stable overall, except for hurricane damage in some places and a decadal decline in stock assessment in Louisiana (Figure 1.11). The biggest concern with oysters is the continued loss of oyster reef habitat. The blue crab fishery is quite variable from state to state with Louisiana

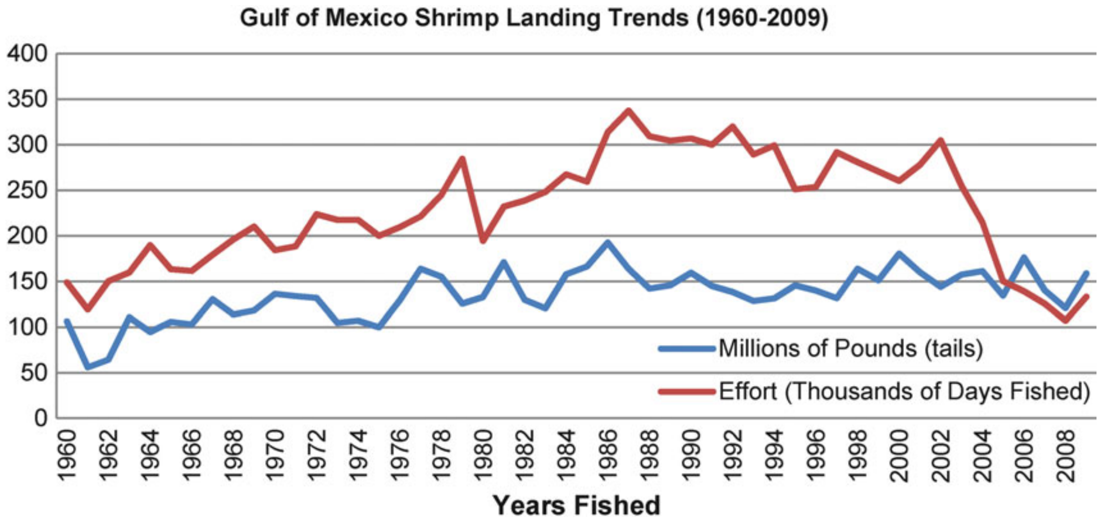


Figure 1.10. Fishery-dependent total Gulf of Mexico (U.S.) shrimp landing trends from 1960 to 2009 using NOAA Fisheries fishery-dependent data (Figure 8.17 from Chapter 8 herein; data from NOAA Fisheries).

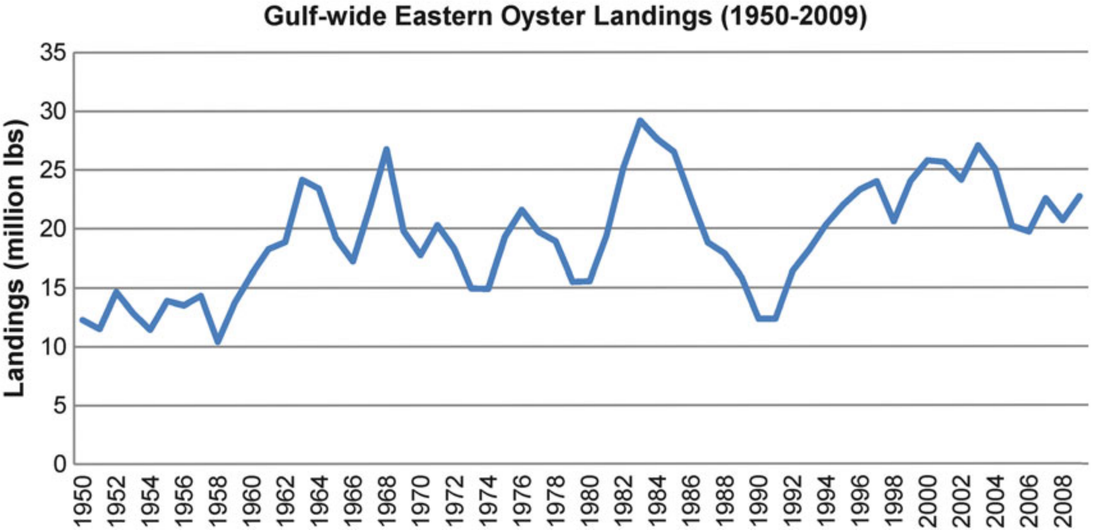


Figure 1.11. Gulf-wide Eastern oyster landings (pounds of meats) from 1950 to 2009 in the northern Gulf of Mexico (Figure 8.37 from Chapter 8 herein; data from NOAA Fisheries).

showing a continued growth; Louisiana has had the largest fishery over the past two decades. Texas shows a decrease in not only the fishery but also in the species populations statewide during the same timeframe. Gulf-wide there is agreement that healthy bays and estuaries lead to more productive fisheries, thus, conservation of some habitats and the restoration of others is needed.

In summary, four of the top five species by value and poundage of landings in the Gulf of Mexico are shellfish species (brown and white shrimp, Eastern oyster, and blue crab), but there are 49 species (28 mollusks, 18 crustaceans, and 3 echinoderms) currently taken as commercial shellfish species in the Gulf of Mexico.

Population trends of shellfish in the Gulf vary widely from year to year, primarily due to environmental fluctuations, but some landings are also influenced annually by exogenous factors (such as market competition from imported shrimp, rising fuel costs, and fleet damage due to hurricanes).

Shrimp populations are flourishing, but the shrimp fishery, the most valuable fishery in the Gulf of Mexico, is in decline due to exogenous factors, especially cheap, imported shrimp. Oyster populations appear fairly stable, but landings in Louisiana have been low for almost a decade compared to the 1990s. Blue crab populations fluctuate widely with Louisiana having the largest fishery and increasing catches.

1.9 FISH RESOURCES OF THE GULF OF MEXICO (CHAPTER 9)*

The Gulf of Mexico, with its unique oceanographic and hydrographic conditions, as well as its geological setting, provides a great diversity of habitats and therefore a dynamic ichthyofaunal community with more than 1,443 finfish species, 51 shark species, and 42 ray/skate species. This chapter evaluates and summarizes the Gulf of Mexico ichthyofaunal community and shark/ray complex, as well as population dynamics of selected key fish species of commercial and recreational importance. General distribution patterns and life history processes of fishes are evaluated, importance and contributions of fishes to the Gulf ecosystem and fisheries are described, and factors contributing to their spatiotemporal dynamics are identified. Fifteen fish species were selected for an in-depth analysis because of their ecological and economic importance and representativeness of the diversity of fish species in the Gulf of Mexico (Table 1.3). This analysis includes their life history processes, trophic levels, population dynamics, habitats, and fisheries (Figure 1.12). In addition, four groups of shark species: (1) coastal large shark complex, (2) coastal small shark complex, (3) pelagic shark complex, and (4) prohibited shark groups, and some important ray species are included in the analysis. This chapter was written by Dr. Yong Chen, Professor of Fisheries Science in the School of Marine Sciences at the University of Maine in Orono and a widely recognized expert on fish stock assessment.

Fish species within the Gulf of Mexico vary greatly in their distribution, life history, and preferred habitat. Most fish species generally use estuaries and inshore shallow waters as their nursery grounds for feeding and for refuge in order to avoid large predators when they are in larval and juvenile stages. Many finfish species spawn offshore, but currents transport their pelagic larvae into inshore shallow waters and estuaries where they spend their early life history stages. Many of the highly migratory finfish and shark species move into the estuaries in the spring to spawn in inshore shallow waters, so their young can utilize the highly productive inshore habitats for feeding and refuge. Water temperature, level of salinity, food availability, life history stage, and avoidance of predators are five of the most important habitat factors influencing the spatiotemporal distribution, recruitment dynamics, and movement of most fish species in the Gulf of Mexico. There are great diversities in the spatiotemporal distribution of different fish species in the Gulf, with some species being ubiquitous, because they are tolerant of large environmental gradients or variations, and other species being more restricted in their distributions because they require more specific types of habitat or narrow ranges of environmental parameters.

---

*Refer Chapter 9–14 are in Volume 2.

Table 1.3. Key Finfish Species of High Commercial and/or Recreational Importance in the Gulf of Mexico, Listed by Habitat (Table 9.3 from Chapter 9 herein)

Habitat	Finfish Species
Benthic	Rock hind grouper (*Epinephelus adscensionis*), Yellowfin grouper (*Mycteroperca venenosa*), Scamp grouper (*Mycteroperca phenax*), Red hind (*Epinephelus guttatus*), Atlantic goliath grouper (*Epinephelus itajara*), Nassau grouper (*Epinephelus striatus*), **Red grouper** (***Epinephelus morio***), Gag grouper (*Mycteroperca microlepis*), Yellowedge grouper (*Hyporthodus flavolimbatus*), Mutton snapper (*Lutjanus analis*), Blackfin snapper (*Lutjanus buccanella*), **Red snapper** (***Lutjanus campechanus***), Lane snapper (*Lutjanus synagris*), Silk snapper (*Lutjanus vivanus*), Yellowtail snapper (*Ocyurus chrysurus*), Vermillion snapper (*Rhomboplites aurorubens*), **Tilefish** (***Lopholatilus chamaeleonticeps***), Blueline snapper (*Lutjanus kasmira*), Golden snapper (*Lutjanus inermis*), **Red drum** (***Sciaenops ocellatus***), Black drum (*Pogonias cromis*), Bluefish (*Pomatomus saltatrix*), Common snook (*Centropomus undecimalis*), Crevalle jack (*Caranx hippos*), Spotted seatrout (*Cynoscion nebulosus*), and **Striped mullet** (***Mugil cephalus***)
Pelagic and highly migratory	Skipjack (*Katsuwonus pelamis*), Albacore (*Thunnus alalunga*), Bigeye (*Thunnus obesus*), **Atlantic bluefin tuna** (***Thunnus thynnus***), Yellowfin tuna (*Thunnus albacores*), Small tunas, **Atlantic blue marlin** (***Makaira nigricans***), White marlin (*Tetrapturus albidus*), **Atlantic sailfish** (***Istiophorus albicans***), and **Atlantic swordfish** (***Xiphias gladius***)
Pelagic	**Dolphinfish** (***Coryphaena hippurus***), Spanish mackerel (*Scomberomorus maculatus*), Cobia (*Rachycentron canadum*), Atlantic thread herring (*Opisthonema oglinum*), **King mackerel** (***Scomberomorus cavalla***), Spanish sardine (*Sardinella aurita*), **Menhaden** (***Brevoortia* spp.**), and **Greater amberjack** (***Seriola dumerili***)

Species *highlighted* were selected for evaluation

Finfish and shark species support important commercial and recreational fisheries, and these are two of the most important industries in the Gulf of Mexico. Gulf fisheries are some of the most productive in the world. Overall, approximately 25 % of U.S. commercial fish landings and 40 % of recreational harvest occur in the Gulf of Mexico. However, a wide variety of long-term anthropogenic and natural stressors, such as rapid coastal development with subsequent degraded water quality and habitat loss, heavy fishing pressure, a large quantity of bycatch in shrimp fisheries, climate change, and natural disasters have negatively impacted the Gulf of Mexico ecosystem and its fishery species. The Gulf receives about 50 % of all U.S. watershed discharge, and there are over 3,100 point source outfalls in the northern Gulf. Pesticides and fertilizers (nutrients) used in the watersheds of the states bordering the Gulf exceed those used in any of the other coastal zones in the United States. During a 1997–2000 assessment, 59 % of the estuarine areas of the Gulf, which are essential nursery and spawning grounds for many finfish and shark species, were considered impaired or threatened. A 2007 study suggested that 78 km^2 (30 mi^2) of coastal wetlands were being lost annually, and that 20–100 % of the seagrass had been destroyed in some areas of the Gulf of Mexico. High fishing mortality in the Gulf, as a result of target fishery and bycatch, reduces stock reproductive potential and impairs the ability of fish stocks to recover from low fish stock abundance. Many fish stocks of high commercial and recreational importance in the Gulf of Mexico were found to be overfished (population level too low) and/or in a state of overfishing (fishing mortality too high) in the 1990s and

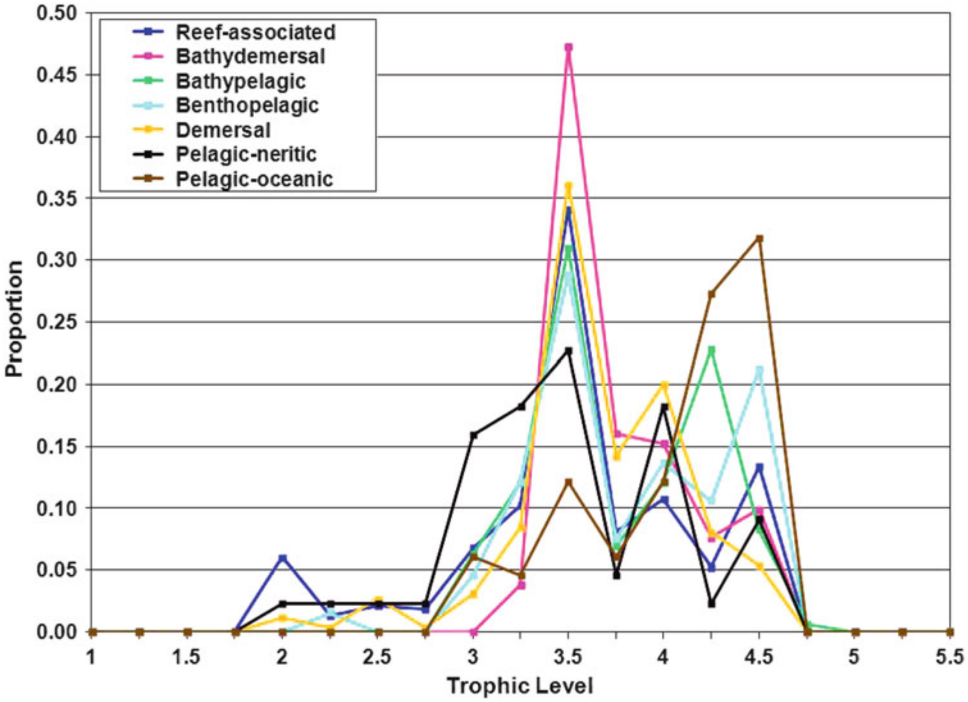


Figure 1.12. The distribution of trophic levels for fish, shark, and ray species of different habitats in the Gulf of Mexico. Trophic level measures the number of steps the fish, shark, or ray is from the start of the food chain: 1 = primary producers that make their own food, such as plants and algae; 2 = primary consumers, such as herbivores consuming primary producers; 3 = secondary consumers, such as carnivores eating herbivores; 4 = tertiary consumers, such as carnivores eating other carnivores; and 5 = apex predators that are at the top of the food chain with no predators (data from FishBase 2013) (Figure 9.2 from Chapter 9 herein).

2000s. These long-term anthropogenic and natural stressors have reduced resilience and robustness of the ichthyofaunal community in the Gulf with respect to human and natural perturbations. Management regulations recently adopted in the fisheries industry, to limit fishing efforts and bycatch in the shrimp fishery, appear to have worked for some finfish species by reducing the number of overfished fish populations and the frequency of occurrence of overfishing in the Gulf of Mexico. Summary findings include the following:

- No formal stock assessments were done for the vast majority of fish species in the Gulf of Mexico immediately prior to the Deepwater Horizon oil spill.
- Of the 15 finfish species evaluated in this chapter, 5 species were being overfished and/or were in the status of overfishing in 2010, including red snapper, red grouper (some local subpopulations), Atlantic bluefin tuna, Atlantic blue marlin, and greater amberjack.
- Of 39 shark species included in the shark Fisheries Management Plan in the Gulf of Mexico, 19 species have been listed as commercially and recreationally prohibited species because of very low population biomass and poor stock conditions.
- Finfish species evaluated in this study that were determined not overfished in the Gulf of Mexico immediately before the Deepwater Horizon oil spill included menhaden, Atlantic swordfish, Atlantic sailfish, red drum, striped mullet, tilefish, king mackerel, Gulf flounder, and dolphinfish.

1.10 COMMERCIAL AND RECREATIONAL FISHERIES OF THE GULF OF MEXICO (CHAPTER 10)

Given its diversity of species, the Gulf of Mexico offers opportunities to both commercial and recreational fishermen. The objective of this chapter is to provide a systematic examination of the commercial and recreational fishing sectors of the Gulf of Mexico, focusing on a variety of topics. The coauthors of this chapter are Walter R. Keithly and Kenneth J. Roberts of Louisiana State University (LSU). Keithly is Associate Professor in the Center for Natural Resource Economics and Policy, Department of Agricultural Economics, and Roberts is Associate Vice Chancellor Emeritus of the LSU Ag Center.

Commercial fisheries are generally described and reported by either landings in weight or value in dollars. Aggregate finfish and shellfish landings attributed to the U.S. Gulf states fluctuate, but the ranking of the states does not change much from year to year (Figure 1.13). Louisiana ranks first due to landings in the five major species (menhaden, brown and white shrimp, blue crab, and oysters).

When examined at the state level, the dockside value of all landings is mostly concentrated in Louisiana and Texas, with shares of 43 % and 26 %, respectively (Figure 1.14). Economic impacts include sales, income, and value added, originating from both landings and imports (Figure 1.15).

With respect to the commercial sector, some of the topics considered in this chapter include trends in production of various species, the value of production associated with these various species, the impact of imports on dockside prices, and processing. Overall, long-term landings of most key commercial species (menhaden, shrimp, blue crab, and oyster) appear to be stable, and recognized changes, where noted, appear to be tied to regulations to manage fish stocks. This is particularly true with respect to finfish stocks. Of all the commercial fisheries examined, the shrimp fishery faces the greatest obstacles in terms of long-term viability. The increasing volume of imports has led to a significant decline in the price that shrimpers receive for the harvested product, and in turn, a reduction in profitability. This reduction has led to a substantial downsizing of the shrimp fishing industry with current effort in the fishery

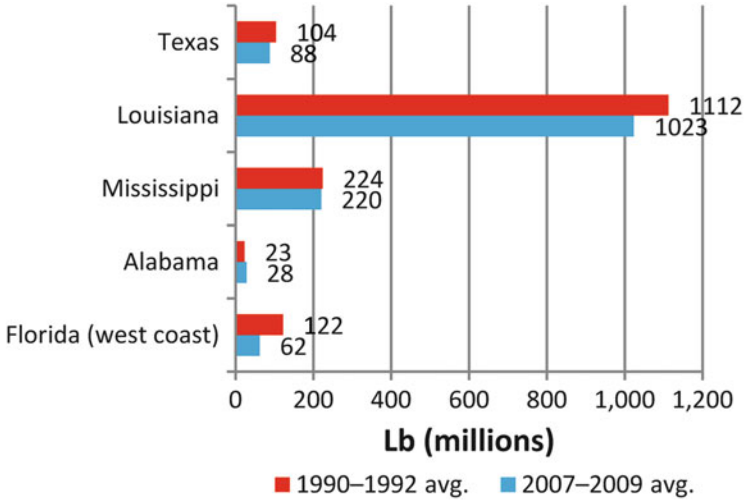


Figure 1.13. Average annual landings by state, 1990–1992 and 2007–2009 (1 lb is equal to 0.454 kg) (Figure 10.6 from Chapter 10 herein; data source from personal communication with National Marine Fisheries Service (NMFS), Fisheries Statistics Division).

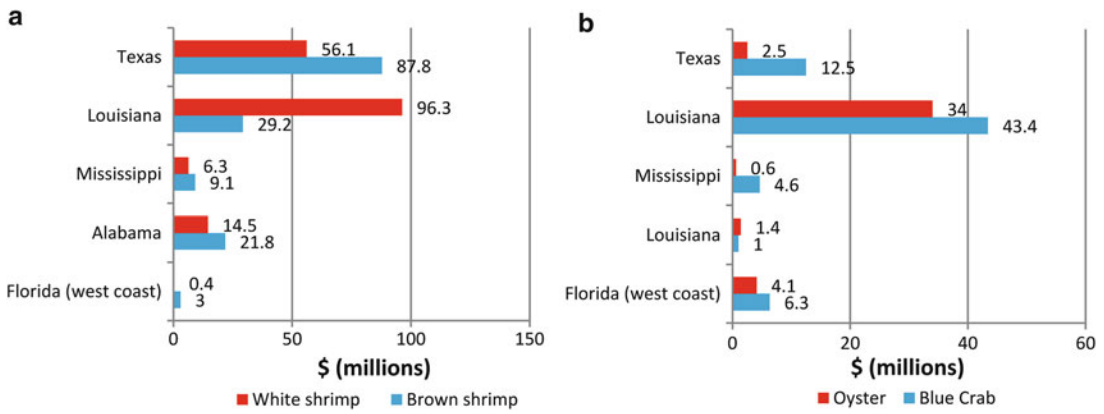


Figure 1.14. Value of commercial landings by state and species (shrimp, *left panel*; oysters and blue crab, *right panel*), 2007–2009 average (Figure 10.9 from Chapter 10 herein; data source from personal communication with NMFS, Fisheries Statistics Division).

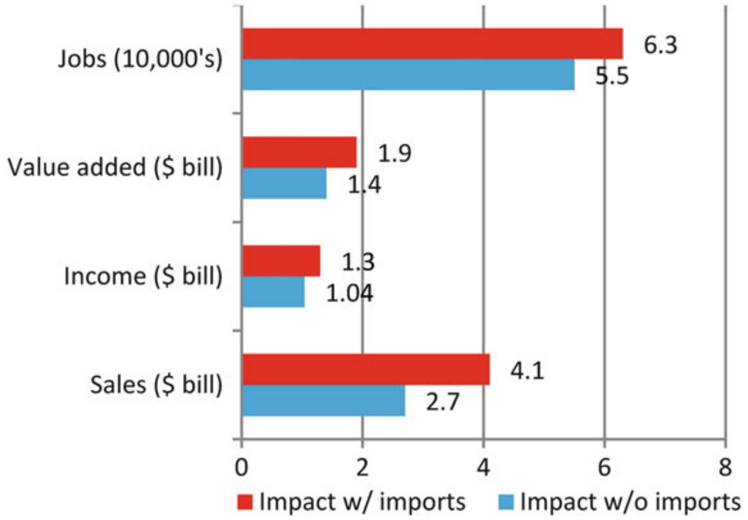


Figure 1.15. Gulf of Mexico commercial seafood industry economic impact, 2009 (Figure 10.10 from Chapter 10 herein; data source, U.S. Department of Commerce 2011).

(measured in days fished) being only a fraction of what it was in the 1990s. This statement applies to both the brown and white shrimp, the two species of prime relevance in the northern Gulf of Mexico.

Like the harvesting sector, the increasing import base also has impacted the Gulf shrimp-processing sector. A steadily eroding marketing margin and, presumably, profit has culminated in consolidation of this sector, and the remaining firms are increasing output in an attempt to counterbalance the declining marketing margin per unit of output.

Direct jobs in the harvesting sector generate jobs elsewhere in the economy via companies that supply inputs and those adding value to the harvest product, which is ultimately, in turn, used by the consumer. In four of the five U.S. Gulf states considered in this analysis (Florida was excluded because the west coast data could not be differentiated from the east coast), seafood industry jobs averaged 92,000 annually from 2007 to 2009. However, the four-state employment fell from 109,000 in 2007 to 63,000 in 2009. Income impacts for the four states equaled $2.1 billion in 2009, and that represented a decline when compared to 2007.

Regarding the recreational sector, topics considered in this chapter include expenditures and impact, angler participation, trips, and catch and harvest. The analysis was based almost exclusively on Marine Recreational Information Program statistics, the new name for Marine Recreational Fisheries Statistics Survey (MRIP/MRFSS), the most continuous and long-term monitoring program on recreational fishing patterns available. Texas opted out of this program and, therefore, is largely excluded from this report with the exception of expenditures and impacts. At the top end in terms of economic impacts, about 42,000 jobs were generated in Florida in response to recreational fishing activities, with an associated $2.4 billion in income. On the bottom end, about 3,200 jobs were generated in Mississippi, with an associated income of $162 million. Louisiana was in the middle of these numbers, with the generation of almost 20,000 jobs and almost $1.0 billion in additional income. Table 1.4 shows the economic impact associated with Gulf of Mexico angling activities from 2006 to 2009.

Overall, marine recreational fishing participation in three of the four states increased significantly from the mid-1990s, with Mississippi being the sole exception. While fishing participation increased substantially, much of the growth occurred prior to the mid-2000s. It is likely that the combination of high fuel prices in recent years, along with the downturn in the economy, negatively influenced both participation and the number of trips.

While the MRFSS/MRIP represents the primary data source for tracking participation over time, state-issued marine fishing license sales also can be used to track changes, but this is subject to a number of caveats. A comparison between MRFSS/MRIP participation estimates and license sales for both Louisiana and Mississippi was prepared to determine whether license sales track with MRFSS/MRIP estimates in a reasonable manner. Disturbingly, some significant differences were noted with the MRFSS/MRIP estimates, which exceeded license sales by a large margin. While there are explanations for these observed differences (for example, a license is not required for saltwater fishing in Louisiana for those under the age of 16), the differences are large enough to justify further examination of the MRFSS/MRIP participation data.

The number of Gulf angler trips (excluding Texas) increased from about 17 million annually during the decade of the 1990s to 23 million annually during the 2000s, with a sharp increase in the number of angler trips beginning in 2000. The explanation for this sharp increase in the number of angler trips is open to speculation, but it does coincide with a sharp increase in the number of nonresident participants in Florida. Florida accounted for approximately 70 % of total Gulf trips during the analysis period, and about one-half of those trips were in inland waters. Louisiana accounted for another 17 % of the total, and about 85 % of the Louisiana-based trips were taken in inland waters.

Given that the vast majority of Louisiana's fishing activities take place in inshore waters, it comes as no surprise that targeting behavior and catch are also largely associated with those species utilizing inshore habitat, and the two primary species include red drum and spotted seatrout. Fully 50 % of all Louisiana-based angling trips target spotted seatrout, and with the catch averaging about 20 million fish per year, Louisiana accounts for about 60 % of the Gulf's total spotted seatrout catch, in terms of numbers of fish. Similarly, Louisiana accounts for about 80 % of the U.S. Gulf of Mexico red drum harvest, in terms of pounds.

While there is considerable red drum and spotted seatrout catch in Florida waters, the state can also lay claim to a large offshore fishery component, where reef fish are generally the target.

In summary, given its diversity of species, the Gulf of Mexico offers ample opportunities to both commercial and recreational fishermen. Both of these sectors generate considerable

Table 1.4. Economic Impacts Associated with Gulf of Mexico Angling Activities, 2006–2009 (Table 10.5 from Chapter 10 herein; Data Source from U.S. Department of Commerce 2011)

Location	Jobs	Sales ($1000 s)	Value Added ($1000 s)	Income ($1000 s)
2006				
Florida (West Coast)	75,257	7,823,752	4,235,087	NA
Alabama	6,572	630,181	325,523	NA
Mississippi	3,731	490,501	189,450	NA
Louisiana	26,612	2,382,034	1,199,333	NA
Texas	34,175	4,197,011	2,154,891	NA
Total	**146,347**	**15,523,479**	**8,104,284**	**NA**
2007				
Florida (West Coast)	65,799	6,829,434	3,704,818	NA
Alabama	6,759	654,353	337,493	NA
Mississippi	4,707	616,930	239,021	NA
Louisiana	27,446	2,453,392	1,234,449	NA
Texas	23,382	3,004,862	1,514,791	NA
Total[a]	**128,093**	**13,558,971**	**7,030,572**	**NA**
2008				
Florida (West Coast)	54,589	5,650,068	3,075,710	NA
Alabama	4,719	455,093	235,481	NA
Mississippi	2,930	382,778	148,837	NA
Louisiana	25,590	2,297,078	1,156,796	NA
Texas	25,544	3,288,135	1,656,545	NA
Total[a]	**113,372**	**12,073,152**	**6,273,369**	**NA**
2009				
Florida (West Coast)	42,314	4,369,022	1,532,821	2,385,738
Alabama	4,924	474,746	155,663	245,437
Mississippi	3,188	417,080	105,472	162,099
Louisiana	19,688	1,774,692	578,767	894,123
Texas	22,127	2,846,858	910,011	1,434,733
Total[a]	**92,241**	**9,900,398**	**3,282,734**	**5,122,130**

[a] The "total" figures should be considered a minimum since they do not account for any trade among individual Gulf States (estimated by authors)

Note: NA not available. *Source*: U.S. Department of Commerce (various issues) (available at: http://www.st.nmfs.noaa.gov/st5/publication/fisheries_economics_2009.html) economic impacts locally, within each of the Gulf States, and throughout the entire nation. In general, commercial landings of most primary species appear to be stable and cases of instability, where observed, tend to be tied to regulations created to manage fish stocks. However, the largest component of the commercial fishing sector—the shrimp fishery—is confronted with obstacles to long-run viability, with the primary obstacle being increasing imports. Increasing imports have led to a decline in dockside price and a concomitant downsizing of the industry.

In the recreational sector, the number of Gulf angler trips (excluding Texas) increased from an estimated 17 million annually during the decade of the 1990s to 23 million annually during the most recent decade. About 70 % of total Gulf recreational trips were based in Florida (west coast); Louisiana accounted for 17 % of total recreational fishing activity. An estimated 92 thousand jobs (including Texas) were generated as a result of Gulf recreational fishing in 2009, with generated income totaling about $5.1 billion.

1.11 SEA TURTLES OF THE GULF OF MEXICO (CHAPTER 11)

The Gulf of Mexico provides important sea turtle nesting habitat, oceanic habitat for juvenile sea turtle growth and development, critical foraging habitat for juvenile and adult sea turtles, and important mating and inter-nesting habitat for adults. Five species of sea turtles are found in the Gulf of Mexico, including the Kemp's ridley, loggerhead, green, leatherback, and hawksbill. Available nesting, distribution, abundance, and habitat use information is summarized in this chapter to characterize the distribution and abundance of sea turtles in the Gulf prior to the Deepwater Horizon event. Life history information is also summarized for each species of sea turtle, and Gulf-of-Mexico-specific data are presented, when available (Figure 1.16). Roldán A. Valverde, Dyson Endowed Professor at Southeastern Louisiana University and Kym Rouse Holzwart, formerly a Certified Senior Ecologist with ENVIRON International Corporation (now Ramboll Environ, Inc.), have written this chapter. Ms. Holzwart is now an Environmental Scientist with the Hillsborough County Conservation and Environmental Lands Management Department in Central Florida.

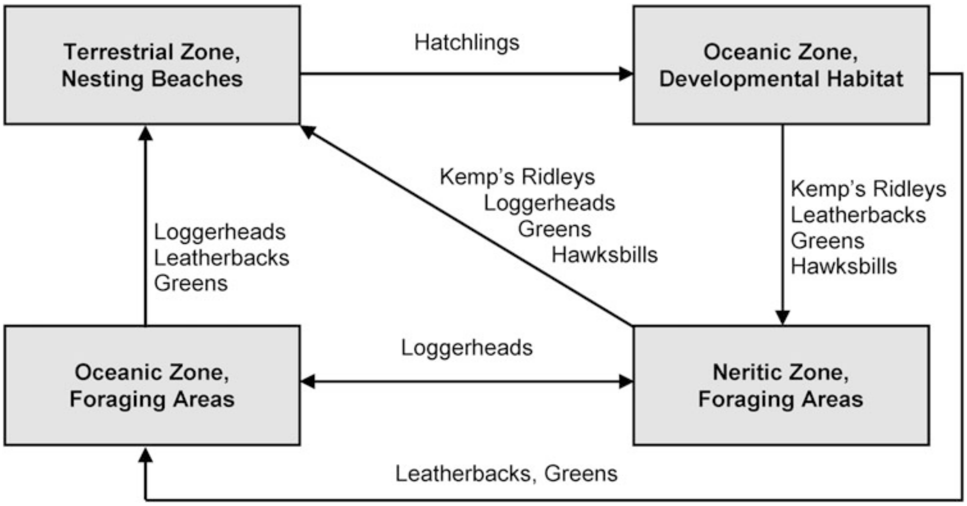


Figure 1.16. Generalized life cycles of sea turtle species that occur in the Gulf of Mexico (Figure 11.1 from Chapter 11 herein).

Available data indicate that the current populations of the five turtle species that inhabit the Gulf of Mexico are well under historical levels. All of these populations were heavily exploited in the Gulf and in the Caribbean for centuries after Europeans came to the New World. Sea turtle fisheries data from the Gulf of Mexico began to be collected in the late 1800s. These data clearly show a steep rise in the exploitation of sea turtles in the Gulf, with a subsequent collapse in catch by the early 1900s. The collapse in the Gulf was so pronounced that markets in the Gulf began to be supplied by sea turtles caught in other regions, until the Endangered Species Act and the Convention for International Trade on Endangered Species were set into place to stop sea turtle fisheries in 1973. Since then, some recovery of the populations has been documented. However, current pressures of fisheries-associated bycatch mortality, mainly in longline and shrimping fisheries, along with pollution and habitat destruction, have significantly hampered the recovery of these populations back to historic levels. Many anthropogenic and natural threats still affect Gulf sea turtles, and this information is summarized in Table 1.5, where impacts are quantified, where possible, using bycatch, stranding, and other threats data.

The Kemp's ridley has made a remarkable recovery from the brink of extinction in the Gulf of Mexico since conservation efforts focused on stressors affecting all life stages. The number of Kemp's ridleys in the Gulf has increased dramatically in recent years, and the population trajectory is promising.

Subpopulations from peninsular Florida, the northern Gulf, the Dry Tortugas, and the Greater Caribbean of the northwest Atlantic Ocean loggerhead population occur in the Gulf of Mexico during some portion of their life cycle. Annual loggerhead nesting on peninsular Florida beaches increased from 1979 to 2000 but then declined from 2001 to 2009. More data are needed to determine the long-term trends of the northern Gulf and Greater Caribbean loggerhead subpopulations. High cumulative threats and significant mortalities to oceanic and neritic juveniles, as well as adults, of the northwest Atlantic Ocean loggerhead population currently result from bycatch in multiple fisheries. The significant overlap between the northwest Atlantic Ocean loggerhead population range and the coastal and oceanic areas where fisheries occur, results in the death of thousands of loggerheads each year.

Loggerheads are the most abundant sea turtle in the western Gulf of Mexico; the majority of loggerheads that occur there are neritic juveniles. In addition, large juveniles have been associated with hard substrates, such as reefs and oil production areas (Figure 1.17), and appear to use these areas for resting. Core areas within the loggerhead's range in the Gulf include several oil and gas platforms that may be visited frequently on a daily, weekly, or monthly basis.

Despite being greatly depleted in the past, green turtle populations in the Gulf of Mexico are increasing, and green turtle nesting along the Mexican Gulf Coast has increased in recent years and remains relatively stable. In addition, nesting at major rookeries in the wider region, such as Tortuguero, Costa Rica, and the east coast of Florida, including Archie Carr National Wildlife Refuge, has increased significantly since the 1970s. While fibropapilloma tumors have been reported in all sea turtle species, the frequency of these tumors is much higher in green turtles when compared to that for the other species, and this disease remains a threat to green turtles. Green sea turtles are also dependent on healthy seagrass meadows for their foraging areas. Although impacts to green turtles resulting from incidental bycatch in fisheries are not as significant as those for loggerheads, some green turtles die each year from fisheries interactions.

The available data for the pelagic leatherback verifies that leatherbacks use the Gulf of Mexico as a foraging area, that they are often found in areas containing an abundance of jellyfish (their main food source), and that they are less abundant than Kemp's ridleys and loggerheads. Determining the current status and historical trends of the Gulf leatherback population is challenging because of their extensive migrations, large foraging areas, and significant data gaps. However, increased leatherback nesting in Florida may indicate that the leatherback population in the Gulf of Mexico, Caribbean, and northwest Atlantic Ocean area is

Table 1.5. Summary of Anthropogenic and Natural Threats Affecting the Various Ecosystems Used by Sea Turtle Populations in the Gulf of Mexico (Table 11.6 from Chapter 11 herein; from NMFS and USFWS 2008; Bolten et al. 2011; NMFS, USFWS, SEMARNAT 2011)

Threat	Terrestrial Zone[a]	Neritic Zone[a]	Oceanic Zone[a]
Incidental capture in commercial and recreational fisheries			
Trawls		X	X
Gill nets		X	X
Dredges		X	X
Pelagic and bottom long lines		X	X
Seines		X	
Pound nets and weirs		X	
Pots and traps		X	
Hook and line		X	X
Illegal harvest			
Eggs	X		
Juveniles		X	
Adults	X	X	
Nesting beach alterations			
Cleaning	X		
Human presence	X		
Driving on beach (cars and off-road vehicles)	X		
Artificial lighting	X	X	
Construction	X		
Nourishment and restoration	X	X	
Sand mining	X	X	
Armoring and shoreline stabilization (drift fences, groins, jetties)	X		
Other anthropogenic impacts			
Channel dredging and bridge building		X	
Boat strikes		X	X
Oil and gas exploration (including seismic activity), development, and production	X	X	X
Stormwater runoff		X	X
Oil and chemical pollution and toxins	X	X	X
Algal Blooms, including Red Tides		X	

(continued)

Table 1.5. (continued)

Threat	Terrestrial Zone[a]	Neritic Zone[a]	Oceanic Zone[a]
Hypoxia		X	
Marine debris ingestion and entanglement	X	X	X
Military activities and noise pollution	X	X	X
Industrial and power plant intake, impingement, and entrainment		X	
Dams and water diversion		X	
Sea level rise due to climate change	X		
Temperature change due to climate change	X	X	X
Trophic changes due to fishing and benthic habitat alteration		X	X
Natural impacts			
Predation	X	X	X
Beach erosion and vegetation alteration	X		
Habitat modification by invasive species	X	X	
Pathogens and disease	X	X	X
Hurricanes and severe storms	X	X	
Droughts		X	
Cold-stunning		X	

[a] Terrestrial zone = nesting beach where females excavate nests and lay eggs, where embryos develop; Neritic zone = inshore marine environment from the surface to the sea floor, including bays, sounds, and estuaries, as well as the continental shelf, where water depths do not exceed 200 m (656 ft); and Oceanic zone = open ocean environment from the surface to the sea floor where water depths are greater than 200 m (656 ft)

stable or increasing. Large numbers of leatherback sea turtles are captured each year in the Gulf as bycatch in pelagic longline fisheries.

Hawksbills are the rarest of the five species of sea turtle that occur in the Gulf of Mexico, and their current abundance is only a fraction of historical levels because millions were killed for tortoiseshell (jewelry, combs, brushes, buttons, etc.) during the past 100 years. Significant threats to hawksbills include destruction of nesting habitat, their dependence on coral reefs (one of the world's most endangered ecosystems) for food and shelter, and the continued trade in hawksbill products. Impacts from bycatch in Gulf fisheries to hawksbill sea turtles are minimal.

In summary, because sea turtles are difficult to study and since some species have been studied more than others, there are significant gaps in the data available by species, as well as by life stage. However, despite the data gaps and limitations associated with selected data sets

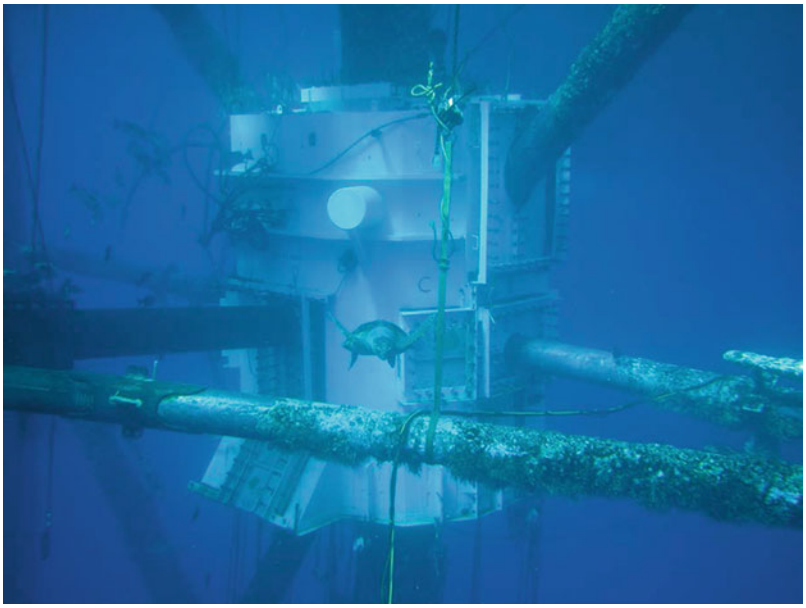


Figure 1.17. Loggerhead sea turtle swimming under an oil and gas platform (photograph courtesy of Ed Elfert, Chevron Corporation, photographer unknown) (Figure 11.23 from Chapter 11 herein).

(nesting and stranding data), characterizing the life history, distribution, and abundance, as well as summarizing impacts for the five species, was possible qualitatively, and sometimes quantitatively. In addition to revealing important data gaps, this summary highlights the variability of sea turtle data and the importance of long-term datasets. Changes in sea turtle populations can be detected, especially on nesting beaches; however, determining the causes of the change is extremely difficult because adequate baseline data are not available, multiple anthropogenic and natural threats affect all life stages of sea turtles, threats affect life stages and species differentially, multiple threat effects may be synergistic, and impacts may not be detected for many years. As new threats emerge and attempts are made to quantify the impacts of various threats in order to develop sea turtle conservation plans and solutions, these issues will continue to be challenges in the future.

1.12 AVIAN RESOURCES OF THE GULF OF MEXICO (CHAPTER 12)

The Gulf of Mexico is a complex mosaic of many habitat types, influenced by political, economic, social, and biological factors, as well as global climate change, sea-level rise and land subsidence, tides, storms, and hurricanes. The Gulf of Mexico ecosystem is a matrix of tropical, subtropical, and temperate habitats, which include different landmasses and different land margin interfaces. Large peninsulas (Florida, Yucatán), large islands (Cuba), barrier islands, offshore islands or keys, barrier beaches, sandy and gravel beaches, open water, mangroves, saltmarshes, and brackish marshes intergrade with freshwater marshes, swamps, and more upland habitats. Joanna Burger, who is Distinguished Professor of Biology at Rutgers University, is the author of the avian resources chapter. She has written more than 20 books and published 500 peer-reviewed journal articles, many of which are on birds.

The Gulf of Mexico is one of the most important regions in the Western Hemisphere for birds. Birds from North America funnel over or around the Gulf during their migratory flights,

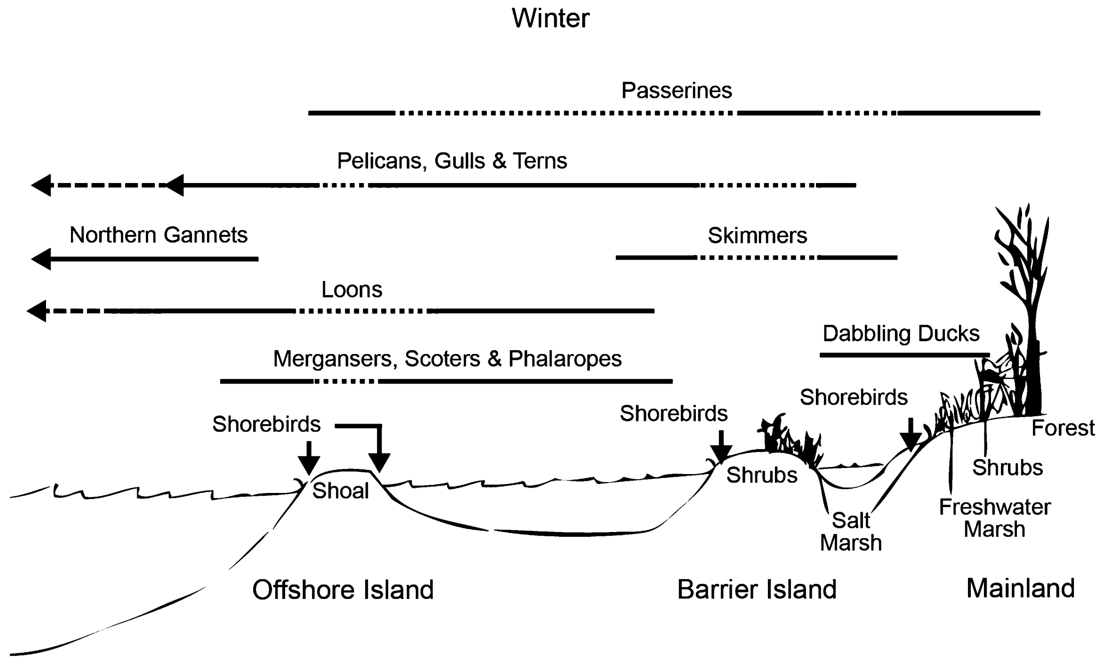


Figure 1.18. Schematic of spatial gradient for birds wintering in the Gulf of Mexico, from open water (pelagic zone) to upland habitats. Solid line indicates normal habitat use, dotted line indicates area not usually used, and dashed line means frequency is less (Figure 12.7 in Chapter 12 herein). © J. Burger.

birds from both north and south come to winter along Gulf shorelines or on the open water, and many species of birds breed in the Gulf. Thus, the coastal areas around the Gulf of Mexico serve as a hotspot of avian diversity (Figure 1.18).

Habitat availability and suitability are important distinguishing criteria within the Gulf of Mexico. Habitat availability is whether habitat is present and available that meets the needs of the species or species groups, such as open sandy beaches for shorebirds to feed, salt marshes for clapper rail and seaside sparrow to breed and forage, isolated islands with suitable vegetation for brown pelicans, terns, skimmers, herons, and egrets to nest, and bare sandy beaches for snowy plover to breed and forage. Habitat suitability, on the other hand, refers to whether the habitat will actually meet the needs of birds with respect to providing adequate places to forage, roost, breed, and migrate free from predators, human disturbance, high tides and storm tides, and other weather-related events. Available habitat must meet the species requirements in terms of vegetation, elevation, and physiognomy, while habitat suitability relates to whether the habitat is usable in terms of predator isolation and freedom from human disturbance. Factors that affect suitability often relate to exposure to the elements (storms, tides, winds, hurricanes, floods, and over the long term, sea-level rise), exposure to predators and people, the degree of competition from conspecific and interspecific interactions, presence of pollutants, and physical disruptions. In short, the habitat has to allow survival and reproduction. In many cases, suitable avian resource habitat is only available on islands or cays isolated from the mainland.

Habitat loss is a major factor affecting bird populations in the Gulf of Mexico and affects all birds, whether residents, migrants, or wintering species. Also, it influences all aspects of their daily lives from breeding and nesting to foraging and having sufficient safe places to roost. Loss of habitat is most severe at the land-sea margin, and it is most severe where anthropogenic activities occur, where the land is modified and is no longer suitable, or where land is completely developed.

Pollutants have affected behavior and populations of birds in the Gulf of Mexico, although this has been to a far lesser degree than habitat loss and modification. The use of DDT in the 1950s and 1960s had a great effect on fish-eating birds, such as osprey, wading birds, and brown pelicans, which declined dramatically. Pelicans were especially hard hit; they were largely extirpated as a successful breeding bird from some regions of the Gulf. In addition, mercury has affected behavior and reproduction in both resident birds (great egrets and other fish-eating birds), and migrants (common loon). Oil, on the other hand, can cause immediate mortality and chronic injury, but it has not been demonstrated to permanently affect any populations of birds in the Gulf. Plastics and fishing lines also cause mortality in the Gulf, particularly in foraging seabirds, but the long-term effects are unclear.

Understanding avian assemblages that use the Gulf of Mexico entails examining several different factors: migrant versus resident, solitary versus colonial nesting, ground versus tree nesting, method of foraging, and location of foraging. The 15 indicator species examined in the avian resources chapter illustrate all of these different lifestyles and behavioral patterns (Table 1.6). Obviously, nesting on the ground exposes nests, eggs, and chicks to ground predators, tidal flooding, and human disturbance, while nesting in trees exposes birds to aerial predators but usually protects them from mammalian predators. Nesting on low islands usually prevents mammalian predators from surviving, because high tides or severe storms wash them away, but nesting there also exposes the birds to flooding from high tides and storms during the breeding season. In addition, the indicator species illustrate different life strategies: some delay breeding, some have small clutch size, others have long parental care, and still others have long lifespans such as common loon and royal tern. Some species (e.g., mottled duck and clapper rail) breed when they are only 1 year old, but they have large clutches and short lifespans. These factors generally determine how fast a species can recover from any negative event or stressor, whether natural or manmade.

The selected indicator species illustrate and are representative of the range of population trends: some are increasing, others are decreasing, and in some, the variation from year to year is so great that it is difficult to ascertain trends. In other species, site fidelity to a specific colony location is so low that it is nearly impossible to census them accurately, and often their populations fluctuate wildly from year to year, depending upon water levels. Nonetheless, for the 15 indicator species, Christmas Bird Count data indicate clear declines over the past 45 years for certain species (mottled duck, black skimmer, and seaside sparrow), and clear increases for others (brown pelican, great egret, and laughing gulls, although data from the last 15–20 years indicate that laughing gull is now declining).

Overall declines seem to be due primarily to habitat loss, coupled with human disturbance and other disruptions to beach, saltmarsh, and coastal environments. Dramatic increases are often the result of laws and regulations (endangered species laws, cessation of the use of pesticides, as with brown pelican and osprey), to specific management practices (whooping crane, piping plover), to habitat creation (brown pelican), inadvertent management (dredge spoil islands for snowy plover and other beach nesting species), and possibly to global warming (more northern movement of southern species, such as roseate spoonbill).

The avian communities and resources of the Gulf of Mexico are varied and diverse, largely because of the diversity of habitats, the richness of the marine-land interface, the presence of a gradient from temperate to tropical, and the geography of the Gulf, which places it as the funnel point for Nearctic-neotropical migrants. Fluctuations in the avian community occur because of short-term and long-term stressors that render habitat either suitable or unsuitable. Habitat loss and destruction in the Gulf, which is continuing at an alarming rate, due to both

Table 1.6. Summary of Rationale for Selection of Indicator Species[a] (Table 12.7 from Chapter 12 herein)

Species	Endangered and Threatened	Largely a Gulf Species	Resident	Migrant	Colonial	Solitary	Open Ocean	Mud Flat	Beach or Sand	Sand, Light Vegetation	Marsh
Common Loon				X		X	X				
Brown Pelican		X	X		X		X				
Great Egret			X		X			X			
Reddish Egret		X	X		X			X			X
Roseate Spoonbill		X	X		X			X			X
Mottled Duck		X	X			X					X
Osprey			X			X					
Whooping Crane	X	X		X	X		X				X
Clapper Rail			X			X					X
Snowy Plover		X	X			X			X		
Piping Plover	X			X		X			X		
Laughing Gull			X		X		X	X	X	X	X
Royal Tern			X				X		X	X	
Black Skimmer			X				X		X	X	
Seaside Sparrow			X			X					X

[a]The last five columns are habitat categories

natural and anthropogenic causes, will result in changes to the bird communities. Protection and management can only counter these losses and changes, and this requires monitoring to assess the overall health of avian communities. Finally, the needs and requirements of the avian communities must be viewed within the context of the human communities that also thrive along the Gulf Coast, and management, protection, and conservation of birds must be designed with the human dimension in mind. The following are important conclusions resulting from this analysis of the avian resources of the Gulf of Mexico:

- The Gulf of Mexico (and environs) is one of the most important places for birds in the Western Hemisphere because it has species whose major ranges are in both North and South America, and hosts a wide range of migrants. Nearly 400 species have been reported from the Gulf.
- Approximately 31 % of the 395 species found in the Gulf have been recorded in all areas of the Gulf.
- The high diversity in birds in the Gulf of Mexico is due to the Gulf's diversity of habitats, richness of marine-land interface, a gradient from tropical to temperate, and the geography of the Gulf which places it as the funnel point for Nearctic-neotropical migrants.
- Most birds that use saltwater to brackish ecosystems are seabirds, herons and egrets, shorebirds, waterfowl, gulls, terns, and specialized marsh species such as clapper rail and seaside sparrow. Assessment of 15 indicator species for the Gulf shows that mottle ducks, black skimmer, and clapper rail have declined over the last 45 years, while brown pelican, great egret, and osprey have increased. Declines seem to be related to habitat loss, coupled with human disturbance and other disruptions.
- Higher species diversity of birds is found in the southern Gulf of Mexico than in the northern coast.
- A higher percentage of some colonial species nesting in North America do so in Louisiana and Texas rather than elsewhere along the Gulf.
- Habitat loss is the primary threat facing birds in the Gulf of Mexico, due to both natural and anthropogenic causes, and it is occurring at an ever-increasing rate. One of the greatest impacts on avian populations in the Gulf of Mexico is habitat loss (either because it is less available, or because what is available is no longer suitable), followed by human disturbance.
- Populations of birds in the Gulf have varied greatly over the past 50 years; some have increased and some have declined.

1.13 MARINE MAMMALS OF THE GULF OF MEXICO (CHAPTER 13)

The Gulf of Mexico has a rich marine mammal fauna with approximately 22 species that occur commonly within this semitropical area (Table 1.7). One is the vegetarian sirenian, the West Indian manatee, which occurs mainly in Florida, but with some individuals migrating into Alabama, Mississippi, and Louisiana as well. All of the rest are cetaceans, which are members of the whale and dolphin clades, and there are no porpoises, sea lions, fur seals, or true seals in the Gulf. Bernd Würsig, who is a Regents Professor in the Departments of Marine Biology and Wildlife and Fisheries Sciences at Texas A&M University, is the author of this chapter. He has written a book on the marine mammals of the Gulf of Mexico, as well as several other books on marine mammals of the world and published numerous peer-reviewed papers on marine mammals during his long and distinguished career.

Table 1.7. Potential Marine Mammal Species in the Gulf of Mexico (Table 13.1 from Chapter 13 herein; from Würsig et al. 2000)

Species	Main Reasons for Former/Present Listing
North Atlantic right whale, *Eubalaena glacialis*	1 Stranding, one sighting of 2; reports of former hunting
Blue whale, *Balaenoptera musculus*	2 Strandings
Fin whale, *Balaenoptera physalus*	5 Strandings and rare sightings
Sei whale, *Balaenoptera borealis*	5 Strandings
Humpback whale, *Megaptera novaeangliae*	Occasional strandings and rare sightings
Minke whale, *Balaenoptera acutorostrata*	Occasional strandings; and rare sightings, Florida Keys
Bryde's whale, *Balaenoptera edeni*	**Strandings and quite common sightings**
Sperm whale, *Physeter macrocephalus*	**Common sightings**
Pygmy sperm whale, *Kogia breviceps*	**Common sightings**
Dwarf sperm whale, *Kogia sima*	**Common sightings**
Cuvier's beaked whale, *Ziphius cavirostris*	**Multiple strandings and occasional sightings**
Blainville's beaked whale, *Mesoplodon densirostris*	**4 Strandings and occasional sightings**
Sowerby's beaked whale, *Mesoplodon bidens*	1 Stranding
Gervais' beaked whale, *Mesoplodon europaeus*	**Multiple strandings and occasional sightings**
Killer whale, *Orcinus orca*	**Common sightings**
Short-finned pilot whale, *Globicephala macrorhynchus*	**Common sightings**
Long-finned pilot whale, *Globicephala melas*	Inferred but with no confirmed records
False killer whale, *Pseudorca crassidens*	**Medium common sightings**
Pygmy killer whale, *Feresa attenuata*	**Medium common sightings**
Melon-headed whale, *Peponocephala electra*	**Common sightings**
Rough-toothed dolphin, *Steno bredanensis*	**Common sightings**
Risso's dolphin, *Grampus griseus*	**Common sightings**
Common bottlenose dolphin, *Tursiops truncatus*	**Common sightings**
Pantropical spotted dolphin, *Stenella attenuata*	**Common sightings**
Atlantic spotted dolphin, *Stenella frontalis*	**Common sightings**
Spinner dolphin, *Stenella longirostris*	**Common sightings**
Clymene dolphin, *Stenella clymene*	**Common sightings**
Short-beaked common dolphin, *Delphinus delphis*	Inferred due to former misidentifications
Long-beaked common dolphins, *Delphinus capensis*	Inferred but with no evidence
Fraser's dolphin, *Lagenodelphis hosei*	**Occasional sightings**
West Indian manatee, *Trichechus manatus*	**Common sightings**

Those in **bold** are the 21 species presented in Chapter 13 that occur commonly within the Gulf

The most ubiquitous and best-known cetacean in the Gulf is clearly the common bottlenose dolphin, which occurs in coastal bays and estuaries, as well as nearshore and deeper waters. There are also upper continental shelf Atlantic spotted dolphins, the deepwater fish and squid eaters, such as the so-called *blackfish* and beaked whales, and members of the tropical genus *Stenella*, including Clymene and spinner dolphins that prefer lower continental shelf and deep waters of the Gulf. Numerically, the most common cetacean is the pantropical spotted dolphin, but the one with most biomass is the sperm whale, which is common in mid-depth waters off Louisiana and the shelf break off Texas. Bryde's whale is the only common baleen whale in the Gulf, and it inhabits upper and mid-slope waters, typically in the eastern Gulf of Mexico. All 22 species covered in Chapter 13 have descriptive information about them (size, color, shape, etc.) and range and distribution with a map, habitat, and field photo.

Recorded knowledge of marine mammals of the Gulf began with commercial whaling of sperm and pilot whales, as well as Risso's dolphins, in the 1700s and 1800s, but it progressed to natural history observations and one of the first volunteer stranding organizations, the Texas Marine Mammal Stranding Network, in the 1970s. In the 1980s and beyond, there have been considerable ship and aerial survey efforts to describe marine mammal populations of the Gulf, with the most intensive work accomplished in the 1990s, linking species, habitats utilized, and oceanographic parameters, under the auspices of the large multidisciplinary, U.S. government-funded project termed GulfCet.

While manatees generally use riverine and shallow oceanic waters for food and safety, the various species of cetaceans utilize all habitats of the Gulf. The GulfCet studies determined that sperm whales and smaller toothed whales are generally associated with the more productive cold-core upwelling gyres and eddies than the warm-core rings that break off from the Loop Current that comes from the south, out of the Caribbean. This fact gives the cetacean fauna of the northern Gulf a most-dynamic and ever-changing spatial dimension that needs to be viewed and considered in light of monthly to yearly changes of physical and biological oceanography.

The sperm whale and West Indian manatee are listed as endangered in the United States, but sperm whales are doing reasonably well worldwide, and there is no reason to believe that the Gulf of Mexico population is in imminent peril. The manatee numbers are in the low thousands of animals off Florida, subject to mortality largely due to periodic cold spells and recreational boat collisions, but hope exists as conservation, management, and public awareness efforts improve. Major anthropogenic threats exist for all marine mammals, but they do not appear to be as intensive in the Gulf of Mexico as in several other ocean basins. These threats include prey depletion, incidental mortality and injury due to fisheries, intentional and direct takes, vessel strikes, disturbance, acoustic (noise) pollution, chemical contamination, ingestion of solid debris, natural oil seeps, and aspects of ecosystem change.

1.14 DISEASES AND MORTALITIES OF FISHES AND OTHER ANIMALS IN THE GULF OF MEXICO (CHAPTER 14)

It is presumed that the health of animals in the Gulf of Mexico would follow along with the health of the Gulf ecosystem. Although there is no widespread monitoring program to measure the health of multiple Gulf species or the ecosystem, episodes of fish kills, infections, and abnormalities in marine species have been documented in the Gulf of Mexico for decades. Acute, mass mortalities have attracted the most attention, but when such an event occurs, attempts are usually made to ascribe a single cause for them. However, elevated mortalities are usually due to a convergence of factors, with interacting hosts, agents, and environmental conditions producing a "perfect storm." Such interacting factors are always present to some degree, but bringing them all together at once seems to be rare. Some microbial agents, parasite infections, and environmental conditions occur in large cycles of multiple years, or even decades, but whether this results from some underlying periodicity or from random co-occurrence of contributing factors is not clear.

The laboratory of Robin Overstreet and William Hawkins, both Professors Emeritus, at the Gulf Coast Research Laboratory of the University of Southern Mississippi in Ocean Springs has been one of the leading facilities for tracking parasites and diseases in coastal and marine species in the northern Gulf of Mexico for over four decades. Their detailed research program and broad study of taxonomy, systematics, development and life histories, diagnoses and management of diseases, ecology, pathogenesis and host–parasite relationships, as well as public health studies, provide the foundation for this overview of diseases and mortalities of coastal and marine species in the Gulf of Mexico, with an emphasis on fishes.

Physical and chemical factors generally trigger large-scale mortalities. Eutrophication occurs throughout the Gulf where high nutrient input occurs, and low oxygen levels associated with eutrophication produce a major stress leading to fish mortality, but it also leads to disease and parasite-caused mortality. Red tides have a major influence on the health of fishes and other animals from the West Coast of Florida and occasionally elsewhere in the Gulf. Mass mortalities from sudden cold spells, which occur primarily inshore where it is hard for some animals to escape, are more disastrous in South Texas and South Florida, because species there are not as well acclimated to tolerate rapid temperature changes as they are in higher latitudes of the Gulf. Likewise, excessive heat, hypersalinity, sulfate reduction, sediments, and drilling fluids all have been implicated in mortality events, but they produce more localized effects. Hurricanes can occur anywhere in the Gulf, but resulting fish kills depend on the geography of the areas the hurricanes pass through and impacts to the environment. As with most catastrophic events, the presence and absence of specific parasites can provide a good indication of environmental health and its restoration.

Few diseases cause mass mortality. When investigated, the cause of such events usually involves one or more stresses, with an interaction between the host, disease agent, and the environment. Most diseases involving infectious agents are usually shown to be highly restricted to certain geographic areas or to certain species. The most obvious infectious disease and mass mortality event in the Gulf of Mexico came from a catfish die-off occurring in 1996 that eventually spread from Texas to Florida and was caused by, either directly or indirectly, a virus. It is not known whether that virus becomes intermittently introduced or if it always occurs in the habitat in low numbers until some threshold is surpassed, triggering a pandemic. Some event, such as reproductive activity in the catfish, may have served as the stressor, but no catastrophic event coincided with the mortality. What seems to be the same agent infects fishes in the southern Gulf of Mexico, South America, Africa, and India.

Parasites often cause disease conditions and mortalities in hosts, usually intermediate hosts, as a part of the parasitic strategy to complete its life history. However, these effects tend to be ongoing at a low level without harm to an overall population or to the ecosystem. In cases where mass mortality occurs, changes in anthropogenic or natural environmental conditions are usually involved. Major stress can affect resistance of a host to disease organisms, especially bacterial or protozoal agents. Diseases caused by a few species seem to serve as a means of host population control. Parasites, even when not harming their hosts, can be extremely useful as bioindicators in providing information about stock assessment, biological activities of hosts such as migration and feeding, restoration of habitats, and habitat and ecosystem health.

Neoplasms, some virally induced, have seldom been observed or reported in Gulf of Mexico fishes, although their occurrence has likely been underestimated, but elsewhere, neoplasms have served as good indicators of various contaminants, particularly sediment-bound PAHs. Consequently, more attention to documenting them is warranted. Developmental abnormalities and histopathological alterations, which have been seen in many Gulf species, can indicate levels of stress from a variety of environmental factors.

Regarding vertebrates other than fish, data on disease conditions are uneven. The best-known condition in sea turtles is fibropapillomatosis, and it appears to have multiple causes. Bird mortality events are sometimes ascribed to bacterial, fungal, and viral infections, but the effects of these agents can be exacerbated by environmental conditions that reduce energy and deplete needed resources. Brevitoxins and morbillivirus have been implicated in periodic marine mammal mortalities, but the cause of others is unclear, and most data are based on skewed samples from strandings.

Concerning invertebrates, diseases of penaeid shrimps and the blue crab have been well documented, but the effect of these diseases on host populations in the Gulf remains unclear. In the eastern oyster, the protozoan disease known as *dermo* has received a great deal of research attention. Researchers know that its impact on oyster populations varies widely according to salinity, temperature, genotype of the infectious agent, and perhaps interaction with specific contaminants, but its variation and severity from location to location in the Gulf has not been adequately explained. Other agents and fouling agents affect oysters also, but their impacts and interactions are less well studied. Loss of corals by bleaching and disease has had a major influence on tropical and subtropical Gulf communities, because along with their loss, there has been a loss of the associated fishes and invertebrates in the coral community.

Although almost 100 images of a wide variety of diseases, parasitic infections, and other causative agents are shown in Chapter 14 on various Gulf of Mexico invertebrates and vertebrates, only a few examples are shown here to demonstrate that variety (Figures. 1.19, 1.20, and 1.21).

To better understand diseases and mortalities in the Gulf of Mexico, there is a need for monitoring both diseases and mortalities; conducting more long-term, broad-scaled field work; acquiring more expertise; and developing more critical tools for evaluating health of the animals and health of the ecosystem.

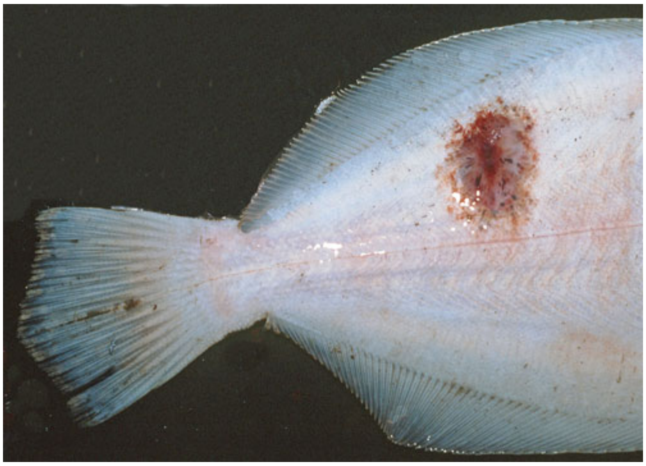


Figure 1.19. Southern flounder, *Paralichthys lethostigma*, exhibiting relatively common bacterial lesion on blind side of specimen from Pascagoula estuary, Mississippi, 1987 (Figure 14.9 from Chapter 14 herein).

Figure 1.20. A few of the many pouch lice, *Piagetiella peralis*, infesting the gular pouch of an American white pelican (Figure 14.74 from Chapter 14 herein).

Figure 1.21. White shrimp, *Litopenaeus setiferus*, with the microsporidian *Agmasoma penaei* in the cephalothorax and along the dorsum, superficially appearing like developing gonads (Figure 14.79 from Chapter 14 herein).

1.15 CONCLUSIONS

The major conclusions of this collection of chapters are included here as an overview of the Gulf of Mexico environment, as well as the current status and historical trends of species and habitats prior to the Deepwater Horizon oil spill:

1. *Water quality*: Patterns and trends in water quality are highly variable in space and through time in the Gulf of Mexico, and coastal environments are highly influenced by human activities where the primary cause of degraded water quality is excess nutrients. Water quality rapidly improves with distance offshore. More than 60 % of assessed estuaries were either threatened or impaired for human use and/or aquatic life over the time period of this review that spans the 1990s to the mid-2000s.
2. *Water quality*: Eutrophication has produced low dissolved oxygen and increased chlorophyll *a* concentrations, diminished water clarity, and other secondary effects including toxic/nuisance algal blooms and loss of submerged aquatic vegetation. Degraded coastal water quality was also indicated by contaminants in biological tissues

and sediments, fish consumption advisories, and beach closing/advisories due to bacterial contamination.

3. *Water quality*: Water quality of Gulf of Mexico continental shelf/slope and abyssal waters was and continues to be good. Exceptions are hypoxic zones on the continental shelf, waters just above natural oil and gas seeps, and ephemeral effects due to produced water discharges during petroleum extraction. Along the northwest/central Gulf of Mexico continental shelf, the seasonal occurrence of waters with low concentrations of oxygen is geographically widespread. These "dead zones" are highly seasonal, and it has been suggested they result from water column stratification driven by weather coupled with Mississippi River outflow that delivers excess nutrients (mostly from agricultural lands) to the offshore region.
4. *Sediments*: Sediment nature and distributions in the Gulf of Mexico are similar to ocean basins. There are basically two primary provinces: terrigenous sediments carried from land to the northern and western portions of the basin, and carbonate sediments that originate on the Florida and Yucatán platforms. Sea-level changes over the past several thousand years have had a major influence on sediment distributions.
5. *Sediments*: Sediments in coastal systems of the Gulf of Mexico have the most complicated distributions, and are dominated by sediments of terrestrial origin. Coastal sediments are composed of mud and sand with biogenic organic debris: sand is dominating in the barrier-inlets systems and mud is the largest sediment component in the estuaries and lagoons. Deep Gulf environments tend to be dominated by mud in a combination of terrigenous and biogenic (coccoliths, diatoms, foraminiferans, and radiolarians) sediments.
6. *Sediment contaminants*: Concentrations and distributions of sediment contaminants in the Gulf of Mexico are spatially and temporally heterogeneous over small scales due to variations in inputs, sediment deposition and accumulation rates, susceptibility to and rates of removal, chemical form, and physicochemical properties and the physical settings of receiving waters.
7. *Sediment contaminants*: Sediment contaminants are found widely in Gulf of Mexico coastal bays and estuaries. Coastal sediments were judged to be in good to poor condition with concentrations of metals and pesticides in more than 40 % and concentrations of PAHs and PCBs in less than 1 % of coastal sediments exceeding levels suspected of causing biological effects. Within bay systems, steep gradients in contaminant concentrations were observed near population centers, agricultural activities, and industrial complexes. Contaminant concentrations decrease with distance offshore, since these regions are remote, with few exceptions, from most contaminant inputs. Natural petroleum seepage is the major source of hydrocarbons in northern-central Gulf of Mexico continental shelf/slope sediments.
8. *Sediment contaminants*: In general, levels of pesticides and contaminant metals appear to have decreased with time in coastal sediments in response to water pollution control regulations.
9. *Oil and gas seeps*: Hydrocarbon seepage is a prevalent, natural worldwide phenomenon that has occurred for millions of years, and it is especially widespread in the deepwater region of the Gulf of Mexico, which is an archetype for oil and gas seepage and where most worldwide studies and knowledge of petroleum seeps are based. Gulf of Mexico seeps are highly variable in composition and volume and include gases, volatiles, liquids, pitch, asphalt, tars, water, brines, and fluidized sediments.

10. *Oil and gas seeps*: Hydrocarbon seeps occur on land and beneath the ocean, and they are biogenic, thermogenic, or mixed in origin. These seeps release considerable amounts of oil and gas to the environment each year, estimated at about 95 % of oil annually discharged to Gulf of Mexico waters. Cold-seep, chemosynthetic communities are common at macroseeps across the northern Gulf of Mexico continental slope, on the abyssal plain, and in the southern reaches of the Gulf of Mexico.
11. *Coastal habitats*: Vegetated coastal and marine habitats of the Gulf of Mexico provide a wealth of ecosystem services, such as food, employment, recreation, and natural system maintenance and regulation to the three countries bordering the Gulf. Salt marshes dominate vegetated shorelines in the northern Gulf, and mangroves dominate in the tropical south.
12. *Coastal habitats*: Coastal vegetated habitats have experienced the greatest temporal changes in areas most susceptible to relative sea-level rise, tropical cyclones, and human disturbances. Consequently, the deltaic coast of Louisiana has the most substantial land and habitat changes in the Gulf of Mexico. Conversely, the more stable coasts of the Yucatán Peninsula, Cuba, and southwestern Florida show the least amount of change. Human disturbances are evident in areas of significant industrial activity and tourism. Human impacts are in large part tied to periodic and chronic stressors and disturbances associated with urban, agricultural, and industrial activities. Draining and filling of wetlands for human habitation, agricultural development, and industrial expansion have dramatically impacted coastal habitats throughout the Gulf.
13. *Coastal habitats*: Nutrient enrichment and resulting eutrophication and hypoxia, altered hydrology from multiple causes, invasive species, and chemical pollutants including those associated with energy extraction and production have challenged the health and sustainability of vegetated marine habitats. In addition, natural disturbances driven by hurricanes, underlying geology, and floods and drought are exacerbated by human impacts.
14. *Offshore biota*: Offshore plankton and benthos of the Gulf of Mexico at the lower end of the food web (phytoplankton, zooplankton, mid-water fishes, and seafloor organisms) in most habitats are characteristic of an oligotrophic ecosystem. That is, the biota is relatively low in numbers of organisms and biomass when compared to other continental margins such as upwelling regions and in temperate and polar latitudes. The principal cause of this oligotrophic condition is the source water from the Caribbean, which is depleted of nitrate in the surface to about 125 m (410 ft).
15. *Offshore biota*: Offshore plankton populations represent a near-surface fauna that declines with depth as a biocline (the greater the distance from the surface, the more depauperate the biomass). All size groups of multicellular organisms decline exponentially as a function of depth and distance from land, so that the abyssal plain supports only a very few seafloor organisms (fishes; zooplankton; mega-, macro-, and meiobenthos). Biodiversity of the macrobenthos follows a different pattern as a function of depth, depending on the taxon studied. In general there is a mid-depth maximum of macrofaunal diversity at about 1.2 km (0.75 mi) in depth. In addition, a decreasing zonation in diversity across a physical gradient is apparent with increasing depth in macrofauna, megafauna, and fishes, most likely due to the decreasing amount of food sources available.
16. *Offshore biota*: Other distinctive offshore biota assemblages or habitats include chemosynthetic benthic fauna associated with and sustained by fossil hydrocarbon seeps in the northwestern Gulf, deep-living, cold-water corals, such as *Lophelia pertusa*, which

provide distinctive habitat for demersal species in a narrow depth band at the upper margin of the continental slope in the northeastern Gulf, and lastly, high diversity hard-bottom areas which are spread across the continental margin as topographic highs (reefs and banks) or low-relief live bottoms.

17. *Offshore biota*: Potential problems in sustaining the offshore biota (plankton, nekton, and benthos) include climate change, turbidity currents and slumps, eutrophication, oil and gas industry accidents, hypoxia, overfishing, trawling the bottom, and hurricanes.
18. *Shellfish*: Shellfish include four of the top five commercial species by value and poundage of landings in the Gulf of Mexico. These include brown and white shrimp, Eastern oyster, and blue crab, but there are 49 species total (28 mollusks, 18 crustaceans, and 3 echinoderms) that are currently taken as commercial shellfish species in the Gulf.
19. *Shellfish*: Population trends of shellfish in the Gulf vary widely from year to year, primarily due to fluctuations in environmental conditions (such as temperature, salinity, etc.), but some landings are also influenced annually by exogenous factors (such as market competition from imported shrimp, rising fuel costs, and fleet damage due to hurricanes).
20. *Shellfish*: Shrimp populations are flourishing, but the shrimp fishery—the most valuable fishery in the Gulf—is in decline due to exogenous factors, especially cheap, imported shrimp. Oyster populations appear fairly stable, but landings in Louisiana have been low for almost a decade compared to the 1990s. Blue crab populations fluctuate widely due to varying environmental conditions with Louisiana having the largest fishery and increasing catches.
21. *Fish resources*: Fish resources from the Gulf of Mexico total 1,536 species and include 1,443 finfish, 51 sharks, and 42 rays/skates.
22. *Fish resources*: Gulf fisheries are some of the most productive in the world with approximately 25 % of commercial fish landings and 40 % of recreational harvest in the United States coming from the Gulf.
23. *Fish resources*: A wide variety of long-term anthropogenic and natural stressors, such as coastal development with subsequent degraded water quality and habitat loss, heavy fishing pressure, a large quantity of bycatch in shrimp fisheries, climate change, and natural disasters have negatively impacted the Gulf of Mexico ecosystem and its fishery species.
24. *Fish resources*: Of the 15 finfish species evaluated, 5 species were being overfished and/or were in the status of overfishing in 2010, including red snapper, red grouper (some local subpopulations), Atlantic bluefin tuna, Atlantic blue marlin, and greater amberjack.
25. *Fish resources*: Of 39 shark species included in the shark Fisheries Management Plan in the Gulf of Mexico, 19 species have been listed as commercially and recreationally prohibited species because of very low population biomass and poor stock conditions.
26. *Fish resources*: Finfish species evaluated that were determined not overfished in the Gulf of Mexico immediately before the Deepwater Horizon oil spill included menhaden, Atlantic swordfish, Atlantic sailfish, red drum, striped mullet, tilefish, king mackerel, Gulf flounder, and dolphinfish.
27. *Commercial and recreational fisheries*: Commercial fisheries are generally described and reported by either landings in weight or value in dollars. Aggregate finfish and shellfish landings attributed to the U.S. Gulf states fluctuate, but the ranking of the states does not change much from year to year. Louisiana ranks first in landings in the

five major Gulf species (menhaden, brown and white shrimp, blue crab, and oysters). Dockside value of all landings is mostly concentrated in Louisiana and Texas, with shares of 43 % and 26 %, respectively.

28. *Commercial and recreational fisheries*: In the recreational fisheries sector, the number of Gulf angler trips (excluding Texas) increased from an estimated 17 million annually during the decade of the 1990s to 23 million annually during the most recent decade. About 70 % of total Gulf recreational trips were based in Florida (west coast); Louisiana accounted for 17 % of total recreational fishing activity. An estimated 92,000 jobs (including Texas) were generated as a result of Gulf recreational fishing in 2009, with generated income totaling about $5.1 billion. Spotted seatrout and red drum are the popular inshore species for recreational fishermen, and reef fish (snapper and grouper) are the most popular offshore species.
29. *Sea turtles*: Five species of sea turtles are found in the Gulf of Mexico, including the Kemp's ridley, loggerhead, green, leatherback, and hawksbill.
30. *Sea turtles*: The Gulf of Mexico provides important sea turtle nesting habitat, oceanic habitat for juvenile sea turtle growth and development, critical foraging habitat for juvenile and adult sea turtles, and important mating and inter-nesting habitat for adults.
31. *Sea turtles*: All sea turtle populations were heavily exploited in the Gulf and Caribbean for centuries after the Europeans arrived in the New World, and even though all species have been protected since 1973 and some recovery has occurred, none of the populations have returned to historic levels. Current pressures from fisheries-associated bycatch mortality, mainly in longline and shrimping fisheries, along with pollution and habitat destruction, have significantly hampered recovery.
32. *Sea turtles*: The Kemp's ridley is the most endangered sea turtle species in the world, and it only nests in the Gulf of Mexico. It has made a remarkable recovery from the brink of extinction in the Gulf since conservation efforts focused on stressors affecting all life stages. The number of Kemp's ridleys in the Gulf has increased dramatically in recent years, and the population trajectory is promising.
33. *Avian resources*: The Gulf of Mexico is one of the most important places for birds in the Western Hemisphere because it has species whose major ranges are in both North and South America, and hosts a wide range of migrants. Nearly 400 species have been reported from the Gulf.
34. *Avian resources*: The high diversity of birds in the Gulf of Mexico is due to the Gulf's diversity of habitats, richness of marine-land interface, a gradient from tropical to temperate, and the geography of the Gulf which places it as the funnel point for Nearctic-neotropical migrants.
35. *Avian resources*: Most birds that use saltwater to brackish ecosystems are seabirds, herons and egrets, shorebirds, waterfowl, gulls, terns, and specialized marsh species such as clapper rail and seaside sparrow. Assessment of 15 indicator species for the Gulf shows that mottle ducks, black skimmer, and clapper rail have declined over the last 45 years, while brown pelican, great egret, and osprey have increased.
36. *Avian resources*: A higher species diversity of birds is found in the southern Gulf of Mexico, compared to the northern coast.
37. *Avian resources*: A higher percentage of some colonial species nesting in North America do so in Louisiana and Texas rather than elsewhere along the Gulf.

38. *Avian resources*: Habitat loss is the primary threat facing birds in the Gulf of Mexico, due to both natural and anthropogenic causes, and it is occurring at an ever-increasing-rate.
39. *Avian resources*: Populations of birds in the Gulf have varied greatly over the past 50 years; some have increased and some have declined.
40. *Marine mammals*: While 31 species of marine mammals have been listed for the Gulf of Mexico, only 28 are confirmed and 22 species occur commonly. These 22 species include one sirenian, the West Indian manatee, and 21 cetaceans (whales and dolphins); there are no porpoises, sea lions, fur seals, or true seals in the Gulf.
41. *Marine mammals*: The most ubiquitous and best-known cetacean in the Gulf is the common bottlenose dolphin, which occurs in coastal bays and estuaries, as well as nearshore and deeper waters. Numerically, the most common cetacean is the pantropical spotted dolphin, but the one with most biomass is the sperm whale, which is common in mid-depth waters off Louisiana and the shelf break off Texas.
42. *Marine mammals*: The sperm whale and West Indian manatee are listed as endangered in the United States, but sperm whales are doing reasonably well worldwide, and there is no reason to believe that the Gulf of Mexico population is in imminent peril. The manatee numbers are in the low thousands of animals off Florida, subject to mortality largely due to periodic cold spells and recreational boat collisions, but hope exists as conservation, management, and public awareness efforts improve.
43. *Marine mammals*: Major anthropogenic threats exist for all marine mammals, but they do not appear to be as intensive in the Gulf of Mexico as in several other ocean basins. These threats include prey depletion, incidental mortality and injury due to fisheries, intentional and direct takes, vessel strikes, disturbance, acoustic (noise) pollution, chemical contamination, ingestion of solid debris, natural oil seeps, and aspects of ecosystem change.
44. *Diseases and mortalities*: There is no widespread monitoring program to measure the health of Gulf species or the Gulf ecosystem, but episodes of fish kills, infections, and abnormalities in marine species have been documented in the Gulf of Mexico for decades. Eutrophication and associated low oxygen have led to fish mortality in certain areas, and red tides, severe cold, excessive heat and hypersalinity have caused localized mass mortalities. A virus caused a massive, widespread die-off of catfish from Texas to Florida in 1996.
45. *Diseases and mortalities*: Parasites and various diseases have caused stress and mortality in selected invertebrates, fish, turtles, birds, and mammals of the Gulf of Mexico for decades, but there is no widespread metric or system to track the health of these animals in the Gulf of Mexico ecosystem.

REFERENCES

Bolten AB, Crowder LB, Dodd MG, MacPherson SL, Musick JA, Schroeder BA, Witherington BE, Long KJ, Snover ML (2011) Quantifying multiple threats to endangered species: An example from loggerhead sea turtles. Front Ecol Environ 9:295–301

Bricker SB, Clement CG, Pirhalla DE, Orlando SP, Farrow DRG (1999) National estuarine eutrophication assessment: Effects of nutrient enrichment in the nation's estuaries. NOAA (National Oceanic and Atmospheric Administration), National Ocean Service, Special

Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, MD, USA, 328 p

Bricker SB, Longstaff B, Dennison W, Jones A, Boicourt K, Wicks C, Woerner J (2007) Effects of nutrient enrichment in the nation's estuaries: A decade of change. NOAA coastal ocean program decision analysis series 26. National Centers for Coastal Ocean Science, Silver Spring, MD, USA, 328 p

Briggs JC (1974) Marine zoogeography. McGraw Hill, New York, NY, USA, 475 p

Bright TJ, Kraemer GP, Minnery GA, Viada ST (1984) Hermatypes of the Flower Garden Banks, Northwestern Gulf of Mexico: A comparison to other western Atlantic reefs. Bull Mar Sci 34:461–476

Britton JC, Morton B (1989) Shore ecology of the Gulf of Mexico. University of Texas Press, Austin, TX, USA, 387 p

Brooks J, Fisher C, Roberts H, Bernard B, MacDonald I, Carney R, Joye S, Cordes E, Wolff G, Goehring E (2008) Investigations of chemosynthetic communities on the lower continental slope of the Gulf of Mexico, interim report 1. OCS study MMS 2008–2009. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA, USA, 332 p

Buster NA, Holmes CW (eds) (2011) Gulf of Mexico origin, waters, and biota, vol 3, Geology. Texas A&M University Press, College Station, TX, USA, 446 p

Capurro LRA, Reid JL (eds) (1972) Texas A&M University oceanographic studies, vol 2, Contributions on the physical oceanography of the Gulf of Mexico. Gulf Publishing Company, Houston, TX, USA, 288 p

Caso M, Pisanty I, Ezcurra E (eds) (2004) Diagnostico Ambiental del Golfo de Mexico, vols 1 and 2. Instituto Nacional de Ecologia, Mexico DF, 1108 p

Cato JC (ed) (2009) Gulf of Mexico origin, waters, and biota, vol 2, Ocean and coastal economy. Texas A&M University Press, College Station, TX, USA, 110 p

CEC (Commission for Environmental Cooperation) (2007) North America Elevation 1-Kilometer Resolution Map, 3rd edn. Collaborators include U.S. Department of the Interior, USGS, National Atlas of the U.S. CEC, Montréal, Québec, Canada. http://www.cec.org/Page.asp?PageID¼924&ContentID¼2841&SiteNodeID¼497&BL_ExpandID¼. Accessed 19 Jan 2015

Cordes EE, McGinley MP, Podowski EL, Becker EL, Lessard-Pilon S, Viada S, Fisher CR (2008) Coral communities of the deep Gulf of Mexico. Deep-Sea Res 55:777–787

CSA International Inc (2007) Characterization of northern Gulf of Mexico deepwater hard bottom communities with emphasis on *Lophelia* corals. OCS MMS 2007-044. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA, USA, 169 p

Darnell RM (2015) The American Sea—a natural history of the Gulf of Mexico. Texas A&M University Press, College Station, TX, USA, 554 p

Darnell RM, Defenbaugh RE (1990) Gulf of Mexico. Environmental overview and history of environmental research. Am Zool 30:3–6

Davis RA Jr (2011) Sea-level change in the Gulf of Mexico. Texas A&M University Press, College Station, TX, USA, 172 p

Davis RA Jr (2014) Beaches of the Gulf Coast. Texas A&M University Press, College Station, TX, USA, 244 p

Day JW, Yanez-Arancibia A (2013) Gulf of Mexico origin, waters, and biota, vol 4, Ecosystem-based management. Texas A&M University Press, College Station, TX, USA, 446 p

Fautin D, Dalton P, Incze LS, Leong JC, Pautzke C, Rosenberg A, Sandifer P, Sedberry G, Tunnell JW Jr, Abbott I, Brainard RE, Broudeur M, Eldredge LG, Feldman M, Moretzsohn F, Vroom PS, Wainstein M, Wolff N (2010) An overview of marine biodiversity in United States waters. PLoS One 5(8), e11914. doi:10.1371/journal.pone.0011914

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

FishBase (2013) http://fishbase.org/. Accessed 31 May 2013

French CD, Schenk CJ (2005) Shaded relief image of the Gulf of Mexico (shadedrelief.jpg). USGS, Central Energy Resources Team, Reston, VA, USA. http://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470L/graphic/data.htm. Accessed Jan 2015

Galtsoff PS (1954) Gulf of Mexico. Its origin, waters and marine life: Fishery bulletin of the Fish and Wildlife Service, fishery bulletin 89. U.S. Government Printing Office, Washington, DC, USA, 604 p

Gore RH (1992) The Gulf of Mexico: A treasury of resources in the American Mediterranean. Pineapple Press, Sarasota, FL, USA, 384 p

Kumpf H, Steidinger K, Sherman K (eds) (1999) The Gulf of Mexico large marine ecosystem: Assessment, sustainability, and management. Blackwell Science, Inc., Malden, MA, USA, 704 p

MacDonald IR, Fisher C (1996) Life without light. National Geographic, October:86–97

Martin RG, Bouma AH (1978) Physiography of the Gulf of Mexico. In: Bouma AH, Moore GT, Coleman JM (eds) Framework, facies, and oil-trapping characteristics of the upper continental margin. Am Assoc Petrol Geol Stud Geol 7:3–19.

McEachran JD, Fechhelm JD (1998) Fishes of the Gulf of Mexico, vol 1. University of Texas Press, Austin, TX, USA, 1112 p

McEachran JD, Fechhelm JD (2005) Fishes of the Gulf of Mexico, vol 2. University of Texas Press, Austin, TX, USA, 1004 p

NMFS (National Marine Fisheries Service) USFWS (United States Fish and Wildlife Service) (2008) Recovery plan for the Northwest Atlantic population of the Loggerhead Sea Turtle (*Caretta caretta*): second revision. Office of Protected Resources, National Marine Fisheries Service, Silver Spring, MD, USA, 325 p

NMFS, USFWS, SEMARNAT (Secretary of Environment and Natural Resources, Mexico) (2011) Bi-national recovery plan for the Kemp's Ridley Sea Turtle (*Lepidochelys kempii*), second revision. National Marine Fisheries Service, Silver Spring, MD, USA, 174 p

NOS (National Ocean Service), NOAA (2011) The Gulf of Mexico at a glance: A second glance. U.S. Department of Commerce, Washington, DC, USA, 51 p

Pequegnat WE, Chace FA (eds) (1970) Texas A&M University oceanographic studies, vol 1, Contributions on the biology of the Gulf of Mexico. Gulf Publishing Company, Houston, TX, USA, 270 p

Rezak R, Edwards GS (1972) Carbonate sediments of the Gulf of Mexico. In: Rezak R, Henry VJ (eds) Contributions on the geological and geophysical oceanography of the Gulf of Mexico, Texas A&M University Oceanography Studies 3. Gulf Publishing Company, Houston, TX, USA, pp 263–280

Rezak R, Henry VJ (1972) Contributions on the geological and geophysical oceanography of the Gulf of Mexico, vol 3, Texas A&M University oceanography studies. Gulf Publishing Company, Houston, TX, USA, 303 p

Rezak R, Bright TJ, McGrail DW (1985) Reefs and banks of the Northwestern Gulf of Mexico. John Wiley & Sons, New York, NY, USA, 259 p

Ritchie KB, Keller BD (eds) (2008) A scientific forum on the Gulf of Mexico: The islands in the stream concept. Marine sanctuaries conservation series NMSP-08-04. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program, Silver Spring, MD, USA, 108 p

Ritchie KB, Kiene WE (eds) (2012) Beyond the horizon: A forum to discuss a potential network of special ocean places to strengthen the ecology, economy and culture of the Gulf of Mexico. In: Proceedings of the forum, Mote Marine Laboratory, Sarasota, FL, USA, May 11–13, 2011, 138 p

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson M, Halpern BS, Jorge MA, Lombana A, Lourie SA, Martin KD, McManus E, Molnar J, Recchia CA, Robertson J (2007) Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. BioScience 57:573–583

Sturges W, Lugo-Fernandez A (eds) (2005) Circulation in the Gulf of Mexico: Observations and models. American Geophysical Union, Washington, DC, USA, 347 p

Tunnell JW Jr (2009) The Gulf of Mexico. In: Earle SA, Glover LK (eds) Ocean: An illustrated atlas. National Geographic Society, Washington, DC, USA, pp 136–137

Tunnell JW Jr, Judd FW (eds) (2002) The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, TX, USA, 346 p

Tunnell JW Jr, Chavez EA, Withers K (eds) (2007) Coral reefs of the Southern Gulf of Mexico. Texas A&M University Press, College Station, TX, USA, 194 p

U.S. Department of Commerce (2011) Fisheries economics of the United States, 2009: Economics and sociocultural status and trends series. U.S. Dept. Commerce, NOAA Technical Memorandum NMFS-F/SPO-118. https://www.st.nmfs.noaa.gov/st5/publication/index.html. Accessed 12 Feb 2013

USEPA (U.S. Environmental Protection Agency) (2001) National coastal condition report. EPA/620-R-01-005. Office of Research and Development and Office of Water, Washington, DC, USA

USEPA (2004) National coastal condition report II. EPA/620-R 03-002. Office of Research and Development and Office of Water, Washington, DC, USA

USEPA (2008) National coastal condition report III. EPA/842-R-08-002. Office of Research and Development and Office of Water, Washington, DC, USA

USEPA (2012) National coastal condition report IV. EPA/842-R-10-003. Office of Research and Development and Office of Water, Washington, DC, USA

Weddle RS (1985) Spanish Sea: The Gulf of Mexico in North American Discovery, 1500–1685. Texas A&M University Press, College Station, TX, USA, 457 p

Whelan J (2004) When seafloor meets ocean, the chemistry is amazing. Originally published online February 13, 2004: in print vol 42, no 2, April 2004. http://www.whoi.edu/oceanus/viewArticle.do?id=2441. Accessed 14 Sept 2014

Wilkinson T, Wiken E, Bezaury-Creel J, Hourigan T, Agardy T, Herrmann H, Janishevski L, Madden C, Morgan L, Padilla M (2009) Marine ecoregions of North America. Commission for Environmental Cooperation, Montreal, Canada, 200 p

Withers K, Nipper M (eds) (English translation) (2009) Environmental analysis of the Gulf of Mexico, vols 1 and 2. Harte Research Institute for Gulf of Mexico Studies, special publication no. 1. Available as e-book only on HRI website, 710 p

Würsig B, Jefferson TA, Schmidly DJ (2000) The marine mammals of the Gulf of Mexico. Texas A&M University Press, College Station, TX, USA, 232 p

Yoskowitz D, Leon C, Gibeaut J, Lupher B, Lopez M, Santos C, Sutton G, McKinney L (2013) Gulf 360: State of the Gulf of Mexico. Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX, USA, 52 p