3. Ecosystem Setting

What Is in This Chapter?

- **Executive Summary**
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- **The Gulf of Mexico: A Nationally Important Resource (Section 3.2):** What human and economic activities depend on Gulf coastlines, waters, and natural resources?
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- **Biota of the Northern Gulf of Mexico (Section 3.6):** What forms of birds and aquatic life, from bacteria and microscopic plankton to dolphins and whales, are found in the northern Gulf?
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Executive Summary

The northern Gulf of Mexico comprises a vast regional ecosystem—an interactive, interdependent network of organisms (from microbes to plants to animals) and their chemical, biological, and physical environment. Ranging from the coastline itself, to its bays and estuaries, to the expansive continental shelf, to the vast open ocean and deep sea, the northern Gulf of Mexico ecosystem contains some of the nation's most diverse and productive natural resources.

The northern Gulf's extensive network of coastal wetlands, estuaries, and barrier islands support important populations of fish and wildlife; help maintain water quality; protect shorelines from storm surge and wave action; and provide enormous enjoyment for the American people. The northern Gulf of Mexico regional ecosystem supports economically valuable recreation and tourism industries; many of the nation's most commercially and recreationally important fish and shellfish species, such as oysters, shrimp, red snapper, and tuna; a diverse and vast array of bird species; and many federally protected species, including whales, dolphins, sea turtles, and the Gulf sturgeon. These complex species and communities are supported by tiny (e.g., single-celled) and benthic (bottom-dwelling) organisms in the water column and ocean floor that play an integral role in the northern Gulf's food web.

The biota of the northern Gulf of Mexico ecosystem reside in an interconnected fabric of linked habitats, including nearshore intertidal marshes, mangroves, submerged aquatic vegetation, sand beaches, and oyster reefs; the estuarine, shelf, and offshore water column (including the highly productive *Sargassum* habitat); and soft-bottom habitats, mesophotic reefs, and deep-sea corals.

The northern Gulf is subject to a wide variety of natural stressors (e.g., drought, fluctuating temperatures, hurricanes, land subsidence, sea-level rise, and saltwater intrusion) and human stressors (e.g., river channelization causing alteration of important wetland flooding and sedimentation regimes; residential development; industrial activities including oil and gas extraction contributing to land loss; agricultural and wastewater discharges; trawling impacts to the sea floor; and invasive species).

Because of its physical and biological connectivity, the northern Gulf of Mexico ecosystem is a complex web, in which physical processes and biological interactions in one location may have an important impact on organisms in other locations. This connectivity means that an impact on one part of the regional ecosystem can have cascading impacts throughout the greater northern Gulf ecosystem. The Trustees' injury assessment and restoration alternatives presented in this Final PDARP/PEIS are based on an understanding of the nature, extent, connectivity, and importance of the northern Gulf of Mexico ecosystem resources.

3.1 The Ecosystem Context for PDARP/PEIS Development

The northern Gulf of Mexico comprises a vast regional ecosystem—an interactive, interdependent network of organisms (from microbes to plants to animals) and their chemical, biological, and physical environment. Ranging from the coastline itself, to its bays and estuaries, to the expansive continental shelf, to the vast open ocean and deep sea, the northern Gulf of Mexico ecosystem contains some of the nation's most diverse and productive natural resources.

> **The Northern Gulf of Mexico Ecosystem**
>
> An ecosystem is an interactive, interdependent network of organisms—from microbes to plants to animals—and their chemical, biological, and physical environment.
>
> Ranging from the coastline through the continental shelf to the open ocean and deep sea, the vast northern Gulf of Mexico regional ecosystem contains some of the nation's most diverse and productive natural resources.

The northern Gulf's extensive network of coastal wetlands, estuaries, and barrier islands support important populations of fish and wildlife; help maintain water quality; protect shorelines from storm surge and wave action; and provide enormous enjoyment for the American people. Sand beaches stretch along hundreds of miles of the northern Gulf coast, providing important habitat for wildlife such as birds and sea turtles, and supporting economically valuable recreation and tourism industries. The coastal habitats and waters of the northern Gulf of Mexico support many of the nation's most commercially and recreationally important fish and shellfish species, such as oysters, shrimp, red snapper, and tuna; a diverse array of bird species; as well as many federally protected species, including whales, dolphins, sea turtles, and the Gulf sturgeon.

All these resources were threatened, and many were injured, as a result of the *Deepwater Horizon* oil spill incident. The Trustees based their approach to assessing this injury (described in Chapter 4, Injury to Natural Resources), as well as developing restoration alternatives (described in Chapter 5, Restoring Natural Resources), on an in-depth understanding of the northern Gulf of Mexico ecosystem resources.

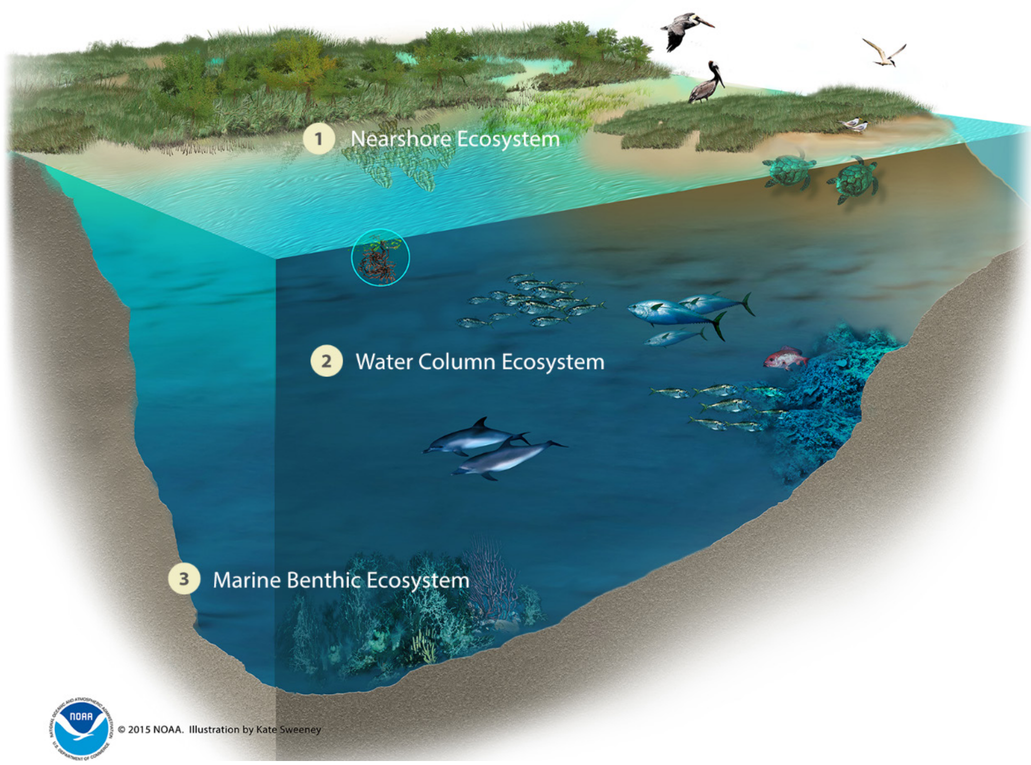
Due to the northern Gulf ecosystem's diversity and complexity, the vast area affected by the oil spill, and the practical challenges of performing scientific studies in some remote areas, it was scientifically and financially impractical for the Trustees to study every species, habitat, and ecological process. Instead, studies focused on *representative* species and habitats. Then, applying an understanding of fundamental ecological relationships and processes, the Trustees made reasonable scientific inferences (see Section 4.11.3, Use of Inference to Assess Natural Injuries not Directly Measured by Trustees) from the study results to assess injury to northern Gulf ecosystem resources and services that were not explicitly studied.

To provide context for understanding the Trustees' injury assessment and restoration recommendations in this Final PDARP/PEIS, this chapter describes the northern Gulf of Mexico regional ecosystem and the wealth of natural resources and services it provides.

Components of the Northern Gulf of Mexico Ecosystem

As a regional ecosystem, the northern Gulf can be divided into component ecosystems—the marine benthic, water column, and nearshore ecosystems—each defined by particular characteristics (see Figure 3.3-1 below). Energy, materials, and organisms move across these ecosystems, creating linkages throughout the larger Gulf of Mexico ecosystem, the Caribbean Sea, and the Atlantic Ocean. Ecosystems contain organisms, communities, and habitats.

- A ***community*** is a group of one or more species that interact within a region. For example, distinct communities of fish are found at different vertical depths in the northern Gulf.
- ***Organisms*** live in ***habitats*** that support them by providing food, shelter, and other needs. Important habitats in the northern Gulf of Mexico include coastal marshes, oyster reefs, dunes, beaches, the water column, and the sea bottom.



1 **Nearshore Ecosystem:** The interconnected habitats between land and the Gulf's open waters, including coastal marshes, mangroves, beaches, dunes, barrier islands, submerged aquatic vegetation, oyster reefs, shallow unvegetated areas, and mudflats. Critical for fish and shellfish life stages and home to birds, sea turtles, and mammals.

2 **Water Column Ecosystem:** Extends from nearshore to the open ocean and from the ocean surface to the ocean floor. Home to a rich community of small planktonic plants and animals, fish, crustaceans, marine mammals, and sea turtles.

3 **Marine Benthic Ecosystem:** The ocean floor, from the continental shelf to the deep sea. Consists of diverse habitats, including sand, mud, and reefs. Home to rare corals, fish, crabs, and myriad small animals and microbes.

Source: *Kate Sweeney for NOAA.*

Figure 3.1-1. The three components of the northern Gulf of Mexico ecosystem.

3.2 The Gulf of Mexico: A Nationally Important Resource

The Gulf of Mexico, shown in Figure 3.2-1, covers approximately 600,000 square miles (EPA 2014), extending across the five Gulf states—Texas, Louisiana, Mississippi, Alabama, and Florida—south to Mexico and east to Cuba. Millions of people live, work, and recreate in the Gulf region, relying on its natural and physical resources. The human communities of the Gulf of Mexico coast are founded on their relationship to the Gulf's resources and their connections to the local environment. Economic activities critical to the region are dependent on Gulf coastlines, waters, and natural resources. They include commercial fishing, tourism and recreation, oil and gas production, and shipping and waterborne commerce:

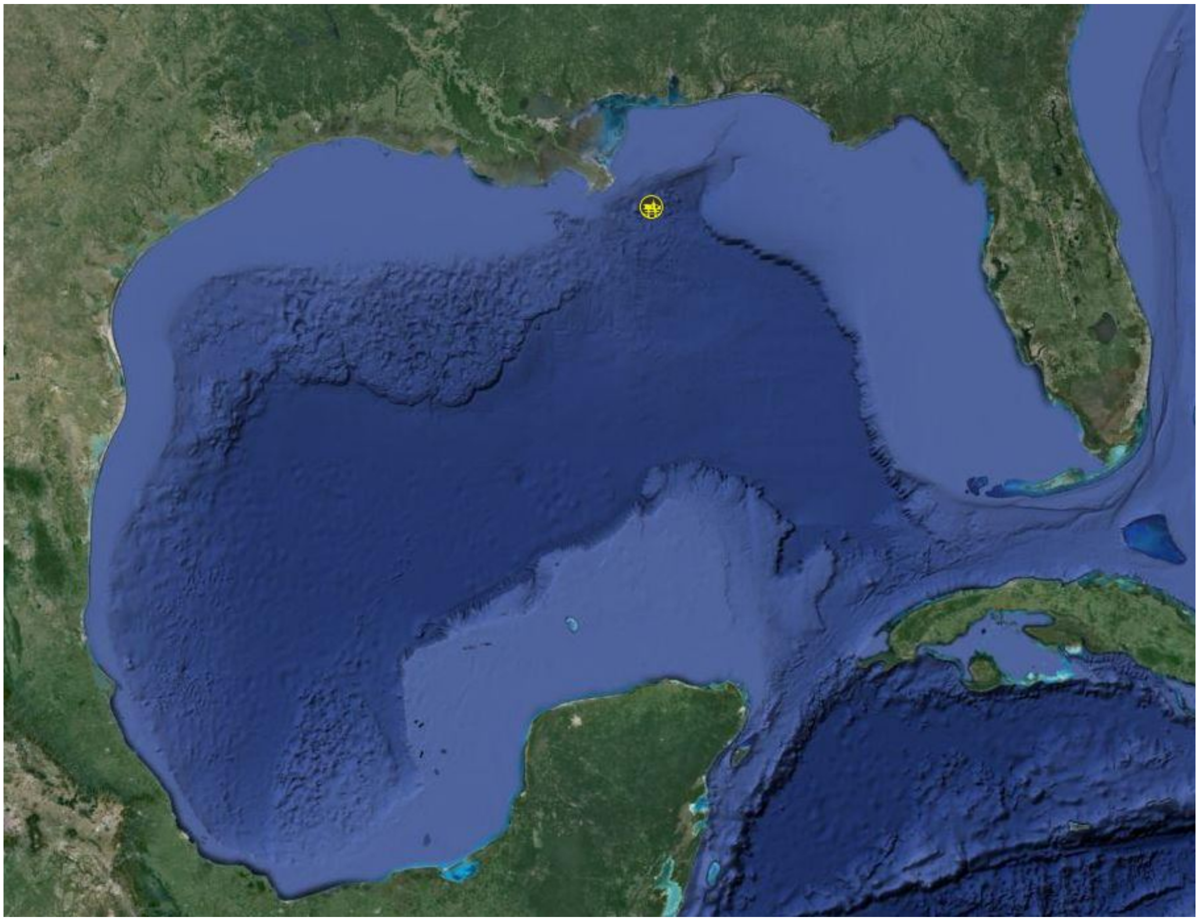
- **Commercial fishing.** The northern Gulf fisheries (within the U.S. Exclusive Economic Zone) are among the most productive in the world and support both commercial and recreational industries. Commercial fishing supports the livelihood of many northern Gulf residents and is an important part of the nation's domestic supply of seafood. In 2009, the year before the *Deepwater Horizon* oil spill, U.S. commercial fishermen in the Gulf of Mexico landed 1.6 billion pounds of finfish and shellfish (NMFS 2011). The northern Gulf also supports a highly popular and profitable recreational fishery for species such as red snapper, red drum, and tuna.

> The northern Gulf of Mexico supports many nationally important commercial fisheries for species such as blue crab, grouper, menhaden, mullet, oysters, red snapper, tuna, and shrimp.

- **Tourism and recreation.** Tourism and recreation are an important part of the regional economy and are highly dependent on the natural resources of the northern Gulf. Tourists are attracted to the northern Gulf of Mexico by its white sand beaches, warm weather, and a range of recreational activities, including swimming, sunbathing, recreational fishing, and boating; wildlife and bird viewing; whale watching and dolphin cruises; and scuba diving and snorkeling. Parks, refuges, and wilderness areas provide recreational opportunities for local residents and tourists and protect our natural and human heritage.

- **Oil and gas production.** The northern Gulf of Mexico is one of the most important regions for energy resources in the United States and the most important for coastal and offshore oil and gas production. As of 2015, more than 2,300 platforms were operating in the northern Gulf (BSEE 2015). Prior to its April 20, 2010, explosion, the *Deepwater Horizon* was one such drilling rig—operating approximately 50 miles offshore on a well that reached the sea floor about a mile below the ocean surface.

- **Shipping and waterborne commerce.** The U.S. economy relies heavily on the ports in the northern Gulf of Mexico region for the import and export of both foreign and domestic goods. The Gulf of Mexico region supports many ports that lead the nation in total commerce (NOAA 2011).



Source: *ERMA (2015).*

Figure 3.2-1. The Gulf of Mexico covers approximately 600,000 square miles, and is bordered by the five Gulf states, Mexico, and Cuba. A yellow marker shows the location of BP's Macondo well.

3.3 The Mississippi River and Northern Gulf of Mexico Geomorphology

The northern Gulf of Mexico's geography and geomorphology, described in this section, create the structural platform for the northern Gulf's complex, interconnected, and productive ecosystem. This platform provides the foundation for a continuous gradient of habitats, from upland terrestrial and riverine habitats, through marsh, estuarine, and beach habitats, across reef habitat, and into deep-sea habitat.

3.3.1 Mississippi River and Delta Influence

The Mississippi River has a profound influence on the Gulf of Mexico ecosystem. The Mississippi flows more than 2,000 miles from Minnesota, delivering nutrients and sediments into the northern Gulf from a drainage area covering approximately 40 percent of the continental United States, from Montana to New York (Figure 3.3-1) (NPS 2015). The river has shaped the coastline, affects ocean circulation, and supplies large quantities of fresh water, sediments, and nutrients that influence a large part of the northern Gulf of Mexico ecosystem.

Source: *National Park Service.*

Figure 3.3-1. The Mississippi River, the fourth longest river in the world, flows more than 2,000 miles from Minnesota to the Gulf of Mexico. Its drainage extends over about 40 percent of the continental United States and covers an area of approximately 1.2 million square miles.

The Mississippi Delta, formed over the past 6,000 years where the river enters the northern Gulf, contains a vast complex of wetlands that grade from freshwater swamps and marshes farther inland, to brackish marshes closer to the Gulf. Nearly 40 percent of the coastal wetlands in the continental United

States lie within southern Louisiana as a result of the great river's actions (USGS 2015). Historically, a balance was maintained between wetland formation and loss through erosion, as the river periodically changed course within the delta. However, the amount of sediment reaching these wetlands has been greatly reduced because of Mississippi River management practices adopted for the important purposes of maintaining navigation and flood control. Additionally, dredging canals for oil and gas exploration and pipelines, sea-level rise, and subsidence all contribute to the ongoing loss of coastal wetlands. Since the 1930s, Louisiana has lost 1,880 square miles of land through erosion, with the risk of losing an additional 1,750 square miles of land in the next 50 years if actions are not taken to reduce this threat (CPRA 2012).

3.3.2 Impact of River Flows on Northern Gulf Geography and Water Quality

River flows into the northern Gulf of Mexico have shaped the geography of the coastline and affect the salinity and water quality of the nearshore northern Gulf waters. The average annual discharge from the Mississippi River at New Orleans is 600,000 cubic feet per second (NPS 2015) or 1.5 billion cubic meters per day. The fresh water and sediment mix with the salt water of the northern Gulf, creating extensive areas of biologically rich estuarine and offshore habitats. Freshwater and sediment inflows also serve as a source of pollution from upstream agriculture, stormwater runoff, industrial activities, and wastewater discharges. In bottom water (the lowermost layer of ocean water), low oxygen availability (a condition known as hypoxia) is a major water quality problem in portions of the northern Gulf of Mexico and its estuaries, caused in large part by nutrient loading from river inflows. The input of nutrient-rich fresh water to the coastal area fuels phytoplankton blooms in the water column. Following the eventual transportation of dead and decaying plant material to the ocean floor, this organic-rich biomass undergoes decomposition by bacteria and results in the depletion of oxygen at depth.

3.3.3 The Northern Gulf's Geomorphological Zones

Moving seaward from the coastline, the northern Gulf of Mexico basin can be described by broad geomorphological zones, including the coastal transition zone, the continental shelf, the continental slope, and the abyssal plain (Figure 3.3-2):

- The bays, estuaries, wetlands, and barrier islands rim the coastline and constitute the **coastal transition zone.**[1]
- The **continental shelf**[2] extends from the barrier islands to the shelf break, and its width varies throughout the basin. The inner continental shelf is characterized not only by shallower waters, but also a gentle slope of a few meters per kilometer (MMS 2006). The outer continental shelf is deeper and extends typically to the 660-foot (201-meter) depth contour (BOEM 2012).

[1] As appropriate to the resource being discussed, this zone includes areas that may be referred to in the document as the coastal and/or nearshore environment.

[2] The continental shelf zone (especially adjacent to the coastal transition zone) also includes areas that may be incorporated in discussions of the coastal and/or nearshore environment.

- Extending from the edge of the shelf to the abyssal plain, the **continental slope** is a steep area with diverse features, such as canyons, troughs, and salt structures.
- Depths on the **abyssal plain** exceed 10,000 feet (Darnell & Defenbaugh 1990).

Source: *ERMA (2015).*

Figure 3.3-2. The northern Gulf of Mexico basin can be divided into broad geomorphological zones, which include coastal transition areas, the continental shelf, the continental slope, and the abyssal plain. BP's Macondo well was located on the continental slope, nearly a mile below the surface and approximately 50 miles offshore from where the Mississippi River enters the Gulf.

3.4 The Northern Gulf Ecosystem: An Interconnected Fabric

The resources and habitats (Section 3.5) of the northern Gulf of Mexico are linked through physical processes and biological relationships (Figure 3.4-1), including:

- Food web dynamics that affect the transfer of energy and matter from primary producers to consumers to apex predators.
- The movement of organisms between habitats.
- The transport of nutrients, sediments, and organic matter (including marine organisms and their reproductive elements) between nearshore and offshore habitats and between surface waters and the sea bottom.

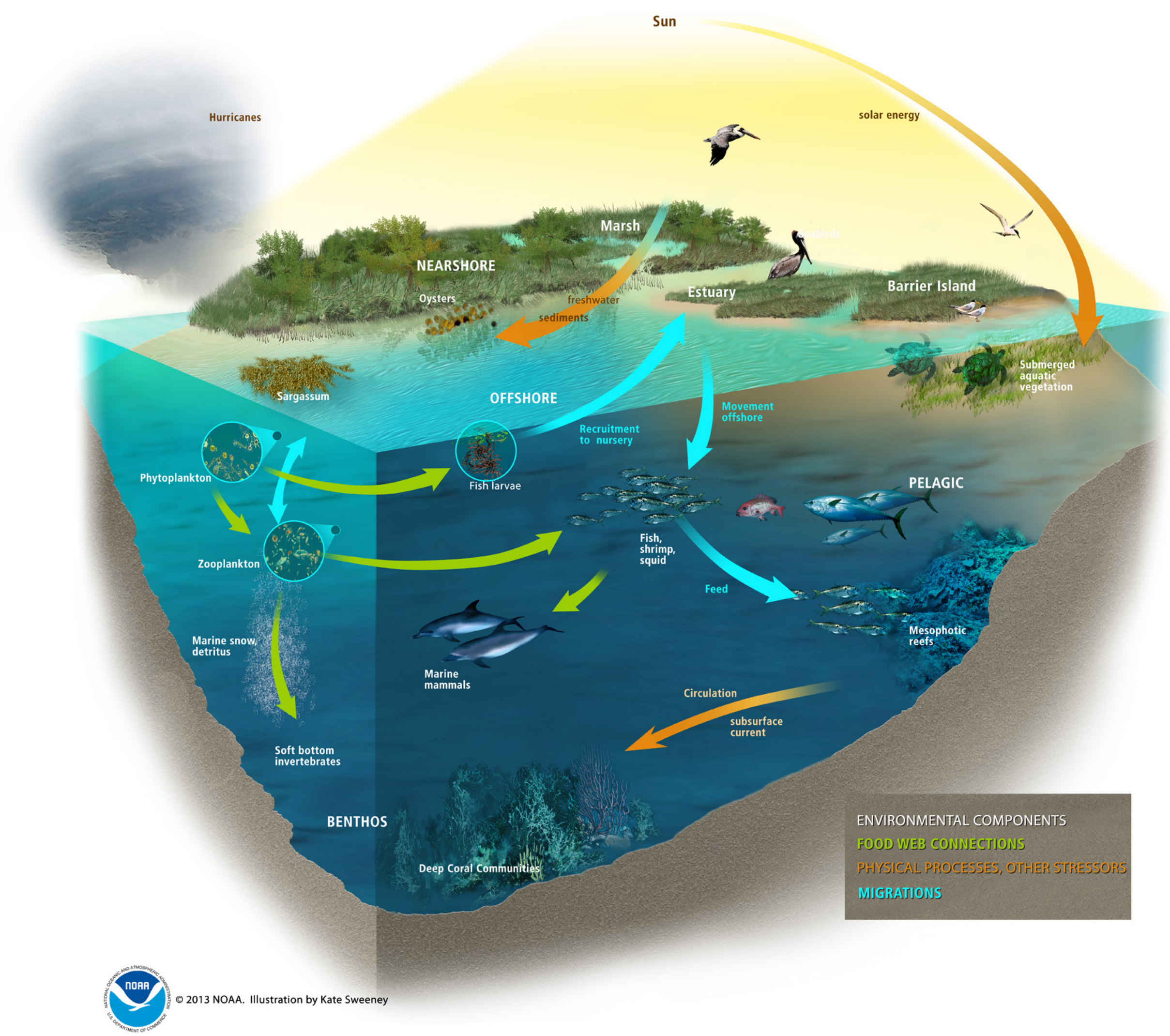
These processes and relationships play important roles in the structure and function of the northern Gulf of Mexico ecosystem.

The connectivity provided by these biological relationships is described below in Sections 3.4.1 to 3.4.3. Physical processes also provide connectivity across northern Gulf habitats. For example, processes governing the movement of water, such as freshwater inundation, winds, ocean currents, and tidal fluctuations, make it possible for nutrients and sediment to be transported, and biota to move into, and interact with, physically distinct geographies and habitats.

Both physical processes and biological movements occur across different timescales, from daily tidal cycles providing small fish and shrimp with access to the rich feeding grounds of flooded marsh platforms, to longer lifecycle timeframes. For example, sea turtles nest and lay eggs on beach habitats, but spend much of their lives in the open ocean, feeding on algae, jellyfish, and other invertebrates, sometimes traveling many thousands of miles along the coastline and across the open waters of the Gulf (Spotila 2004). Many migratory bird species use Gulf coastal habitats as stopover locations, where they feed and rest on the way to breeding grounds worldwide (Condrey et al. 1996).

The physical and biological connectivity of the northern Gulf of Mexico ecosystem results in a complex web, wherein physical processes and biological interactions in one location may have an important impact on populations of organisms in other locations. The linkages and the close relationship between physical and biological connectivity means that when one part of the regional ecosystem is affected, it can have cascading impacts throughout the greater northern Gulf of Mexico regional ecosystem. Similarly, restoration benefits to one part of the ecosystem—especially when occurring at large spatial scales—can have cascading benefits throughout the greater northern Gulf ecosystem.

> The northern Gulf of Mexico is a complex and interconnected ecosystem. Injuries to one habitat or species can have cascading impacts throughout the greater northern Gulf of Mexico regional ecosystem. The same can hold true for restoration benefits.

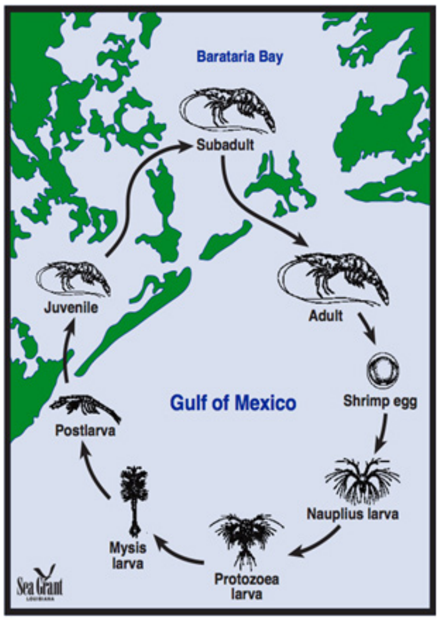


Source: *Kate Sweeney for NOAA.*

Figure 3.4-1. The northern Gulf of Mexico ecosystem is connected through food webs, physical processes, the movement of organisms, and the flow of nutrients.

3.4.1 Biological Connectivity Across the Northern Gulf Regional Ecosystem

Predator-prey relationships create an interconnected web of organisms, with energy flowing from primary producers, such as phytoplankton, through a number of trophic linkages, to top predators, such as tuna, sharks, and pelicans (e.g., Althauser 2003; de Mutsert et al. 2012; Masi et al. 2014; Tarnecki et al. 2015). Because of these relationships, injuries to components of these predator-prey networks can have broad direct and indirect ecological consequences (Fleeger et al. 2003; Fodrie et al. 2014; Peterson et al. 2003; Tarnecki et al. 2015).



Source: *Matherne (2013).*

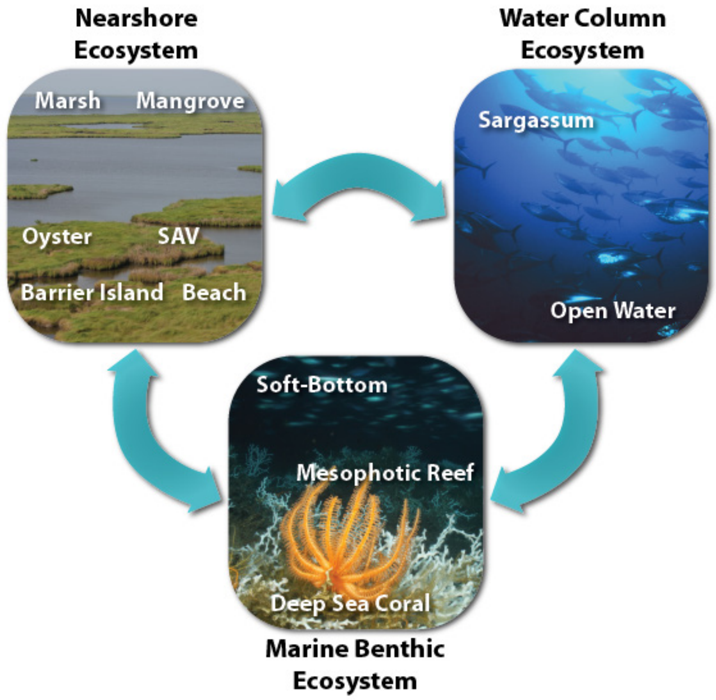
Figure 3.4-2. The life cycle of the brown shrimp, showing utilization of distinct Gulf habitats by different life stages.

The **movement of species** between habitats is another important ecological characteristic of the northern Gulf ecosystem. Nearshore organisms like shrimp and economically important fish species that depend on marshes and estuaries during the early part of their life cycle move to offshore environments as adults to spawn (Able 2005; Able & Fahay 1998; Day et al. 2013; O'Connell et al. 2005), linking these two habitats and their respective food webs (Figure 3.4-2). Gulf sturgeon, designated as a threatened species under the Endangered Species Act, is an anadromous species found in the northern Gulf of Mexico, foraging in coastal waters during the winter months but migrating into river systems to spawn during the summer (FWS & GSMFC 1995; FWS & NOAA 2003). Sea turtles also move across and depend on shoreline and offshore habitats during different parts of their life cycle (Spotila 2004). In addition, a number of different species (including zooplankton, fish, and marine mammals) move vertically in the water column in response to food availability and predation (e.g., Block et al. 2001; Ducklow et al. 2001; Miller 2004; Nybakken 2001; Teo et al. 2007; Würsig et al. 2000), thus transporting energy (from food) and organic matter between the surface and deep water environments. Sperm whales, for example, have been documented to dive to depths of over 1.9 miles to feed (Würsig et al. 2000). In addition to movement within the Gulf of Mexico, some organisms migrate over great distances and across hemispheres, connecting this ecosystem globally. For example, many species of birds migrate annually to the Gulf of Mexico from South America, the northern United States, or Canada, using the coastal beaches and marshes as migratory stopovers or overwintering habitat (Condrey et al. 1996). Bluefin tuna have been found to migrate from their spawning grounds in the northern Gulf of Mexico to the northern Atlantic during the summer months (Teo et al. 2007).

Nutrients, sediment, and organic matter are also transported horizontally and vertically through the water column. Currents and winds move water horizontally, connecting the highly productive and nutrient-rich waters of the coastal zone with the more oligotrophic (lower nutrient) offshore waters (Miller 2004; Nybakken 2001). This horizontal transport of material also occurs at smaller scales, with the tidal movement of detritus from the vegetated shorelines to adjacent shallow waters (e.g., Day et al. 2013). Vertically, organic matter is transported from the surface to deep water zones through the sinking of dead or dying plant and animal material as well as fecal matter (Ducklow et al. 2001; Miller 2004; Nybakken 2001). The decomposition of this organic material releases nutrients that may be upwelled from dark deep water zones into surface water, where they stimulate more primary production (Miller 2004; Nybakken 2001).

3.5 Habitats of the Northern Gulf of Mexico

The northern Gulf of Mexico is home to a diverse variety of habitats that extend from the shoreline to offshore areas, and from the water surface to the sea floor (Figure 3.5-1). In Sections 4.4 through 4.10 in Chapter 4, the Trustees assess the degree to which resources or the use of those resources were harmed by the *Deepwater Horizon* incident.



Source *(clockwise from upper left): USFWS, NOAA, NOAA.*

Figure 3.5-1. The northern Gulf of Mexico supports a variety of habitats and communities in the nearshore, water column, and marine benthic ecosystems. Organisms and nutrients move among and between these local ecosystem zones, supporting the overall connectivity of the larger northern Gulf of Mexico regional ecosystem.

3.5.1 Nearshore Ecosystem

The nearshore ecosystem of the northern Gulf of Mexico includes a diverse array of interconnected habitats that form a transition zone from upland freshwater and terrestrial habitats, to the open Gulf environment. These vast, biologically diverse and inter-related habitats stretch from Texas to Florida along the U.S. Gulf coast. Important habitats in this nearshore ecosystem include coastal marshes, mangroves, beaches and dunes, barrier islands, submerged aquatic vegetation (SAV), oyster reefs, shallow unvegetated areas, and mudflats.

These nearshore habitats are among the most biologically productive coastal waters in the United States. They provide invaluable spawning, nursery, and feeding grounds for the many commercial and recreational fish and shellfish species that depend on the estuary to complete their lifecycles (EPA

1999). They also are home to many species of birds, sea turtles, and mammals. Through the movement and transport of organisms and nutrients, the nearshore ecosystem is linked to and supports the health and productivity of the offshore ecosystem.

3.5.1.1 Marshes

The northern Gulf of Mexico is recognized for its vast coastal tidal wetlands (Figure 3.5-2), which are estimated to represent half of the total saltwater intertidal wetland habitat in the lower 48 states (Dahl & Stedman 2013). Louisiana alone contains nearly 40 percent of coastal wetlands in the continental United States (USGS 2015). These marshes play a critically important role in buffering coastal areas against storm and wave damage and attenuating flooding. They also help protect water quality by capturing suspended sediment and removing excess nutrients and pollutants from upland environments (Bricker et al. 1999; Fisher & Acreman 2004).

Source: *USFWS Refuge Staff/USFWS.*

Figure 3.5-2. Marsh habitat, Cameron Prairie National Wildlife Refuge, Louisiana.

The marsh edge, in particular, serves as a critical and highly productive transition zone between the emergent marsh vegetation and open water. It is important for the movement of organisms and nutrients between intertidal and subtidal estuarine environments (Levin et al. 2001), and supports high densities of fish and crustacean species at its interface (Baltz et al. 1993; Minello et al. 2008; Minello & Rozas 2002; Peterson & Turner 1994).

Marshes are also important habitats for terrestrial animals, including amphibians, reptiles, and mammals, and support extraordinary bird species diversity. These habitats are especially important for birds, because many different species nest, forage, or loaf in the varying types of marshes in the northern Gulf of Mexico. Also, three major bird flyway corridors (routes between wintering grounds and summer nesting grounds)—the Central, Mississippi, and Atlantic—occur within the Gulf, whose marshes migratory species use either as winter habitat or as stopover as they migrate further south (USACE 2009).

Source: *LDWF (2005).*

Figure 3.5-3. Black mangrove habitat, Louisiana.

3.5.1.2 Black Mangroves

Black mangroves are found along the barrier islands and fringing salt marshes of the northern Gulf of Mexico (Figure 3.5-3). Black mangrove habitat helps stabilize and protect shorelines and is an essential feeding and nursery habitat for juvenile fish such as snapper (FDEP 2015; FWS 1999). The root-like projections, known as pneumatophores, that emerge from the water and soil provide excellent habitat for small organisms. Some species of colonial water birds, such as herons, egrets, and pelicans, build nests in mangroves and forage in or near mangroves (FWS 1999).

3.5.1.3 Barrier Islands

Barrier islands are the first line of defense for the coastline against storms (Figure 3.5-4). Barrier islands help create estuarine systems and protect the associated emergent and submerged estuarine habitats from high offshore wave energy (Hester et al. 2005; O'Connell et al. 2005). They also provide important habitats for a diverse array of wildlife, including nesting sites for colonial shorebirds and nursery grounds in back-barrier marshes for fish and aquatic invertebrates (Hester et al. 2005; O'Connell et al. 2005).

Source: *Erik Zobrist, NOAA photo library.*

Figure 3.5-4. Chandeleur barrier islands, Louisiana.

3.5.1.4 Beaches and Dunes

Beaches and dunes are ecologically, recreationally, and economically important shoreline habitats that serve as important breeding, nesting, wintering, and foraging habitats for nearshore biota. Found along mainland shorelines and barrier islands throughout the northern Gulf of Mexico, sand beaches are home to a host of small and large organisms:

- Crabs, clams, shrimp, snails, and other small organisms live and feed on and within the sand and beach wrack (decomposing vegetation washed up on the shore by the surf).
- Northern Gulf of Mexico beaches are also vitally important habitat for some of the world's most recognized marine species, including the federally protected loggerhead sea turtle (Figure 3.5-5), which nests on sand beaches in the northern Gulf of Mexico (Dow et al. 2007).
- Sand beaches and dunes are also breeding and nesting habitat for many resident and migratory bird species. For example, northern Gulf of Mexico beaches are home to approximately 70 percent of the wintering

Threatened or Endangered Species That Utilize Sand Beaches and Dunes in the Northern Gulf of Mexico

- Loggerhead turtle (*Caretta caretta*)—Endangered.
- Kemp's ridley turtle (*Lepidochelys kempii*)—Endangered.
- Green turtle (*Chelonia mydas*)—Threatened, except for the Florida breeding population, which is endangered.
- Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*), Alabama beach mouse (*P. polionotus ammobates*), Choctawhatchee beach mouse (*P. polionotus allophrys*), St. Andrew beach mouse (*P. polionotus peninsularis*)—Endangered.
- Piping plover (*Charadrius melodus*)—Threatened throughout the winter range.
- Rufa red knot (*Calidris canutus rufa*)—Threatened throughout its range.

population of the threatened piping plover (Elliott-Smith et al. (2009), as cited in Brown et al. (2011)).

- The Perdido Key, Choctawhatchee, St. Andrew, and Alabama beach mouse all live their entire lives in coastal sand dunes and are dependent upon all components of the dune system, from high elevation scrub, where they can survive flooding during storm events, to beach wrack, in which they forage.

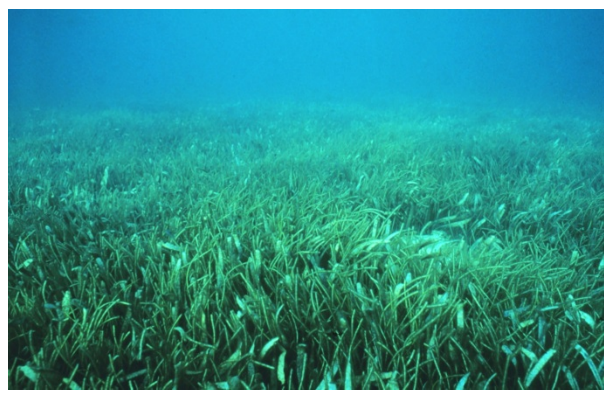
Source: *National Park Service.*

Figure 3.5-5. Kemp's ridley sea turtle depositing eggs in her nest on a beach at Padre Island National Seashore, Texas.

In addition to serving as habitat, these beaches and the coastal strand play a key physical role in the ecosystem, acting as a buffer from storms and hurricanes for other habitats and human communities. They also provide a diverse array of recreational opportunities for people, including swimming, fishing, or simply relaxing in the sand.

3.5.1.5 Submerged Aquatic Vegetation

Among the most productive of coastal habitats, submerged aquatic vegetation provides habitat, food, and shelter for fish, shellfish, invertebrates, and other aquatic species. SAV is found throughout the Gulf states, primarily in shallow water and lagoon habitats (Figure 3.5-6). It is estimated that the northern Gulf of Mexico has greater than 50 percent of the total U.S. distribution of seagrasses and at least 5 percent of the known global occurrences (Green & Short 2003).



Source: *H. Dine, NOAA photo library.*

Figure 3.5-6. Turtlegrass *(Thalassia testudinum),* a type of submerged aquatic vegetation.

3.5.1.6 Oyster Habitat

Oysters are integrated throughout the coastal ecosystem in both nearshore and subtidal areas, creating habitat for other aquatic organisms (such as shellfish, crabs, and finfish), stabilizing shoreline areas, and improving water quality and clarity through their filtering action (Grabowski & Peterson 2007). Intertidal oyster beds provide foraging sites at low tide, when the shellfish are accessible to American oystercatchers, a shorebird. Oyster beds above mean high tide serve a critical function for oystercatchers by providing foraging and high-quality, high tide roost sites. Commercial oysters are predominantly harvested from subtidal areas that state management agencies have designated as open to harvest. Oyster reefs in nearshore or subtidal waters designated as closed to harvest can act as sanctuary areas for oysters spawning stock. In some states, oysters and other bivalves can colonize human-made reefs, which provide oyster habitat that is not subject to commercial harvest.

3.5.2 Water Column Ecosystem

The water column ecosystem is an ever-changing habitat under the influence of winds, currents, tides, and vertical mixing processes. It is home to a rich community of small planktonic plants and animals, fish and crustaceans, marine mammals, and sea turtles.

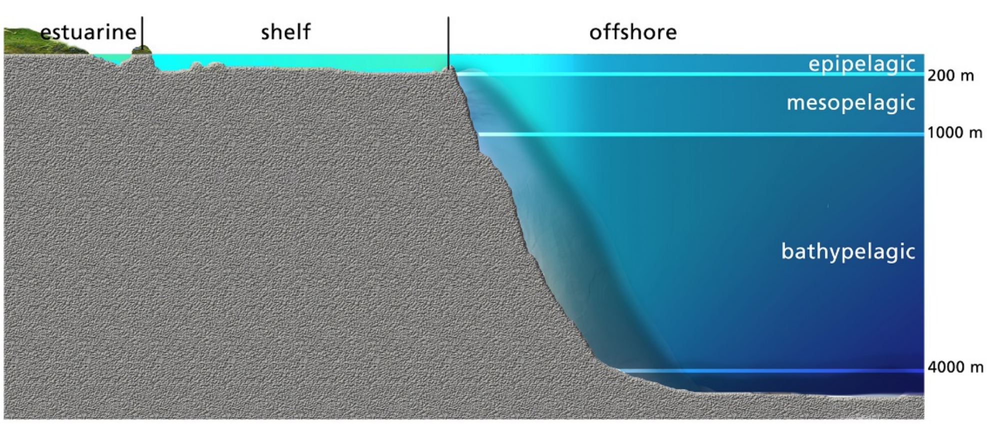
Horizontally, the water column can be separated into estuarine, shelf, and offshore waters (Figure 3.5-7). Offshore waters can be further refined into three layers, according to depth:

- The **epipelagic zone** extends from the ocean surface to a depth of about 650 feet (200 meters). Sunlight can penetrate this zone, which supports photosynthesizing organisms, such as phytoplankton (small, single-celled organisms that live in the water) that convert light from the sun into energy via photosynthesis, just like terrestrial plants (Miller 2004; Nybakken 2001). Although many of these organisms are invisible to the naked eye, they are a critical component of the Gulf of Mexico food web and ecosystem. Currents and tides move organisms, organic matter, and nutrients horizontally in the epipelagic zone. For example, they transport fish eggs and larvae from the open ocean to protected estuaries and bays where young fish can hide from predators and grow (Day et al. 2013; O'Connell et al. 2005). *Sargassum*, a floating marine macro-alga, creates an important offshore habitat at the surface for juvenile fish and turtles, providing both shelter and food.

- In the **mesopelagic zone**, which extends from about 650 to 3,300 feet (200 to 1,000 meters) below the ocean surface, there is some light but not enough for photosynthesis. Organisms that live in this part of the water column include octopus, squid, and many fish species.

- At still greater depths (3,300 to 13,120 feet; 1,000 to 4,000 meters) is the **bathypelagic zone**, also known as the "midnight" zone because no light penetrates to these depths. In this zone, temperatures drop and organisms are adapted to life without light.

Water Column Areas and Zones



Source: *Kate Sweeney for NOAA.*

Figure 3.5-7. The horizontal and vertical zonations of the water column.

3.5.3 Marine Benthic Ecosystem

Spanning from the continental shelf to the deep sea, the northern Gulf of Mexico marine benthic ecosystem is composed of diverse and abundant habitats, including soft-bottom habitats consisting of sand or mud, hard substrate habitats, mesophotic reefs, and deep-sea coral communities. Rare corals, fish, crabs, and myriad small animals and microbes live in these diverse habitats on the sea bottom and are important links within the benthic food web.

- **Soft-bottom habitat.** In the northern Gulf of Mexico, the majority of the ocean floor is soft-bottom habitat, characterized by a mixture of sand, clay, and silt sediments (Rowe & Kennicutt II 2009). This habitat supports a diverse assemblage of organisms living within or on the sediment, including crustaceans, gastropods, bivalves, and worms, as well as many larger animals such as fish, crabs, and sea cucumbers, which live and feed on the sea floor (MMS 2006).
- **Hard substrate habitat.** Including artificial reefs, oil and gas platforms, and natural reef or rock substrates, hard substrate habitat accounts for 4 percent of the total area of the marine benthic habitat. These habitats can occur both nearshore and offshore and support a wide variety of marine life, with species differences reflecting depth and other environmental factors.
- **Mesophotic reefs.** Mesophotic reefs are coral reefs that exist at the lowest depths to which light penetrates through the ocean waters, occurring up to depths of 650 feet (200 meters). These reefs harbor diverse species of corals and associated animals, including fish, anemones, sponges, and sea cucumbers. Mesophotic reefs may serve as a refuge for recolonization of shallow water coral populations (Kahng et al. 2010). One important mesophotic community in the northern Gulf of Mexico is the Pinnacles reef, found along the edge of the continental shelf south of Mississippi and Alabama in depths of 196 to 295 feet (60 to 90 meter).
- **Deep-sea corals.** In the deep sea, corals colonize rocky outcroppings that cover a very small percentage of the ocean floor (Figure 3.5-8). They are known to support a diverse assemblage of associated organisms that may be orders of magnitude higher in abundance when compared to the surrounding sediment (CSA 2007). The deep-sea reefs form complex three-dimensional structures made up of diverse coral species that provide shelter and food for many other invertebrates and fish. Coral branches support sponges, anemones, clams, starfish, and sea urchins. Large mobile predators such as fish and crabs also live between the coral branches. Deep-sea corals are slow growing and can live for over 1,000 years.

Source: *NOAA photo library.*

Figure 3.5-8. Deep-sea coral.

3.6 Biota of the Northern Gulf of Mexico

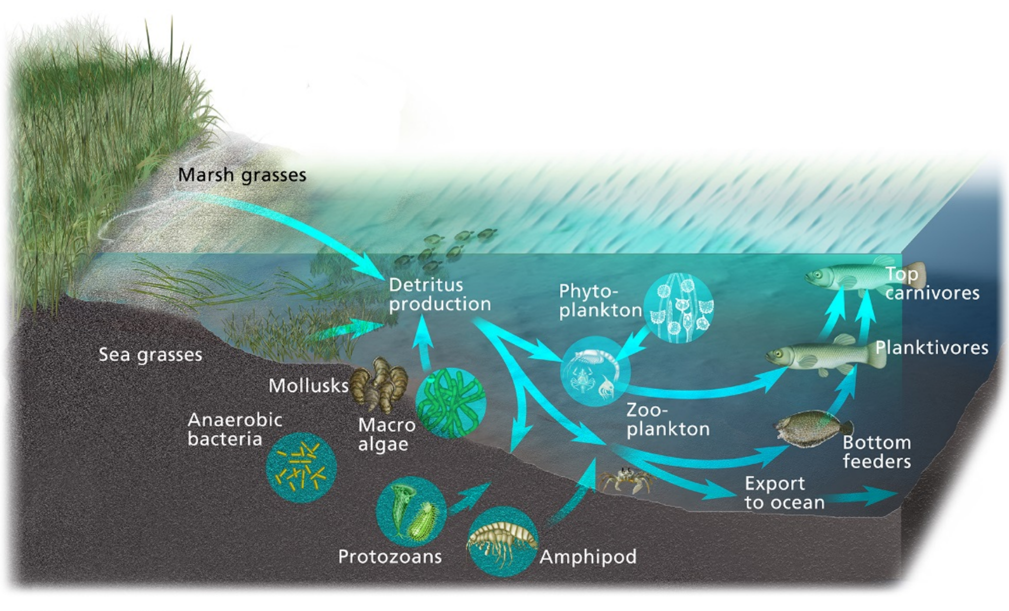
As described below, the northern Gulf of Mexico supports complex food webs composed of a wide range of aquatic and terrestrial biota, from bacteria and microscopic plankton to dolphins and whales. In Sections 4.4 through 4.9 in Chapter 4, the Trustees assess the degree to which these resources were harmed by the *Deepwater Horizon* oil spill incident.

3.6.1 Phytoplankton and Zooplankton

The base of the aquatic food web consists of very small single-celled to multi-cellular organisms, such as phytoplankton and zooplankton (Figure 3.6-1). Similar to terrestrial plants, phytoplankton require sunlight and nutrients to grow. Common types of phytoplankton include diatoms and dinoflagellates (Miller 2004). Zooplankton, in contrast, are planktonic animals (i.e., they float or drift with tides and currents) and include single-celled protozoans, such as foraminifera; gelatinous zooplankton, such as jellyfish; crustaceans, such as copepods; and vertebrates,

Fish Early Life Stages

Most marine fish are broadcast spawners, releasing thousands of eggs into the water column to become fertilized. After hours to days, these fertilized eggs (embryos) hatch into planktonic larvae. On average, only one out of every few thousand to million fish larvae survive to a year in age. The rest are likely eaten by larger organisms, serving as an important food base for the Gulf of Mexico food web.



Source: Kate Sweeney for NOAA. Modified from Day et al. (2013).

Figure 3.6-1. Food web diagram for a typical estuarine ecosystem showing feeding links among some of the major trophic groupings. Blue lines and arrows indicate flow of food from source to consumer.

such as larval fish (Miller 2004). These small creatures, some so small that they are invisible to the naked eye, play an integral role in the Gulf of Mexico food web. They serve as an important food source to other animals, supporting an increasingly complex web of species and communities, including fish and shellfish, marine mammals, sea turtles, birds, and terrestrial wildlife.

3.6.2 Benthic Organisms

Benthic organisms live in or just above bottom sediments in the intertidal and estuarine zones, as well as throughout the continental shelf and deep sea. Benthic organisms are another important food source for birds, fish, marine mammals, and other animals. Mollusks (clams, mussels, oysters, snails), sponges, polychaetes (marine worms), and amphipods (small shrimp-like crustaceans) are examples of benthic organisms. As shown in Figure 3.6-2, nearshore oysters are found fringing along salt marshes.

3.6.3 Fish and Crustaceans

A huge diversity of fish and crustaceans are found in the northern Gulf of Mexico (Felder & Camp 2009), which supports some of the most productive commercial and recreational fisheries in the world (EPA 2014; NMFS 2012). These species serve as both predators and prey, and depend on a range of Gulf of Mexico habitat types during their growth and development. Estuarine-dependent species, such as brown shrimp, spotted sea trout, red drum, and southern flounder, are found in coastal estuaries during at least one part of their life cycle (Able 2005; Able & Fahay 1998; Day et al. 2013; O'Connell et al. 2005) and can be described as either facultative (they may benefit from using estuarine habitat, but do not require that habitat for survival or reproduction) or obligate (without estuarine habitat, the species could not survive and/or reproduce). For example, many commercially and recreationally important species rely on coastal estuaries as nursery grounds and migrate offshore as adults to spawn (O'Connell et al. 2005), making them important vectors in the movement of energy from the nearshore to shelf and offshore systems.

Coastal and oceanic species, such as sardines, mackerels, and tunas, spend their entire life in the pelagic environment. Mid- and deep water column species, such as lanternfish, bristlemouths, shrimp, mysids, and squid, are found within the mesopelagic zone of the water column (Hopkins et al. 1994; Hopkins & Sutton 1998; Passarella & Hopkins 1991) and have adapted to little or no light and low food availability (Miller 2004). Commercially and recreationally important shelf reef fish, such as groupers and snappers, congregate around reefs on the continental shelf (Addis et al. 2013; Dance et al. 2011). The threatened Gulf sturgeon is one anadromous fish species

Source: *Earl Melancon*

Figure 3.6-2. Marsh and nearshore oyster habitats in Louisiana.

found in the coastal waters of the northern Gulf of Mexico during the winter months (FWS & GSMFC 1995; FWS & NOAA 2003).

3.6.4 Marine Mammals

Marine mammals, including dolphins and whales, are highly intelligent, long-lived animals with complex and important social structures. Marine mammals are found in bays, sounds, estuaries, continental shelf waters, and deeper oceanic waters (Würsig et al. 2000). Marine mammals inhabiting the northern Gulf of Mexico have adapted strategies to exploit many of the available habitats in the northern Gulf ecosystem (Heithaus & Dill 2009). For example, bottlenose dolphins—shown in Figure 3.6-3—living in bays, sounds, and estuaries primarily eat fish and shellfish, while oceanic dolphins eat fish and squid (Würsig et al. 2000). Many species are top-level predators that depend on a wide variety of resources within a given habitat. All marine mammals are protected under the Marine Mammal Protection Act, which prohibits actions that may cause injury or disruption to marine mammal activities such as migration, nursing, breeding, and feeding.

Source: *USFWS.*

Figure 3.6-3. Bottlenose dolphin.

3.6.5 Sea Turtles

Sea turtles move across many habitats throughout their lives, and different species rely on distinct food sources. Five sea turtle species are found within the Gulf of Mexico, all of which are listed under the Endangered Species Act: the green turtle, the hawksbill, the loggerhead (Figure 3.6-4), the Kemp's ridley (Figure 3.5-5, above), and the leatherback. Throughout their life history, sea turtles rely on both marine and terrestrial habitats and, thus, connect ocean and land. For example, sea turtles returning to beach nesting sites transport marine nutrients to terrestrial environments, which helps fertilize and enhance beach vegetation cover (Bouchard & Bjorndal 2000). In the marine environment, sea turtles use a variety of habitats, including open ocean, continental shelf areas, and *Sargassum*. Sea turtles are specialized feeders; each species typically relies on one primary food source, which ranges from seagrass to sponges, jellyfish, and other prey items (Bjorndal 1997).

Source: *USFWS.*

Figure 3.6-4. Loggerhead sea turtle hatchlings.

3.6.6 Birds

Birds found in the Gulf of Mexico include waterfowl and other water-dependent species, pelagic seabirds, raptors, colonial water birds, shorebirds, marsh-dwelling birds, and passerines. Many Gulf birds use a broad range of habitats at different life and migratory stages, from feeding and resting in the open water to nesting and rearing young in estuarine and marsh, as well as beach and dune, habitats. Others are more uniquely tied to a single habitat—such as the clapper rail and seaside sparrow, which live their entire lives within small areas in coastal marshes, and are referred to as "secretive marsh birds" due to their camouflage and elusive nature. The northern Gulf of Mexico is also home to many important bird colonies, including colonies that host the highest abundance found anywhere in the world for some species. Figure 3.6-5 shows one such colonial bird species.

Source: *James C. Leupold/USFWS.*

Figure 3.6-5. Reddish egret, a colonial water bird found in the Gulf of Mexico.

In addition to being home to Gulf residents, the northern Gulf of Mexico is vitally important migration and wintering habitat for birds. Parts of the Central, Mississippi, and Atlantic flyways (well-described routes between wintering grounds and summer nesting grounds) are used by hundreds of millions of birds that converge on the northern Gulf Coast, where they migrate along the northern Gulf Coast before reaching their destination, follow the Mexico-Texas coastline, or cross the Gulf between Mexico's Yucatan Peninsula and the Texas Coast. For many species, such as white pelican, common loon, and a variety of waterfowl and shorebirds, the coastal areas in the northern Gulf provide important wintering habitat. Additionally, portions of the shoreline in the northern Gulf of Mexico have been designated as critical habitat for wintering threatened and endangered piping plovers.

3.7 Environmental Stressors Affecting the Northern Gulf

Like many coastal regions, the northern Gulf of Mexico environment has been affected by a variety of human-induced stressors and natural stressors (e.g., drought, fluctuating temperatures, hurricanes, sea-level rise, and land subsidence [sinking]). Human stressors have contributed to coastal land loss, water quality impairment, and harm to aquatic species, as described below.

Understanding these stressors provides a necessary context to inform planning and actions to restore the health and integrity of the northern Gulf in a sustainable manner. Restoration actions provide opportunities to mitigate anthropogenic stressors and thus yield tangible ecosystem benefits. Such mitigation must be considered in planning restoration projects to ensure sustainable ecological success.

3.7.1 Coastal Habitat Loss

Coastal habitat loss is an important and ongoing challenge in managing the coastal resources of the northern Gulf of Mexico. Prevalent in all Gulf states, coastal land loss is most severe in Louisiana (CPRA 2012). It results from a combination of factors, including river channelization that alters important wetland flooding and sedimentation regimes, oil and gas channelization within marshes, land subsidence, and sea-level rise. Numerous additional anthropogenic impacts, such as dredging, filling, and residential development, have also limited the sustainability and resiliency of many coastal habitats.

3.7.2 Water Quality Impairment

Nutrients, sediments, and pollutants flow into the Gulf of Mexico from upstream agriculture, stormwater runoff, industrial activities, and wastewater discharges. These inputs impair water quality, resulting in degradation and loss of aquatic habitats. Low oxygen availability (known as hypoxia) is a particularly important water quality issue in portions of the northern Gulf of Mexico. Hypoxia occurs in the bottom water layer along a large area on the Louisiana and Texas continental shelf, and in at least 105 distinct locations within northern Gulf of Mexico estuaries such as Weeks Bay, Alabama (NOAA 2011).

3.7.3 Fishing Impacts

Fishing can impact the water column food web, as well as benthic habitats. The effects of discarded bycatch[3] of aquatic organisms from fishing activities in inshore, nearshore, and offshore waters is an ongoing challenge to resource management. Many key species, including non-targeted catch of bluefin tuna, sea turtles, and marine mammals, are affected through bycatch. In addition, trawling operations

[3] The Magnuson-Stevens Fishery Conservation and Management Act (16 USC §§ 1801-1884) defines bycatch as "[f]ish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch and release fishery management program." A second definition, inclusive of resources other than managed fish species, is identified in NOAA's National Bycatch Report (Karp et al. 2011) as "[d]iscarded catch of any living marine resource plus retained incidental catch and unobserved mortality due to a direct encounter with fishing gear." Both definitions are relevant in this document.

can physically damage benthic habitats, including both soft- and hard-bottom areas, and cause large quantities of sediment to resuspend and redeposit, posing a smothering risk to benthic organisms.

3.7.4 Invasive Species

In both aquatic and terrestrial environments, invasive species pose environmental threats, often displacing native species. Invasive aquatic species include lionfish, orange cup coral, Asian tiger shrimp, and green mussel. Invasive terrestrial species includes plants, such as Chinese tallow and cogongrass, as well as animals, such as nutria and feral hogs.

3.8 An Ecosystem-Level Approach to Restoration

As outlined in this chapter, biological and physical connections exist between and among nearshore habitats such as estuaries, coastal wetlands, beaches and dunes, nearshore sediments, SAV, and oyster reefs; between these nearshore habitats and the water column (including both nearshore and offshore locations, surface waters, and deeper oceanic layers); between deep benthic environments and the water column; between these habitats and the living organisms that make use of them; and between these habitats and organisms and the human uses of these resources. An understanding of these connections was fundamental to the Trustees' approach to both injury assessment and restoration planning.

In Chapter 4 (Injury to Natural Resources), the Trustees document the broad nature and extent of injuries to offshore and nearshore resources and the services those resources provide. The biological and physical connections described in Chapter 3 supported the Trustees' approach to the assessment. Their approach, described in Section 4.1 (Approach to the Injury Assessment), includes using reasonable scientific inference to determine that the injuries caused by the *Deepwater Horizon* incident extend beyond those identified in the injury studies. For example, if studies showed that a specific organism or habitat was injured by the incident, the Trustees reasonably inferred that the ecological functions or services provided by that organism or habitat were also injured. See Section 4.11.3 (Use of Inference to Assess Natural Injuries not Directly Measured by Trustees) for a detailed discussion of inference methods used.

> **An Ecosystem Approach to Restoration**
>
> An understanding of the northern Gulf of Mexico ecosystem provides a foundation for the Trustees' restoration plan.

In Chapter 5 (Restoring Natural Resources), the Trustees propose a restoration plan of sufficient size and scope to benefit a wide range of resources and ecosystem services. In developing their preferred restoration alternative (Section 5.5, Alternative A: Comprehensive Integrated Ecosystem Restoration), the Trustees sought to maximize the connections among resources, habitats, and human uses described in Chapter 3. Their intention was that implementing restoration projects that address different interacting and connected parts of the ecosystem will yield long-term benefits to the full range of resources and ecosystem services injured by the *Deepwater Horizon* incident.

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