SEER

U.S. OFFSHORE WIND SYNTHESIS OF ENVIRONMENTAL EFFECTS RESEARCH

ENVIRONMENTAL EFFECTS OF OFFSHORE WIND ENERGY IN THE GULF OF MEXICO

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1.0 INTRODUCTION TO THE GULF OF MEXICO AND OFFSHORE WIND

Introduction and Scope of Document

As planning for offshore wind energy in the United States (U.S.) Gulf of Mexico is currently underway, people and organizations in the region will need to understand how potential development could interact with the local and regional environment. Knowledge gained from industrial activity in the Gulf of Mexico combined with research from offshore wind energy projects in other domestic and international locations can help define the potential environmental effects of future offshore wind energy development. The purpose of this document is to synthesize current knowledge about the environmental effects of offshore wind energy on ecosystem processes, habitats, and wildlife in the U.S. Gulf of Mexico for a broad audience while providing links and references to supporting scientific documents for more detailed information. The scope of the following chapters includes interactions between the environment and offshore wind energy infrastructure but does not address effects on commercial activities, fisheries, or socioeconomics.

Ecological Background of the Gulf of Mexico

The Gulf of Mexico is a warm, semi-enclosed marginal sea of the western Atlantic Ocean that is approximately 1.5 million square kilometers (km^2) (580,000 square miles). Its seabed is characterized by a broad continental shelf, a geologically complex continental slope, and abyssal plains with water depths up to 4,000 meters (m) (13,000 feet [ft]). Waters from the Atlantic Ocean enter the Gulf of Mexico through the Loop Current, where warm water travels from the Caribbean into the Gulf, then out through the Florida Straits. Fresh water draining from the Mississippi and Atchafalaya Rivers deposit sediment and nutrients into the Gulf of Mexico that contribute to the biological productivity, particularly on the continental shelf near Louisiana.

The Gulf of Mexico has an estimated 15,000 resident and migratory species across its range of habitats [1]. These habitats include coastal marshes, mangroves, barrier islands, and deep-water abyssal plains, some of which are protected habitats, such as the Flower Garden Banks National Marine Sanctuary, that host a diverse set of plants and animals.

- Hundreds of species of birds are found within the region, including passerines, raptors, seabirds, waterfowl, shorebirds, and wading or marsh birds. Numerous bird species cross the Gulf of Mexico during their migrations.
- There are five bat species that potentially migrate across the Gulf of Mexico, including the hoary bat, northern yellow bat, red bat, Seminole bat, and Brazilian free-tailed bat. At least 150 species of flying insects, including monarch butterflies, occur offshore in the Gulf of Mexico.
- Diverse marine mammal and sea turtle communities are distributed throughout the Gulf of Mexico. The region is inhabited by 21 species of whales and dolphins (known as cetaceans) and five species of sea turtles (loggerhead turtle, green turtle, hawksbill turtle, Kemp's ridley turtle, and leatherback turtle).
- The Gulf of Mexico provides habitat for a high biodiversity of fish species, including 1,443 finfish species, more than 51 shark species, and at least 49 species of rays and skates. The region is especially known for commercially fished species such as shrimp, menhaden, oyster, crabs, spiny lobster, red snapper, and red grouper.

Human activities and resource extraction are connected to the environmental health and ecological change of coastal and marine habitats around the Gulf of Mexico. Overfishing, nutrient pollution, sea level rise, subsidence, and anthropogenic disasters, such as the Deepwater Horizon oil spill, have led to environmental damage. Understanding the potential environmental effects of offshore wind energy must be informed by and considered within the context of new or shifting human use patterns.

History of Industry in the U.S. Gulf of Mexico

The oil and gas industry has been interacting with the Gulf of Mexico ecosystem since offshore oil drilling began in 1942. In the U.S. Gulf of Mexico, there are more than 1,300 active oil and gas platforms [2], 26,000 miles of pipelines [3], and 570 decommissioned platforms that have been converted to permanent artificial reefs [4]. Following the Deepwater Horizon oil spill in 2010, the region received funding for environmental restoration and research to address the ecological damage caused by the spill. These restoration efforts and other research related to oil and gas infrastructure can support analysis and improve understanding of the potential effects of offshore wind in the region. For example, the relationship between oil and gas platforms and fish populations has been a topic of study for many years and could provide analogues to the effects of new offshore wind structures in the region.

Offshore Wind in the U.S. Gulf of Mexico

In 2021, the U.S. Bureau of Ocean Energy Management (BOEM) began a process to identify and lease areas for offshore wind development in federal waters[1] of the Gulf of Mexico (Figure 1.1). This siting process started by considering offshore areas in the western and central Gulf of Mexico from the state seaward boundary[2] out to 1,300 m (4,300 ft) water depth [5]. From this broad starting point, BOEM, with assistance from the National Oceanic

1 Federal waters are the economic exclusive zone of the U.S. extending to 200 nautical miles from the U.S. territorial sea.
2 The state seaward boundary is the line at which jurisdiction of submerged lands changes between state and federal control. The seaward boundary is 3 nautical miles from the coastline for all U.S. states except for Texas, Florida (Gulf Coast only), and Puerto Rico, where it is 9 nautical miles.

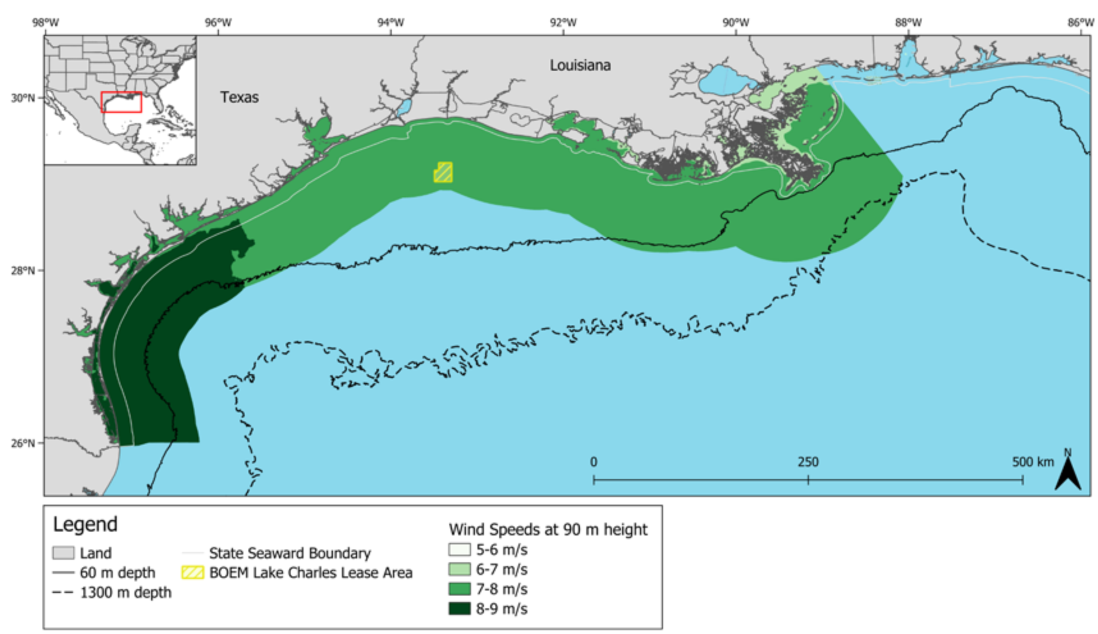

Figure 1.1. Offshore wind areas and wind speeds in the northwest Gulf of Mexico. The boundary of the wind speeds, shown in green, reflects the extent of the modeled wind speed data and does not align with any jurisdictional boundary. *Image from Pacific Northwest National Laboratory.*

and Atmospheric Administration's (NOAA's) National Centers for Coastal Ocean Science, identified 14 wind energy areas using a marine spatial planning approach that minimized or avoided overlap with protected species, vessel traffic, fish havens, and commercial and recreational fishing grounds [6]. Using this analysis, three wind energy areas were prioritized for an initial lease auction. In 2023, BOEM held an auction for these three areas. The auction resulted in the first lease for offshore wind energy in the Gulf of Mexico off the coast of Lake Charles, Louisiana (Figure 1.1); leases for the other two areas off the coast of Texas were not awarded [7]. Following the first lease sale, BOEM has continued to delineate potential call areas and issue requests to gauge commercial interest [8]. In addition to offshore wind energy in federal waters, Louisiana approved Operating Agreements for two offshore wind energy projects in state waters [9,10]. At the time of publishing, offshore wind is in the early phases of planning. Up-to-date information about planning and projects in federal waters can be found on BOEM's Gulf of Mexico Activities page.

Offshore wind energy in the Gulf of Mexico could include fixed-bottom turbines, which are directly attached to the seabed in shallow waters less than 60 m (200 ft) deep, or floating wind turbines, which are connected to the seabed with mooring lines and anchors in deeper waters (Figure 1.2). Given the large expanse of shallow continental shelf waters in the Gulf of Mexico, current planning includes only fixed-bottom wind turbines. Future development that may occur in deep waters farther from shore could make use of floating offshore wind technology that is generally suitable for waters up to 1,300 m (4,300 ft) deep. Each type of technology (Figure 1.2) will interact with the environment in different ways due to the seabed conditions, type of infrastructure introduced in the water column, and the location chosen. The Gulf of Mexico has unique environmental conditions, such as lower average wind speeds, softer soils, and increased risk of hurricanes compared to the U.S. Atlantic and Pacific coasts—these conditions may require specially designed wind turbines and foundations to optimize power generation and reliability.

Figure 1.2. Offshore wind foundation types for fixed-bottom turbines (three turbines on left) and floating wind turbines (three turbines on right). *Illustration by Josh Bauer, National Renewable Energy Laboratory.*

Using offshore wind turbines in the Gulf of Mexico to generate electricity would reduce greenhouse gas emissions compared to the natural-gas-fired power plants [11] that currently produce most of the region's electricity [12]. Along with the benefits of reducing emissions that exacerbate climate change, local and regional environmental effects from offshore wind energy development are considered throughout the siting and permitting process.

The remainder of this document presents the current state of knowledge of how offshore wind energy development may interact with the environment in the Gulf of Mexico. The document is split into short chapters that summarize potential effects on ecosystem processes (Chapter 2), habitats (Chapters 3 and 4), and wildlife (Chapters 5–10). Each chapter provides a summary of the topic, documents potential risks and environmental effects, describes monitoring and mitigation methodologies, and discusses knowledge gaps and research needs. Each chapter is intended to provide an educational overview of offshore wind's potential environmental effects in the Gulf of Mexico. For more detailed information about offshore wind environmental effects in the United States, refer to the 2022 U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER) Booklet [13] or browse available literature on the Tethys Knowledge Base.

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ECOSYSTEM PROCESSES AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Marine ecosystem dynamics and species distributions are strongly influenced by oceanographic processes, and it is important to understand how offshore wind energy might affect these processes.
- Collecting baseline oceanographic and biological data prior to development and implementing robust environmental monitoring programs are necessary for understanding potential effects of offshore wind energy on ecosystem processes.
- Data-driven models and research focused on the dynamics between physical and biological processes are critical to understanding the potential effects of offshore wind energy development on marine ecosystems.

TOPIC DESCRIPTION

The geographic and biophysical setting of the Gulf of Mexico supports a highly productive ecosystem that is home to diverse wildlife, including seabirds, marine mammals, sea turtles, fish, and other species [1]. The Gulf of Mexico is a marginal sea of the Atlantic Ocean (i.e., a large semi-enclosed ocean basin) with a climate that varies from subtropical in the north to tropical in the south [2,3]. The Loop Current is the dominant oceanographic feature in offshore waters, bringing warm waters into the Gulf of Mexico through the Yucatan Channel and exiting through the Florida Straits (Figure 2.1) [4]. Numerous rivers from North America, including the Mississippi River, drain into the Gulf of Mexico, bringing nutrients that support primary production in the northern Gulf [4,5]. During the summer, nutrient pollution from the Mississippi River causes high rates of primary production that contribute to one of the world's largest hypoxic zones (an area with low or reduced oxygen) [6]. The transport of riverine water offshore into the northern Gulf of Mexico is affected by seasonal wind patterns and offshore movement of the Loop Current and its associated eddies (Figure 2.1) [4]. Easterly winds drive westward surface currents in the northern Gulf of Mexico during much of the year, with disruption of winds by the episodic passage of cold fronts and a summertime seasonal shift to more southerly winds [7]. The Gulf of Mexico also experiences tropical cyclones and major hurricanes, which affect coastal ecosystems [8,9].

The physical and biological oceanography of the northern Gulf of Mexico is highly dynamic, resulting in variable phytoplankton and zooplankton productivity. Offshore waters of the Gulf of Mexico are generally low in nutrients and low in phytoplankton biomass

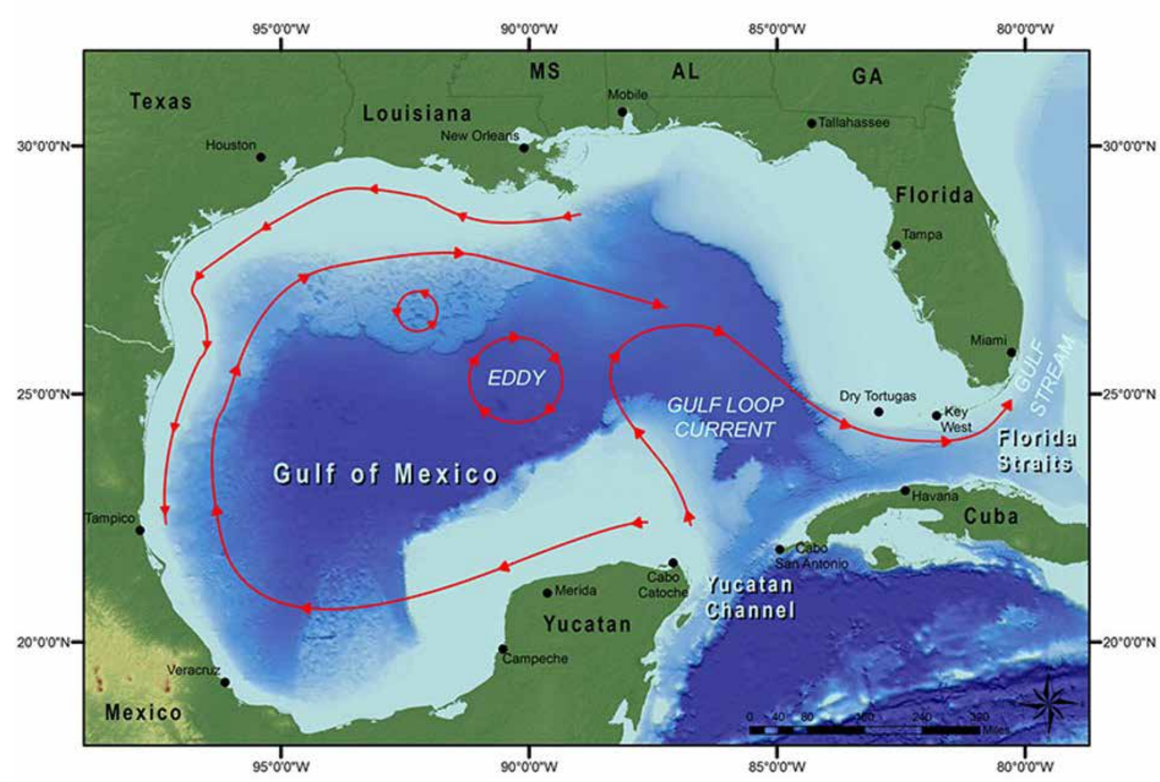

Figure 2.1. Bathymetry (depth; shown by shade of blue: darker = deeper) and generalized ocean current patterns (shown by the red arrows) in the Gulf of Mexico. *Image from Flower Garden Banks National Marine Sanctuary [10].*

compared to nearshore waters [11]. Chlorophyll concentrations (an indicator of phytoplankton in the water) demonstrate a clear seasonal cycle that is primarily triggered by the seasonal variation of the mixed layer depth (i.e., the thickness of the top layer of the ocean that is actively mixed by wind, waves, and currents resulting in uniform temperature and salinity). While the Loop Current contains low-nutrient waters, the edges of the Loop Current and its eddies have been associated with larval transport and higher productivity [12,13]. Depending on physical conditions such as river flows, wind patterns, and currents, as well as nutrient loads, the Mississippi River plume can extend over the deep Gulf and support high rates of primary productivity and large amounts of phytoplankton and zooplankton in waters farther offshore [13,14].

Over the last several decades, water in the Gulf of Mexico has been warming due to climate change, with a rate of warming in the upper water column that is about twice that of the global ocean [15]. The warming in the Gulf of Mexico could affect various physical and ecosystem processes, including sea level rise, hypoxic events, hurricane intensity, wetland loss, water column stratification, phytoplankton production, and dynamics across higher trophic levels of marine species. On longer timescales, the Atlantic Multidecadal Oscillation, a climate mode associated with variability of sea surface temperatures in the North Atlantic Ocean, is also considered to be a major physical driver in the region [16].

MAIN RISKS & EFFECTS

Marine ecosystem dynamics and species distributions in the Gulf of Mexico are strongly influenced by oceanographic conditions, such as sea surface temperature, primary productivity, sea surface height, surface current patterns, and bathymetric variables [17]. Understanding how offshore wind energy might impact these oceanographic processes informs the understanding of potential interactions with ecosystem dynamics.

Potential effects of offshore wind energy on oceanographic and ecosystem processes in the Gulf of Mexico may result from wind wake and hydrodynamic effects. Future wind energy structures in the region could have physical effects on the environment both above and below the water surface. Above the water, turbines generate electricity by extracting energy from the wind. Wind wake effects occur as energy is extracted; winds downstream from a turbine have less energy and reduced speeds compared to those upstream (Figure 2.2) [18]. In Europe, studies of wind farms have shown that wind speeds could be affected from several

Definitions of Oceanographic Processes

- **Downwelling:** Movement of surface water to deeper depths
- **Hydrodynamic effects:** Changes to the movement and structure of water
- **Scour:** Erosion of sediment around the base of a structure caused by hydrodynamic processes
- **Stratification:** Separation of ocean water into horizontal layers by density
- **Turbidity:** A measure of the level of particles, such as sediment, in a body of water
- **Upwelling:** Process where deep, nutrient-rich, cold water rises to the surface
- **Wind wake effect:** Reduced wind speeds in the wake downstream from a wind turbine

miles downstream of the wind turbine arrays up to tens of miles, depending on local conditions [18,19]. While such studies provide helpful insights, it is important to note that studies from other regions may not be directly comparable to the Gulf of Mexico. The potential scale of wind wake effects in the Gulf of Mexico, including the distance over which they persist beyond the turbines, will depend on multiple factors unique to the wind farm, including wind farm size, turbine spacing, and ambient wind speeds.

The presence of offshore wind structures and changes to the wind field can impact hydrodynamics directly and indirectly. In addition to affecting wind speeds, the extraction of wind energy has the potential to affect wave energy, turbulence, and eddy formation inside the wind farm's footprint and from downwind wakes [20,21]. Locally, upwelling, downwelling, and ocean currents may be affected, depending on local conditions and wind farm size [21]. At the regional scale, wind wake effects on hydrodynamics are challenging to understand, but models suggest changes in sea surface height may occur, which could affect ocean processes such as wave formation and mixing [22]. Research conducted on the effects of offshore wind farms on hydrodynamics in the North Sea found the magnitude of regional changes to be relatively small compared to long-term natural variability in oceanographic conditions [21]. The presence of turbine foundations can create local structure-induced friction with the surrounding water and can block ocean

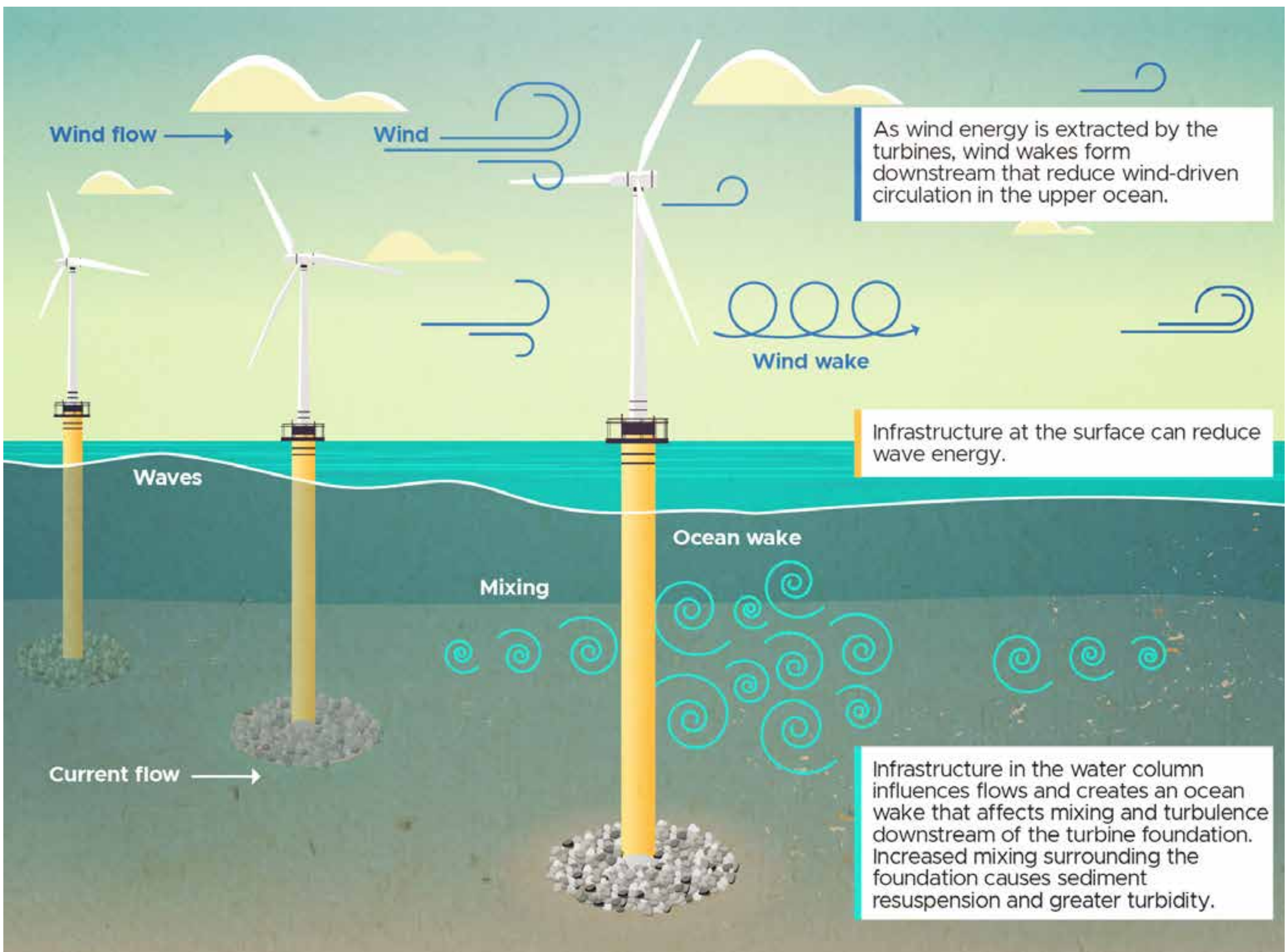

Figure 2.2. Illustration of potential wind wake and hydrodynamic effects from an offshore wind facility. *Illustration from Pacific Northwest National Laboratory.*

hydrodynamics [23]. These effects on hydrodynamics can cause lateral and vertical changes in the temperature and salinity profiles within the water column, with implications for ocean stratification and the residence time of waters in a region.

The placement of wind turbine structures and associated effects on hydrodynamics can in turn affect ocean biogeochemical and water quality characteristics. Increased mixing around turbine foundations can result in increased sediment erosion and suspended sediment concentrations in the water column, causing increased turbidity [21]. As observed in satellite imagery, offshore turbine structures can increase near-surface suspended sediment concentrations in the form of turbid wakes (Figure 2.3) [24]. Suspended sediment concentrations affect light attenuation in the water column, which is one of the variables determining phytoplankton growth.

In addition to turbidity, any impacts of offshore wind farms on hydrodynamics and mixing will likely affect water column stratification and the vertical profiles of nutrient, oxygen, and chlorophyll concentrations within the water column [20]. For example, in the North Sea, measurements taken to examine the potential impacts of 160 wind turbine foundations across two non-operating German offshore wind farms showed that vertical mixing was increased within the wind farms, leading to a decrease in seasonal stratification and a subsequent transport of nutrients into surface waters. Nutrients were then taken up rapidly by phytoplankton in the water column, as evidenced by an increase in primary production [25]. For a much larger-scale regional offshore wind buildout scenario (120 gigawatts) in the North Sea, modeling has suggested greater changes in annual primary production over larger areas with associated decreases in bottom-water oxygen concentrations [26]. The northern Gulf of Mexico is also a seasonally stratified regime that is modulated by upwelling-favorable winds and thus may also experience changes in productivity and water quality, as have been observed in other regions [27]. However, as noted previously, findings for one region may not be directly applicable to another region, and it is important to conduct similar research for the Gulf of Mexico.

Figure 2.3. Satellite image showing plumes of suspended sediments in the wake of wind turbines at the Thanet wind farm in England. *Image from NASA Earth Observatory [28].*

MONITORING & MODELING METHODOLOGIES

Collecting meteorological and oceanographic data in areas of potential offshore wind energy development in the Gulf of Mexico is important for understanding potential effects on ecosystem processes. A variety of platforms and sensors can be used to understand baseline ecosystem processes before wind farm installation, as well as after installation, to monitor and adaptively manage potential effects on the environment. Satellites, aircraft, and high-frequency radar provide information on atmospheric and surface ocean processes at relatively large spatial scales. These technologies have been used in the Gulf of Mexico to provide information on surface currents, water quality, and weather patterns [29,30]. Observations collected from these types of sensors are also important inputs for regional species models that describe wildlife distributions, densities, and movements [31].

In the water, ship-based sampling, buoys, and bottom-mounted sensors collect data on ocean circulation, water column stratification, primary and secondary productivity, and water quality (Figure 2.4). For example, the NOAA Southeast Area Monitoring and Assessment Program collects plankton data along with environmental data such as conductivity, temperature, depth, dissolved oxygen, fluorescence, and turbidity [32]. Additionally, autonomous surface and underwater vehicles, including gliders, can adaptively provide data at the different temporal and spatial scales needed to understand processes around individual offshore wind turbines, around wind farms, and at a regional scale. Data such as these are collected by the Gulf of Mexico Coastal Ocean Observing System, which provides a centralized data collection and dissemination center for coastal and ocean data in the region to support marine operations, including the deployment and operation of future wind farms in the region [33,34].

Figure 2.4. A moored oceanographic buoy measuring sea surface conditions in the Gulf of Mexico. *Image from NOAA National Data Buoy Center.*

In addition to collecting oceanographic data, various types of models are needed in the Gulf of Mexico to understand the potential effects of offshore wind development on environmental processes and how to minimize those effects throughout the wind farm life cycle. Wind and wake models provide an understanding of the wind resource, wake effects from turbines, and other effects from wind farms [22]. Such models could be used to simulate how various scales of wind farm development might affect wind forcing and associated impacts to ocean dynamics. Hydrodynamic and biogeochemical models can be used to simulate the potential effects of wind farms on waves, three-dimensional current fields, temperature, salinity, upwelling, frontal zones, nutrients, and phytoplankton [26]. A variety of hydrodynamic and biogeochemical models have been applied in the Gulf of Mexico and could be further developed to understand potential wind farm effects on ocean processes [35–37]. Hydrodynamic modeling is also useful for understanding the potential extent of scour around an offshore wind turbine depending on the type of foundation used and the seabed soil conditions where the turbine is installed [38,39].

Models and research focused on the dynamics between physical and biological processes are critical to understanding the potential effects of offshore wind development on marine ecosystems. Hydrodynamic, particle tracking, and larval dispersal models can all be used to inform effects on species. These models were used to explore offshore wind farm scenarios off Massachusetts and Rhode Island and showed potential impacts to subpopulations resulting from changes to connectivity, settlement, and recruitment; however, shifts in larval settlement were not considered impactful to regional fisheries management [40]. Larval dispersal models have also been developed in the Gulf of Mexico and could be applied to better understand potential effects of regional offshore wind development on larval dispersal, settlement, retention, and export [41]. In addition, existing coupled physical-biological and ecosystem models for the region could be adapted to provide more information on potential changes in primary production, phytoplankton biomass, zooplankton, and the functioning of food webs [42,43]. To help inform decision making, NOAA is implementing an Integrated Ecosystem Assessment in the Gulf of Mexico to model baseline conditions and to characterize the impacts of wind energy development on protected species, marine goods and services, and fish and fisheries.

KNOWLEDGE GAPS & RESEARCH NEEDS

Research needs for assessing potential impacts of offshore wind development on ecosystem and oceanographic processes in the Gulf of Mexico can be informed by the research that has been undertaken in Europe and other regions of the United States where offshore wind development has a longer history [20]. However, it is critical to collect robust baseline data, develop effective monitoring programs for the region, and improve modeling capabilities. Important information gaps are summarized below:

- **Baselines:** Determining baseline conditions through collection and analysis of physical and biological data is an important step toward planning and appropriately siting future offshore wind farms. There is already a wealth of data for the Gulf of Mexico, but additional baseline data for the region, especially where offshore wind development is planned, will improve future assessments of potential effects on marine resources. Data collected over long time frames that measure hydrodynamic and oceanographic conditions as well as productivity (i.e., phytoplankton and zooplankton) are also needed, so that changes due to stressors such as climate change can be differentiated from any changes that may be associated with offshore wind farms.
- **Scales of Effects:** Studies need to be conducted at different scales, ranging from a single turbine to multiple wind farms, to better understand the potential types and magnitude of ecosystem effects. Understanding potential effects at different scales is important for estimating the cumulative impacts of offshore wind development and the potential regional ecosystem effects.
- **Monitoring:** Monitoring programs to collect relevant ecosystem data are necessary for appropriately siting offshore wind farms and adaptively managing them after construction. Monitoring programs are most useful when methods and data products are standardized, and data are made publicly available.
- **Models and Validation:** Models to understand potential atmospheric, hydrodynamic, oceanographic, and ecosystem effects from offshore wind development need to be developed specifically for the Gulf of Mexico. These models need to be tested and validated with observational data once wind farms are constructed and operational. Integrating this data into models will improve the analysis of effects and can inform adaptive management efforts.

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U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

3.0

COASTAL HABITATS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- The Gulf of Mexico is a biodiverse region with a variety of coastal habitats such as beaches and barrier islands, estuaries, wetlands, submerged aquatic vegetation, and coral reefs.
- The main risks for coastal habitats associated with offshore wind energy development in the Gulf of Mexico are benthic disturbance and coastal land disturbance.
- There are a variety of methods to monitor and mitigate the effects of offshore wind energy on coastal habitats, such as careful project siting and use of appropriate construction methods.

TOPIC DESCRIPTION

The Gulf of Mexico is a biodiverse region with a variety of coastal habitats (Figure 3.1), such as beaches and barrier islands, estuaries, wetlands (e.g., mangroves), submerged aquatic vegetation (e.g., seagrasses), and coral reefs [1,2]. The geographic range of these habitats is vast, spanning from 30.5°N near the Florida Panhandle shoreline to 18°N along the Veracruz-Tabasco shoreline of Mexico. Coastal habitats in the Gulf of Mexico serve as important foraging, nesting, and nursing grounds that support many species of migratory and nonmigratory birds, freshwater and marine fishes and invertebrates, terrestrial and marine mammals, and protected sea turtles. Most of the Gulf of Mexico, for example, is designated as essential fish habitat for federally managed fish and invertebrate species.

Beaches and barrier islands stretch along the Gulf of Mexico and provide important stopover habitat for migratory birds, nesting habitat for wintering birds and most species of sea turtles, and dune habitat for crustaceans and small mammals [1]. These dynamic, sandy habitats can be inhospitable due to their harsh conditions (e.g., wave action, heat, predators), but offer refuge to a variety of species. Barrier islands, which are mobile sand bars that run parallel to the coast, can also act as a shield against coastal flooding and erosion by diminishing wave energy. However, the increasing intensity of hurricanes in the Gulf of Mexico, as well as other natural and anthropogenic influences, are weakening the protective nature of these and other coastal habitats [3].

Estuaries are partially enclosed regions, such as bays, lagoons, and sounds, where marine saltwater mixes with freshwater from rivers and streams. Estuaries occur throughout the Gulf of Mexico and provide key foraging, resting, and wintering habitat for many bird species, as well as foraging, spawning, and nursery habitat for a variety of fishes and invertebrates [1].

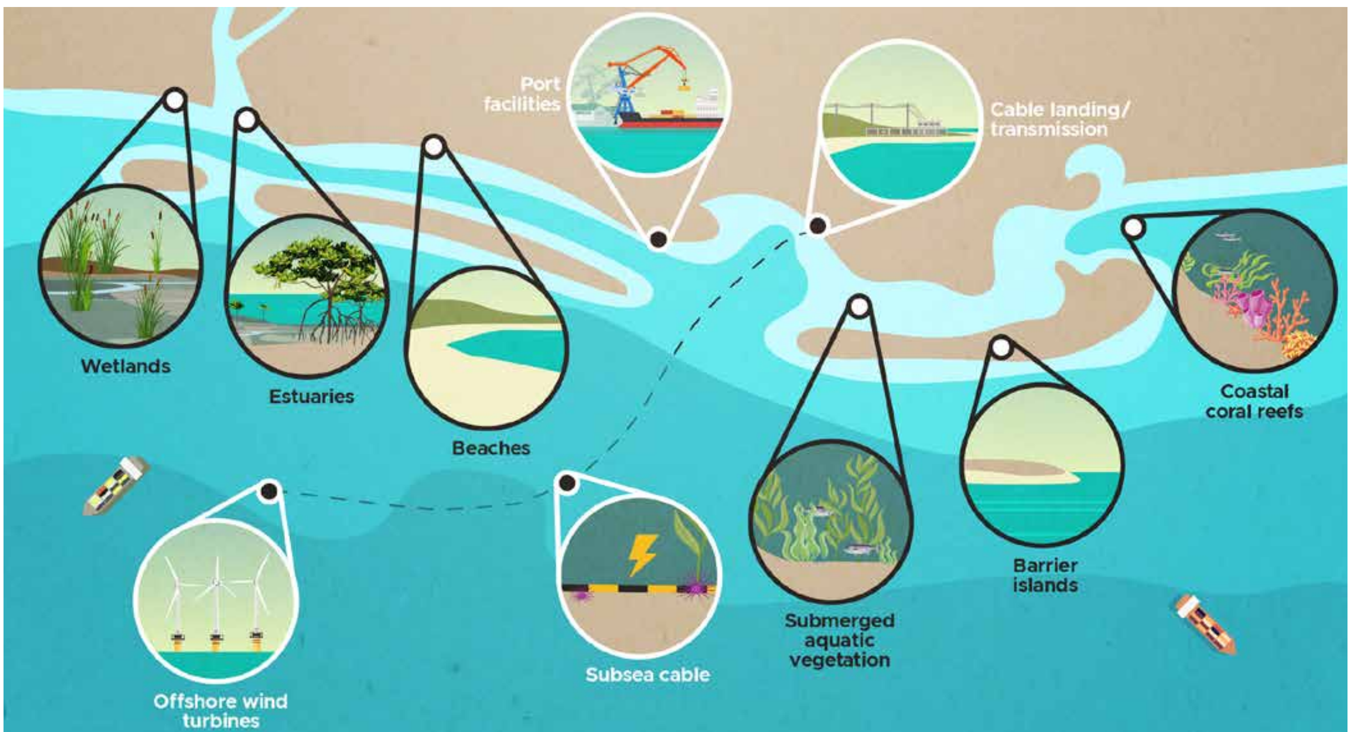

Figure 3.1. Coastal ecosystems in the Gulf of Mexico (black circles) and offshore wind infrastructure (white circles). *Image from Pacific Northwest National Laboratory.*

Along with strong currents and tides, the influx of fresh water, nutrients, and sediments can foster highly dynamic and productive estuarine ecosystems [4].

Wetlands, such as mangroves, reed beds, and salt marshes, are common throughout the Gulf of Mexico and provide many essential functions and ecosystem services [2]. For example, mangrove habitats, which are dominated by the black mangrove (*Avicennia germinans*), red mangrove (*Rhizopora mangle*), and white mangrove (*Laguncularia racemosa*), support a wide variety of threatened species, stabilize shorelines, and buffer coastal storms. However, wetland habitats are particularly susceptible to natural and anthropogenic stressors such as coastal flooding and sea level rise [5].

Submerged aquatic vegetation, such as seagrasses and macroalgae, typically grow in shallow, nearshore waters and serve several important ecological functions by providing food, shelter, and nursing grounds for many marine species [1]. The five main species of seagrasses in the Gulf of Mexico are Engelman's seagrass (*Halophila engelmanni*), manatee grass (*Syringodium filiforme*), shoalgrass (*Halodule wrightii*), turtlegrass (*Thalassia testudinum*), and widgeon grass (*Ruppia maritima*) [2].

Coastal coral reefs also play a crucial role in ecosystem functioning but only occupy a small area of the Gulf of Mexico, primarily off the coast of Florida [6,7]. Like those around the world, coral reefs in the Gulf of Mexico are in decline; there are five threatened coastal coral species, including the boulder star coral (*Orbicella franksi*), elkhorn coral (*Acropora palmata*), lobed star coral (*Orbicella annularis*), mountainous star coral (*Orbicella faveolate*), and staghorn coral (*Acropora cervicornis*) [8].

Existing threats to coastal habitats in the Gulf of Mexico include coastal development, habitat degradation, invasive and non-native species, resource extraction, agriculture and nutrient pollution, hurricanes and storms, coastal flooding and erosion, and sea level rise and climate change [1,2,3]. As offshore wind development expands in the Gulf of Mexico, associated construction and operations activities such as cable laying and increased vessel traffic may put additional stresses on these vulnerable coastal habitats and the communities and marine life that rely on them.

MAIN RISKS & EFFECTS

The main risks for coastal habitats associated with offshore wind energy development in the Gulf of Mexico are disturbances to seafloor or benthic habitats and coastal land disturbance [1]. Changes to coastal habitats and associated communities can be caused directly and indirectly by offshore wind farms and associated infrastructure (e.g., subsea cables, onshore facilities, substations) during preconstruction surveys, construction, operations and maintenance, and decommissioning.

Benthic Disturbance

During construction, the installation of turbine foundations, anchors, and subsea cables can disturb benthic habitat and affect local benthic communities [1]. For example, cable installation methods such as dredging, jetting, and trenching can disturb sediment, increase water turbidity, and lead to direct habitat loss. The addition of rock or concrete mattresses to protect exposed subsea cables can also introduce additional hard substrate in areas that are primarily composed of soft bottom habitats, which could result in changes to local biological communities. However, most physical effects on benthic habitat are localized or temporary, and the actual effects and recovery from offshore wind activities depend on a variety of factors, including the methods used, existing habitat types, and other project- and location-specific details.

Learn more about offshore wind and benthic disturbance in Chapter 4 and in Benthic Disturbance From Offshore Wind Foundations, Anchors, and Cables [9].

Coastal Land Disturbance

Coastal land disturbance from the construction and operation of coastal infrastructure, such as ports, support facilities, and vessel navigation channels, can temporarily or permanently alter coastal habitats [1]. For example, the creation and maintenance of navigation channels and increased vessel traffic can lead to changes in water quality and turbidity, increased coastal erosion, and habitat loss or degradation. Land clearing activities for power transmission line rights-of-way and the construction and expansion of onshore facilities can also modify or destroy coastal habitats and affect the many species reliant upon them [10]. However, development on and along the coastline is common across the Gulf of Mexico, and offshore wind projects would likely be sited to avoid vulnerable coastal habitats such as estuaries and wetlands, much of which are highly regulated.

Additional Risks

Additional risks of offshore wind energy development on coastal habitats and the communities they support include contamination due to vessel discharges or spills, introduction of invasive or non-native species, and underwater noise effects from vessels and construction activities [1,10]. While construction activities could contribute to changes in water quality (e.g., by resuspending contaminated sediments) and accidental chemical and oil releases may happen during operations and maintenance, these would likely cause low impacts to coastal habitats [11]. Furthermore, offshore wind projects and related vessel traffic will have to comply with regulatory requirements related to the control and prevention of discharges and non-native species. Although noise from offshore wind operations is not expected to directly harm coastal habitats, noise from onshore construction, cable trenching, and vessel traffic may indirectly impact sensitive species nearby. For example, underwater noise can disrupt larval settlement for estuarine and coral species that rely on acoustic cues for navigation and habitat selection [12].

Learn more about offshore wind and underwater noise in Underwater Noise Effects on Marine Life Associated With Offshore Wind Farms [13].

MONITORING & MITIGATION METHODOLOGIES

Monitoring and mitigating the impacts of offshore wind energy development and other human activities on coastal habitats and communities requires a regional, multilayered approach throughout a project's life cycle. Typically, site characterization is completed to gather baseline information on physical and biological conditions before construction to inform siting, and a variety of additional monitoring campaigns are carried out to detect changes during installation, operation, and decommissioning. Typical habitat monitoring methods include acoustic sonar surveys, photo/video surveys, grab/core sampling, and water quality sampling.

Careful siting and use of appropriate construction methods can further reduce potential impacts of offshore wind energy development on coastal habitats and wildlife in the Gulf of Mexico. For example, siting cable routes and landfalls to avoid vulnerable coastal habitats and species and using cable installation methods that minimize effects to bottom habitats are typically required by various state and federal regulations (e.g., Coastal Zone Management Act, Clean Water Act). Overall, the likelihood and strength of offshore wind's environmental effects on coastal habitats in the Gulf of Mexico will depend on project- and site-specific factors, the regulatory requirements in place, and the adoption of existing best practices and mitigation measures.

Many local, state, regional, and federal agencies are working together to monitor, restore, and enhance coastal habitats in the Gulf of Mexico. Since the Deepwater Horizon oil spill, several federal and state agencies are implementing a comprehensive, integrated ecosystem restoration plan, which includes monitoring and adaptive management throughout the region [14].

KNOWLEDGE GAPS & RESEARCH NEEDS

Additional data and research could further inform coastal habitat management in the Gulf of Mexico and better mitigate the potential risks from offshore wind energy development and from other known threats (e.g., coastal development, hurricanes, sea level rise). For example, continued monitoring at the local and regional scales could help inform adaptive management as more and larger offshore wind farms are proposed in an increasingly busy seascape. The potential combined and cumulative effects of multiple environmental stressors from offshore wind energy development and other activities in the Gulf of Mexico may result in additional impacts on coastal habitats that should be examined within the context of the global climate change crisis.

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4.0

BENTHIC HABITATS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- The northern Gulf of Mexico continental shelf is mainly composed of soft sediment habitat, with some rocky outcrops and a large network of coral reefs, as well as hydrocarbon seep and brine pool habitats along the continental margin and slope.
- The numerous oil and gas installations on the continental shelf have gradually become artificial reefs highly colonized by benthic invertebrates, demersal fish, and pelagic predators, as well as non-native species.
- The loss of benthic habitat is inevitable directly under turbine foundations, substations, and other offshore wind farm infrastructure; however, this represents a small portion of the total wind farm area (less than 1%) and will offer new hard-structure artificial reef habitat, similar to what has happened with oil and gas installations.
- Seafloor disturbance during construction activities and movement of water around turbines during operation may resuspend fine sediments and existing pollutants in the water column, with unknown effects to local fish and invertebrate populations.
- Offshore wind farms can act like marine protected areas and boost populations of fished species when fishing pressure decreases, resulting in increased species diversity and abundance, which could potentially benefit surrounding areas.

TOPIC DESCRIPTION

Initial planning for offshore wind energy development in the Gulf of Mexico includes investigating areas where fixed-bottom turbines could be installed. In the longer term, floating offshore wind turbines could be considered in the Gulf of Mexico if there is commercial interest to build wind farms in waters deeper than 60 meters (m). Fixed-bottom turbines will be in direct contact with benthic habitats through jacket or monopile foundations, whereas floating turbines will be attached to the seafloor via mooring lines and anchors. Impacts to benthic habitats can be positive or negative, depending on how the infrastructure is sited and the types of monitoring and mitigation in place.

Benthic habitats on the continental shelf are dominated by flat-bottom soft sediment [2], comprising assemblages of sand, mud, and gravel from the shore to 100-m water depth, and mud or sandy mud in deeper areas of the shelf, the slope, and the abyssal plain (Figure 4.1). Rocky reefs are present in parts of the northern Gulf of Mexico, from relatively shallow areas of the continental shelf to the bottom of the slope.

Soft sediment habitats where oxygen is limited—known as hypoxic zones—are dominated by annelid worms and amphipods, but sand banks—a type of soft sediment—that rise above these zones have a greater diversity of organisms [1]. On the Outer Continental Shelf, soft sediment benthic communities tend to be dominated by macrofauna (e.g., shrimp, crabs, sea cucumbers) while small benthic invertebrates like nematodes and copepods are predominant in sandy and muddy areas along the continental slope [1]. Large predators (e.g., benthic sharks and skates) are relatively abundant across benthic habitats [1].

The Outer Continental Shelf and slope have numerous hydrocarbon cold seeps (i.e., seafloor areas where fluids rich in hydrogen sulfide, methane, and other hydrocarbons slowly leak out) and brine pools (i.e., seafloor areas with dense, highly saline water)

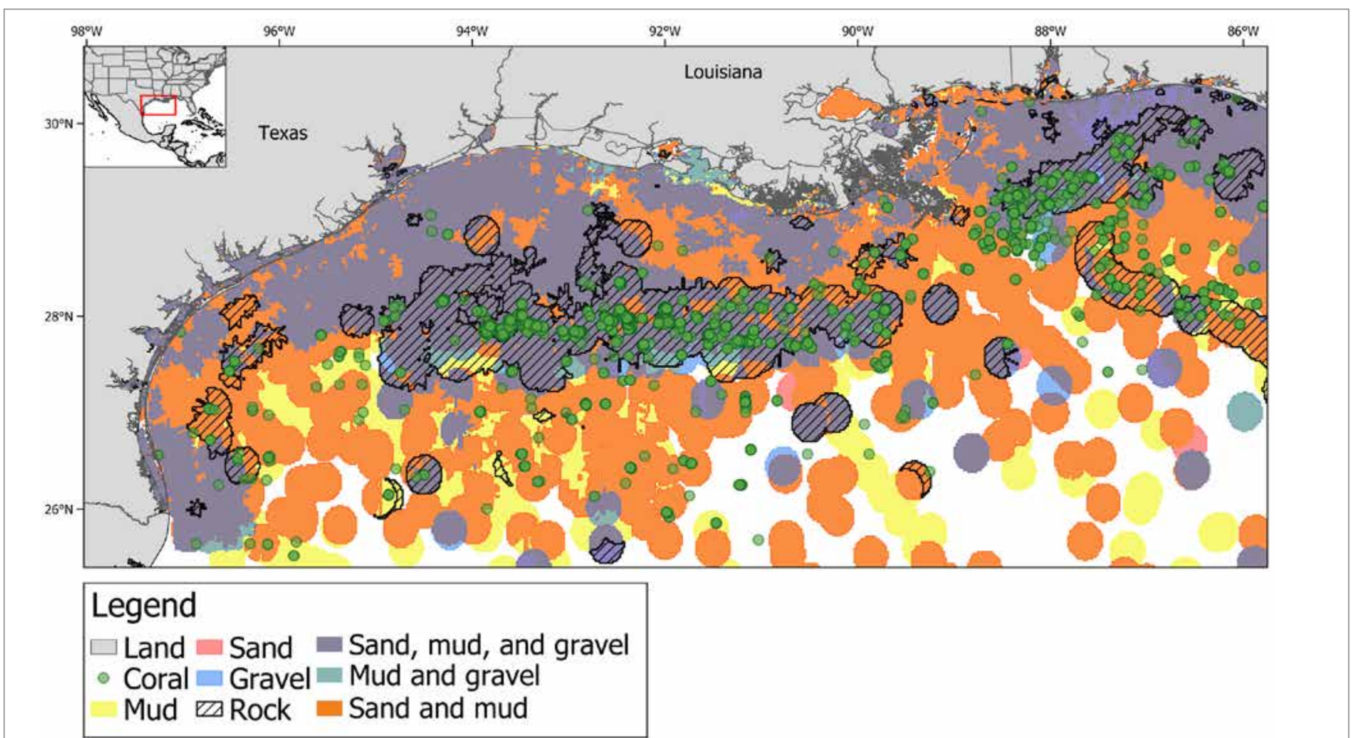

Figure 4.1. Diversity of benthic habitats in the northern Gulf of Mexico. *Image from Pacific Northwest National Laboratory.*

[1,3]. Chemosynthetic (i.e., capable of converting inorganic molecules into organic matter) communities dominated by tube worms and mussels can be found around cold seeps and brine pools in seepage areas scattered between depths of 250 m and 2,200 m along the continental slope [1].

Across the Gulf of Mexico, numerous reefs are home to rich communities of mid- and deep-sea corals and sponges (Figure 4.1). Large coral gardens found along the outer shelf, and often growing on salt structures in low light conditions, are called mesophotic coral ecosystems (MCEs). The most well-known in the northern Gulf of Mexico is the Flower Garden Banks, composed of several reef systems along the continental margin off the coast of Texas [4]. The Pinnacles reefs, off Alabama, are drowned relicts of shallow-water coral reefs that now harbor rich assemblages of fish and invertebrates.

Colonies of low-light corals are recognized as "sentinel species," or indicators of ecosystem changes that would otherwise remain unseen [5]. These corals represent key benthic habitat for the Outer Continental Shelf and slope and are highly connected among each other through larval dispersal [2,6]. The MCE habitats vary with depth and light availability from reef-building coral habitat in the shallower areas to algal nodule habitat, coralline algal reefs, and deep coral habitats where little light reaches the seafloor. Highly diverse communities of fish and invertebrates thrive among the corals and algae of the MCEs. However, a drastic decline in coral condition was observed in the aftermath of the Deepwater Horizon oil spill; larger colonies displayed more injuries after the spill [4].

Figure 4.2. Organisms using decommissioned oil and gas platforms as habitat in the Gulf of Mexico. *Image from Johnston et al. [10].*

Oil and gas infrastructure in the northern Gulf of Mexico has provided a widespread network of artificial habitats for several decades (Figure 4.2). Sessile invertebrates (organisms that generally do not move around like sponges, soft corals, tunicates) and algae grow abundantly on these structures. Mobile invertebrates and juvenile and adult demersal fish find shelter and food, and pelagic fish hunt among these artificial reef communities [7]. New wells, platforms, and pipelines are often fully colonized within a year of installation and become complex ecosystems with species diversity many times higher than surrounding soft sediment natural habitats. This observation has led to the establishment of the "Rigs-to-Reefs" program that enabled the transformation of many obsolete offshore platforms into artificial reefs [8,9]. However, decades of leakage from uncapped boreholes and wells and waste disposal around operational rigs, along with effluents from the Mississippi River, have turned the continental shelf of the northern Gulf of Mexico into one of the most polluted seafloors in U.S. waters [1].

MAIN RISKS & EFFECTS

The potential effects on benthic habitats from offshore wind energy developments in the northern Gulf of Mexico are similar to those seen in other regions, which are discussed in detail in Benthic Disturbance from Foundations, Anchors, and Cables [11].

The seafloor footprint (i.e., spatial extent) of offshore wind turbines varies based on the type of foundation used. Additionally, scour protection material (e.g., rocks, mats, concrete blocks) is often added around the foundations to limit the sediment erosion caused by hydrodynamics, and concrete mattresses or rock dumps are commonly used to protect cables laid on top of the seafloor. The presence of the foundations and scour protection inevitably results in the loss of benthic habitat directly underneath turbines, especially for organisms living at the water-sediment interface [12]. Floating offshore wind turbines are kept in place by mooring lines attached to anchors on the seafloor, which can lead to some habitat loss directly underneath the anchors or within the drag footprint of catenary mooring lines. Overall, the loss of benthic habitat due to the infrastructure footprint is restricted to small areas within an offshore wind farm, typically less than 1% of the total wind farm area [13]. In addition, careful initial characterization of the northern Gulf of Mexico benthic habitats will enable siting offshore wind infrastructure away from vulnerable habitats.

Altered water movement directly around turbine infrastructure on the seafloor can lead to sediment scour—the erosion and washing away of soft sediment—which can disturb benthic habitats by removing the finest sediment (e.g., silt, mud, sand) and affect infauna species [13]. Both sediment scour and the process to lay down export cables may result in the resuspension of fine sediments in the water column as well as pollutants from previous industrial activities that had settled overtime within the sediment [14]. Because sediments on the northern Gulf of Mexico continental shelf are heavily polluted, large releases of pollutants could be detrimental to benthic habitats, especially MCEs. Suspended sediments tend to settle down rapidly after cable laying [14], but the fate of suspended sediments and pollutants downstream of turbine foundations remains unknown.

Similar to offshore wind farms around the world, submerged structures (e.g., foundations, scour protections, cables) in the northern Gulf of Mexico are expected to be colonized rapidly by sessile and mobile invertebrates and fish, becoming artificial reefs and fish aggregation devices [15–17]. As observed with oil and gas infrastructure in the Gulf of Mexico, offshore wind turbines will provide food and shelter for many nearshore species on foundations in the upper water column and for subtidal benthic species on foundations, scour protections, and anchors on or near the seafloor (Figure 4.3) [8,15,17]. However, these structures can also become places for non-native or invasive species to settle, potentially providing opportunities to expand their range [18,19]. For example, two invasive species—the cup coral and lionfish—are already well established on oil and gas platforms in the northern Gulf of Mexico and threaten MCEs and other natural benthic habitats [20,21].

Fouling communities on offshore wind turbine structures, including encrusting organisms and small mobile invertebrates, are predominantly suspension feeders, filtering the food particles in the water column [22]. Lower turbidity and higher light penetration may be found downstream of turbines as a result of these organisms' removal of particles from the water through filtering (Figure 4.3). However, the abundance of organisms growing on the turbine structures often results in seafloor enrichment due to the fall of organic matter (e.g., feces, dead organisms) to the surrounding seafloor, which in turn results in higher diversity and/or abundance of macrofaunal species in the sediment closer to the turbine foundations [18,23]. Similar to oil and gas platforms already installed in the Gulf of Mexico, shell debris falling from mussels, barnacles, and other calcified organisms colonizing the foundations and anchors may accumulate in shell mounds around the base of the turbines and provide additional new habitats to fish and invertebrates [8,24].

Bottom fishing in the northern Gulf of Mexico predominantly targets shrimps, using trawls and dredges to scoop them out of the soft sediment on the continental shelf. Because of seafloor infrastructure associated with offshore wind farms, such as scour protection and export cables, bottom fishing would be excluded within a farm and along cable routes. With decreased fishing pressure, a reserve effect may be observed as offshore wind farms can provide benefits similar to marine protected areas, enabling local populations of fished species to thrive [8,17]. When populations sufficiently recover from past fishing pressures, a spillover effect may occur, where a population expends beyond the spatial closure of an offshore wind farm and into areas that are open to fishing [25].

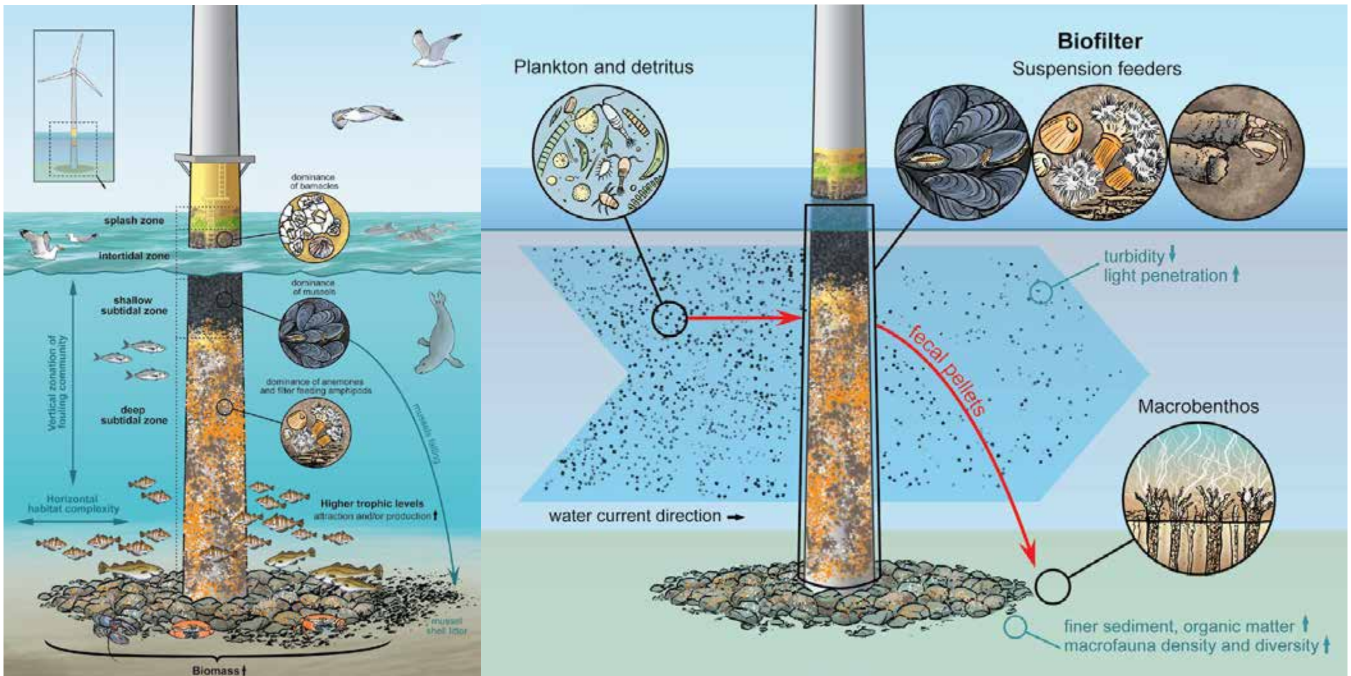

Figure 4.3. Submerged structures associated with offshore wind turbine foundations provide hard habitat for biofouling organisms, especially sessile invertebrates, and attract predators; such artificial reefs act as "biofilters," where filter feeders remove organic matter from the water column and enrich the surrounding seafloor. *Figure from Degraer et al. [22].*

MONITORING & MITIGATION METHODOLOGIES

Monitoring surveys are important at each stage of an offshore wind farm life cycle: prior to construction to identify the least impactful location for each component in contact with the seafloor and to characterize the natural variability of benthic habitats and communities; during construction if specific mitigation measures are required; during the operational phase to identify and track any changes to the benthic habitats; and after decommissioning to ensure no detrimental effects persist once the wind farm has ceased to operate. Techniques for monitoring effects on benthic habitats in the northern Gulf of Mexico do not differ from those in other regions where offshore wind is developed, which are described in Benthic Disturbance from Foundations, Anchors, and Cables [11].

For projects in federal waters, BOEM provides guidelines on monitoring surveys and mitigation measures best suited for offshore wind projects on the Atlantic Outer Continental Shelf [26,27] as well as for seafloor and sub-seafloor surveys [28], that are transferable to the northern Gulf of Mexico. In addition, BOEM also provides guidelines relative to oil and gas exploration in the Gulf of Mexico, ranging from shallow hazards on the Outer Continental Shelf [29], to biologically sensitive habitats shallower than 300 m [30], and to deep-water benthic communities [31]. High-level summaries of these guidelines are provided in the SEER research brief listed above [11] and in [32]. Key recommendations from the Minerals Management Service (BOEM's predecessor) guidelines that are applicable to offshore wind energy development in the northern Gulf of Mexico are:

- **Shallow hazards:** geotechnical seafloor surveys with state-of-the-art sonars and profilers, sediment core samples, and/or underwater imagery following a grid pattern with lines no more than 150 m apart, within and around the lease area [29]
- **Biologically sensitive features:** seafloor habitat surveys with underwater color cameras along transects within and around the lease area, with full coverage of any live-bottom feature [30]
- **Deep-water benthic communities:** high-resolution seismic survey to identify seafloor and shallow geological features potentially disturbed within the lease area and in a buffer area up to 300 m [31].

KNOWLEDGE GAPS & RESEARCH NEEDS

Over the years, several research programs have been dedicated to studying the impacts of oil and gas installations in the Gulf of Mexico, such as changes in benthic habitat and the artificial reef effect. Knowledge gained from these studies can be leveraged in the offshore wind context despite differences in the technology type and spacing between platforms. There is much to learn about how offshore wind development in the northern Gulf of Mexico may lead to changes in benthic habitat and communities. Some research topics that could help address knowledge gaps include:

- The impact of offshore wind development on population dynamics, community structure, and functional diversity of benthic habitats
- The potential ecosystem-wide changes (e.g., energy pathways, trophic interactions) resulting from offshore wind development
- The net effect of increased seafloor artificialization for benthic communities in both soft and rocky habitats
- The use of the new hard substratum by larval stages of local species and potentially non-native invasive species
- The impact of increased sediment and pollutant resuspension on local species.

Future monitoring surveys (pre- and post-construction) for offshore wind development in the northern Gulf of Mexico should be designed with these research needs in mind. This will ensure the collection of sufficient good-quality data that will further the understanding of offshore wind energy development effects on benthic habitat and communities.

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SEER

U.S. OFFSHORE WIND SYNTHESIS OF ENVIRONMENTAL EFFECTS RESEARCH

5.0

BIRDS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Billions of birds, representing more than 500 species, regularly use the waters and coastal regions of the Gulf of Mexico for all or part of their annual life cycle.
- The risk of offshore wind energy to birds in the Gulf of Mexico is uncertain, but information on how birds interact with offshore oil and gas platforms and land-based wind farms can provide some insights.
- Interactions between birds and offshore wind farms will likely depend on the time of year and weather conditions, and may include attraction, avoidance, displacement, and collision.
- Baseline monitoring of offshore bird activity is necessary to understand potential collision risk and behavioral responses to the presence of wind farms. Several technologies are available to monitor birds both prior to construction and during their interactions with wind turbines.
- Mitigation strategies to avoid, minimize, and compensate for impacts may be necessary. These strategies can be developed and adapted using data collected during well-designed research studies.

TOPIC DESCRIPTION

Billions of birds, representing more than 500 species, regularly use the waters and adjacent lands of the Gulf of Mexico for all or part of their annual life cycle, including breeding, foraging, wintering, and migrating (Table 5.1) [1–3]. The Gulf of Mexico represents a critically important geographic area with most migratory birds in eastern North America passing across or around the region during spring and autumn migration (Figure 1) [1]. In addition, coastal barrier islands and similar habitats in the Gulf of Mexico are important for beach nesting birds, with 16%–42% of populations of some species found in the area [4]. The coastal regions are also important for wintering waterfowl, with more than 3 million ducks and geese spending the winter season in the region [1].

Given the importance of the Gulf of Mexico as bird habitat, there is concern regarding adverse interactions with human-made structures, including offshore wind turbines. The current absence of offshore wind turbines in the Gulf of Mexico makes it difficult to assess their potential risk, but information regarding the interactions between birds and offshore oil and gas platforms, offshore wind turbines in the U.S. Atlantic, and land-based wind turbines may provide some relevant insight. Offshore oil and gas platforms provide opportunities for birds to rest and refuel [5]. Songbirds (e.g., warblers, sparrows), egrets, herons, doves, and falcons are examples of birds observed using these platforms during migration [5]. The platforms can also present a collision risk. Of the reported bird fatality events at platforms, collisions made up 34% and 48% in spring and autumn, respectively [5]. Research at two offshore wind turbines off the coast of Virginia reported ~11,000 bird detections, 99% of which occurred in autumn [6]. In that study, shorebirds, gulls, raptors, woodpeckers, and songbirds were observed. Certain species of birds are also vulnerable to land-based wind turbines, such as some songbird species (e.g., horned lark and red-eyed vireo) and raptors (e.g., golden eagles, red-tailed hawks, and American kestrels). Given that regulations exist to protect birds, including the Migratory Bird Treaty Act, the Endangered Species Act, and the Bald and Golden Eagle Protection Act, it is important to monitor and, when necessary, mitigate the risk presented by offshore wind turbines.

Table 5.1. Examples of Birds That Occupy the Gulf of Mexico During All or Part of the Year

GROUP	EXAMPLES
Land birds	Doves, woodpeckers, songbirds
Marsh birds	Rails, bitterns, songbirds
Raptors	Hawks, kites, owls
Seabirds	Gannets, gulls, terns
Shorebirds	Curlews, plovers, sandpipers
Wading birds	Cranes, egrets, herons
Waterfowl	Teal, mergansers, scaup

Patterns of Offshore Bird Activity

Trans-Gulf Migrating Birds

In the Western Hemisphere, migrating birds fly north from South and Central America to areas of increasing foraging and nesting habitat. They return south in autumn as colder temperatures decrease food availability. Birds that cross over the Gulf of Mexico are often referred to as trans-Gulf migrants [1]. These birds can travel nearly 1,000 kilometers, roughly the distance between the Yucatan Peninsula in Mexico to the U.S. Gulf Coast states, which requires approximately 20 hours of sustained flight for small to medium-sized birds [7]. Trans-Gulf migration tends to occur at night; as birds approach the U.S. Gulf Coast, they begin descending, landing at the first available location to rest and refuel [8]. Large-scale weather events play a critical role in the success of migration, particularly in the spring [9]. Strong tailwinds can influence the timing of migration and help minimize the time and energy required to cross the Gulf of Mexico [5].

Between March and May, millions of birds cross the Gulf of Mexico [10]; nearly half move through the region within an 18-day period from mid-April to mid-May [2,5,11]. The total number of migrants and annual peak timing remained constant between 2000–2015, and 1995–2015, respectively [2]. The timing of peak migration varies by group: waterfowl and wading birds peak in early April, songbirds in late April, and shorebirds in mid-March and late May. In autumn, most trans-Gulf migration occurs between mid-August and early November [5], and peaks in migration activity can occur like they do in spring. For example, Farnsworth and Russell [12] reported that nearly 40% of detections occurred on one night (September 10) in 1999, and 98% of detections were within a 13-night period.

Summer and Winter Seabirds

Seabirds use the waters of the Gulf of Mexico year-round, but densities and composition can differ based on time of year and distance to the coastline [13]. In summer, terns are the most common species reported, whereas in winter, gannets, skuas, and gulls are regularly observed [13–15]. Relative density of seabirds is greatest along the continental shelf and closer to shore and declines over the middle of the continental shelf and in the open ocean [13].

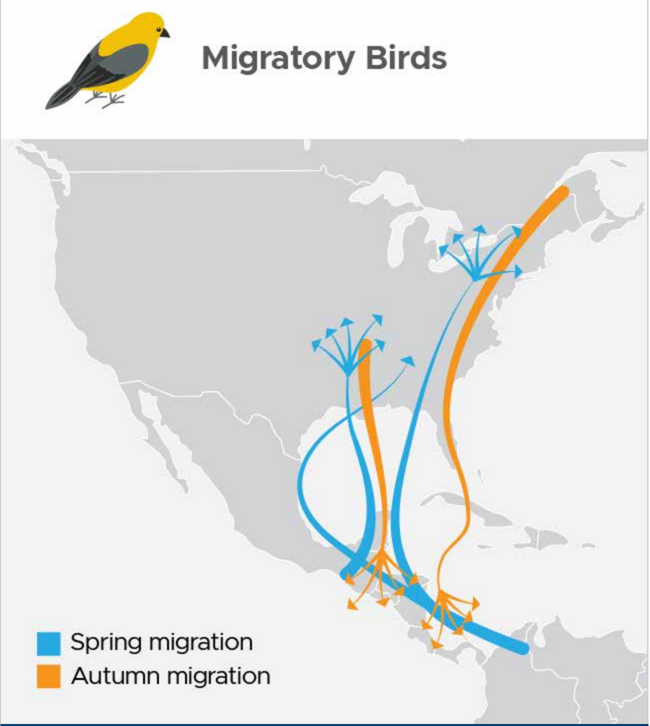

Figure 5.1. Spring and autumn bird migration around and across the Gulf of Mexico. *Image from the Pacific Northwest National Laboratory, modified from the Gulf Coast Bird Observatory.*

MAIN RISKS & EFFECTS

Birds migrating across the Gulf of Mexico face inclement weather coupled with no natural refueling or resting opportunities [7]. Factors such as fat stores, wind direction, and wind speed are critical for a successful migration. Survival is unlikely for birds migrating during strong headwinds regardless of body condition, or for lean birds regardless of favorable wind condition [16]. The presence of human-made structures can offer places to rest and refuel but can also present risk to birds during this energy-exhausting period.

Collision (Effect)

Tall, stationary structures can pose a collision risk for birds, and there is evidence of collision fatalities occurring at offshore oil and gas platforms [5]. The addition of moving turbine blades can increase collision risk, particularly during low-visibility conditions. Although rare, bird fatalities have been reported at offshore wind farms in Europe [17]. Flight height may play a role in potential collision risk, particularly for species that regularly fly within the airspace occupied by the rotor-swept area of the turbine (e.g., roughly between 25 and 260 meters above sea level) [18,19]. Temporally, collision risk at offshore wind energy farms may be highest during spring and fall migration, but for certain species of seabirds, risk may exist throughout the year.

Attraction (Effect)

As with oil and gas platforms, birds may interpret offshore wind turbines as potential resting sites during migration [5]. In addition, offshore wind structures in the water can create new habitat, referred to as the reef effect. Marine organisms, including zooplankton, corals, and bivalves, can quickly colonize new hard substrates, like wind turbine monopoles, which then attract fish that may be preyed on by birds [20]. Aerial insects can also congregate near offshore wind turbines and provide a resource for bird species that eat insects [6]. These resting and foraging opportunities can benefit the biodiversity in an area but may increase collision risk for birds.

Artificial light can attract nocturnally migrating birds, particularly in low-visibility conditions [5,21–23]. Light can attract insects, which may increase foraging activity by birds, and birds may also use light to orient themselves during flight. BOEM has lighting guidance for renewable energy development to reduce undue harm to natural resources, including wildlife [24].

Displacement/Avoidance (Effect)

Birds may alter their flight behavior in response to the presence of offshore wind turbines. Some species may avoid offshore wind farms altogether (macro-avoidance), avoid specific turbines or turbine rows (meso-avoidance), or make last-minute adjustments near the spinning turbine blades (micro-avoidance) (Figure 5.2) [25]. This requires additional energy during migration, which is already an energetically expensive time. Offshore wind farms may also displace birds from traditional foraging or commuting areas. The term "barrier effect" is applied when a wind farm physically excludes birds from accessing an area. Such displacement may increase flight times and decrease food availability, impacting survival or reproductive success [26].

Learn more about offshore wind and birds in Bat and Bird Interactions with Offshore Wind Energy Development [27].

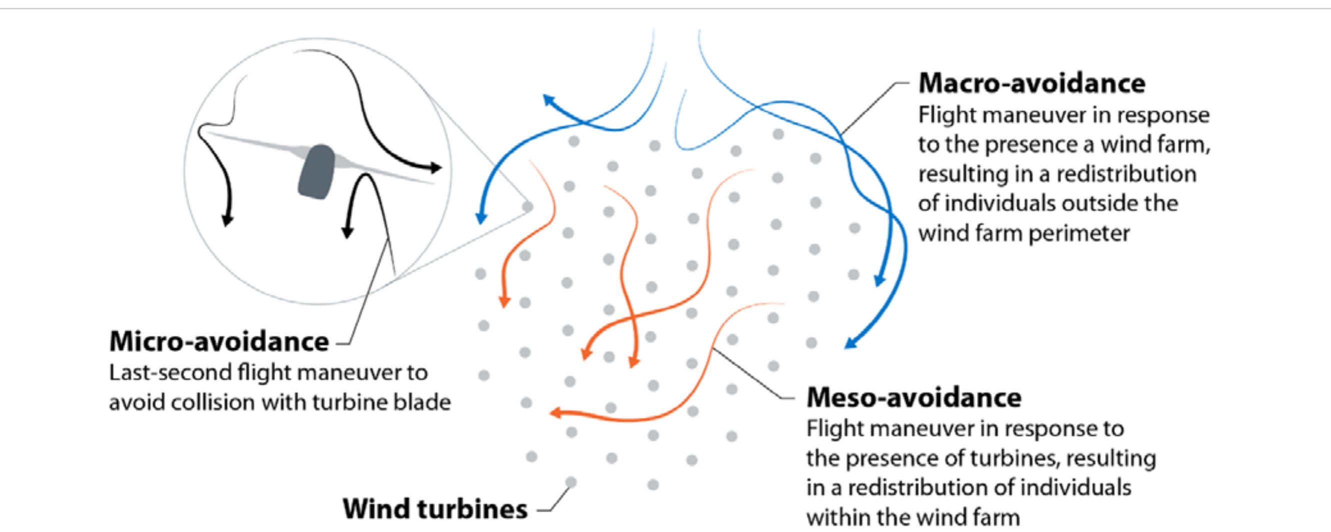

Figure 5.2. Macro-, meso-, and micro-avoidance behaviors near wind turbines. *Image from Nicole Leon, National Renewable Energy Laboratory.*

MONITORING & MITIGATION METHODOLOGIES

Frameworks and guidelines for monitoring bird activity in the Gulf of Mexico and understanding bird interactions with offshore wind turbines can be helpful in designing studies (see [3,28,29]). There are several existing and emerging technologies for monitoring bird activity patterns and interactions with wind turbines. Using these technologies to collect baseline or preconstruction data is useful for assessing normal use and movement patterns and for developing collision risk models. Data collected after an offshore wind farm is fully operational will allow researchers to validate models, assess changes in behavior, and quantify collision risk.

Radar, boat surveys, telemetry, and high-definition aerial surveys provide data on larger-scale spatial and temporal movement patterns, abundance, distribution, passage rates, flight height, and flight speed. Cameras and acoustic detectors are useful to assess more localized activity and behavior. At the time of publishing, there are no commercially available technologies that quantify fatality events, but strike-detection systems are being developed. These systems use a combination of sensors installed on the turbine blade to detect collision events, and cameras and/or acoustic detectors may be used to provide information about individual birds.

There may be times or conditions in which mitigation steps are necessary to avoid, minimize, or compensate for impacts. Siting offshore wind farms in areas of low risk is the best approach to avoid impacts and requires an understanding of the use and movement patterns of birds. Curtailing wind turbines, or slowing the rotation of the turbine blades, can be an option for specific times and conditions when birds are most at risk. For example, curtailment might be appropriate during peak migration season or in low-visibility conditions. Lastly, compensating or offsetting may be necessary for any impacts that were not avoided or minimized. These measures are often designed to create or restore habitat, remove invasive species, or reduce other human-caused impacts.

KNOWLEDGE GAPS & RESEARCH NEEDS

The potential impacts of offshore wind energy development on birds in the Gulf of Mexico is uncertain. An understanding of the daily and seasonal activity patterns of birds in the Gulf of Mexico is needed to determine the species, timing, and weather conditions associated with avoidance and displacement behaviors and collision risk. Research will need to be conducted prior to offshore wind construction and operations to reduce uncertainty. Key topics include:

- Collecting baseline data, such as abundance, distribution, movement patterns, flight height, and flight speeds. The extensive network of offshore oil and gas platforms can provide infrastructure to install monitoring equipment.
- Assessing potential behavioral changes (e.g., attraction, avoidance, and displacement) by birds in response to the presence of offshore wind turbines. Compare baseline data collected before construction to data collected after the site is operational.
- Quantifying collision risk using models and validating the results using monitoring technologies that measure collision events.
- Developing mitigation strategies to avoid high-risk areas or conditions, minimize fatality or behavioral changes, and compensate impacts. Baseline data collection may help identify commonly used areas and conditions that increase risk. Moreover, the data can be used to develop curtailment strategies during specific times to reduce collision risk.

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U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

6.0

BATS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Bats are known to interact with land-based wind turbines, often leading to fatal collisions. The risk is particularly high during the fall migration period.
- There are significant knowledge gaps regarding the extent and nature of bat activity in the Gulf of Mexico and the potential risks posed by offshore wind turbines in the region.
- Mexican free-tailed bats may account for most offshore wind turbine encounters in the Gulf of Mexico because they are the most abundant species along the Gulf Coast and may cross open waters during their annual migration.
- Various monitoring technologies, including acoustic detectors, visual and thermal cameras, radar, and radio telemetry, can be used to better understand bat presence, species composition, movement, and behaviors of bats flying over the Gulf of Mexico.

TOPIC DESCRIPTION

Species Abundance and Distribution

Bat abundance and distribution throughout the coastal and offshore environments of the Gulf of Mexico are uncertain. Based on existing range maps, several long-distance (>500 kilometers [km]) and short-distance (<500 km) migratory species are present along the Gulf Coast of Texas (Table 6.1) [1,2]. Long-distance migrants, including hoary bats, silver-haired bats, and eastern red bats, account for most offshore occurrence records in the Atlantic, and hoary bats account for most records in the Pacific. Short-distance migratory species present in the Gulf of Mexico region, including species in the genus Myotis and the tricolored bat (*Perimyotis subflavus*), are less frequently encountered offshore [3]. Nevertheless, these species have been recorded at coastal and offshore acoustic stations in the Atlantic [3,4]. In the Atlantic, Thomson et al. [5] observed several Myotis individuals landing on and subsequently roosting on their fishing vessel 110 km offshore, and Thornton et al. [6] recently observed a tricolored bat on their vessel 103.5 km offshore.

Mexican free-tailed bats are the most abundant and active species in the region surrounding the Gulf of Mexico. They are long-distance migratory bats that roost in caves, and the abundance of cave structures in Texas provides suitable maternity colonies to raise pups during the summer. Annually, millions of bats migrate from the United States to wintering habitats throughout Mexico and Central America (Figure 6.1).

The proclivity for millions of individuals to roost together and make nightly commutes to foraging areas make them the only North American bat

Table 6.1. Conservation Status and Migratory Habits of Bat Species in States With Wind Energy Areas in the Gulf of Mexico

Common Name	Scientific Name	Gulf States	Federal Status (Endangered Species Act)	Migratory Habit
Mexican free-tailed bat	*Tadarida brasiliensis*	Texas, Louisiana, Mississippi	Not listed	Migration > 500 km
Eastern red bat	*Lasiurus borealis*	Texas, Louisiana, Mississippi	Not listed	Migration > 500 km
Hoary bat	*Lasiurus cinereus*	Texas, Louisiana, Mississippi	Under review	Migration > 500 km
Northern yellow bat	*Lasiurus intermedius*	Texas, Louisiana, Mississippi	Not listed	Migration < 500 km
Southern yellow bat	*Lasiurus ega*	Texas	Not listed	Migration < 500 km
Little brown bat	*Myotis lucifigus*	Louisiana & Mississippi	Under review	Migration < 500 km
Southeastern myotis	*Myotis austrorparius*	Texas, Louisiana, Mississippi	Not listed	Migration < 500 km
Big brown bat	*Eptesicus fucscus*	Texas, Louisiana, Mississippi	Not listed	Migration < 500 km
Tri-colored bat	*Perimyotis subflavus*	Texas, Louisiana, Mississippi	Under review	Migration < 500 km
Evening bat	*Nycticeius humeralis*	Texas, Louisiana, Mississippi	Not listed	Migration < 500 km

species that move in sufficient densities as to be detected on NEXRAD radar. Because of their relatively high summer abundance, Mexican free-tailed bats account for most land-based wind turbine-related bat fatalities reported in Texas. The abundance, density, and documented migratory behavior of Mexican free-tailed bats indicate that this species has the greatest chance of encountering offshore wind turbines in the Gulf of Mexico.

Patterns of Offshore Bat Activity

Studies in Europe and along the U.S. Atlantic and Pacific coasts have documented bat activity offshore from April through November, but this activity increases throughout the fall migration period, or roughly between July and October, regardless of geography [3,8–13]. Increased bat presence offshore during fall migration may be related to traveling the most direct route between summering and wintering areas [14–18]. Offshore occurrences may be further related to foraging opportunities if bats take advantage of ephemeral pulses of high-quality insect prey that may also migrate offshore [19–23].

Offshore bat activity tends to decrease with increasing wind speed [3,8,12,13,24,25,26], but bats may be present in wind conditions exceeding 35 kilometers per hour (22 miles per hour) [24]. Bats may fly at heights offshore ranging between 1 and 200 meters (m) (33–650 feet [ft]) above sea level [24,27,28]; however, existing flight height measurements are likely biased by sampling methods that focus on monitoring close to sea level. Peurach

Figure 6.1. Roosting locations and possible migratory routes of Mexican free-tailed bats. *Image from Pacific Northwest National Laboratory, modified from Wiederholt et al. [7].*

[29] recorded a hoary bat at 2,438 m (8,000 ft) above sea level, and Mexican free-tailed bats regularly fly at altitudes greater than 1,000 m (3,300 ft) [30]. Thus, bats traveling offshore likely travel at flight heights many times greater than the viewshed of the most commonly deployed bat monitoring techniques.

MAIN RISKS & EFFECTS

Rotating Turbine Blades (Risk)/Collision (Effect)

Based on the activity and fatality data collected at land-based and offshore wind energy studies, exposure to rotating turbine blades is greatest during fall migration [3,9–12,31] and may similarly be highest during the autumn in the Gulf of Mexico.

Presence of Structures (Risk)/Attraction (Effect)

Bats may exhibit similar behavior surrounding offshore wind farms in the Gulf of Mexico as has been observed around wind turbines at land-based and offshore wind energy facilities located elsewhere [26,32]. The presence of structures may attract bats that are seeking resting and refueling opportunities after long-distance flights over the open ocean. Recent evidence from wildlife monitoring at two offshore wind turbines off the coast of Virginia shows that insects are regularly offshore, and bats use the wind turbines for foraging opportunities [26]. If insects are present at offshore wind turbines constructed in the Gulf of Mexico, foraging may increase collision risk [24,33,34]. Although bats often interact with offshore structures, the frequency of such interactions is expected to be highest during fall migration periods.

Lighting (Risk)/Attraction (Effect)

The effect of lights on bats is species-specific and depends on behavioral contexts. Lights may affect bat foraging [35–37], roosting [38], and orientation [39]. Attraction to artificial light may draw bats toward offshore wind energy facilities where they may encounter ships that they subsequently attempt to roost on (which may bring them farther offshore and in closer proximity to turbines) [5].

Learn more about offshore wind and bats and in Bat and Bird Interactions with Offshore Wind Energy Development [40].

MONITORING & MITIGATION METHODOLOGIES

Several monitoring technologies are used to monitor bats offshore. To monitor bat presence and species composition, acoustic detectors use ultrasonic microphones to record the vocalizations of bats. Monitoring individual flight metrics (e.g., speed, height, maneuverability) is accomplished with visual and thermal cameras used to record daytime [26] and nocturnal bat activity [41,42]. For monitoring the behavior of individuals, radio telemetry provides information on movement patterns of tagged animals at scales exceeding the viewshed of most camera applications (~200 m), which may be used to identify flight paths, movement corridors, and high-use areas. Acoustic detectors, cameras, and radio tag receiver stations can be deployed offshore in several ways, including on turbine platform structures, buoys, and boats. Monitoring collision effects is difficult, but camera technologies that capture collision events or carcasses falling from the rotor-swept area can be used, as can strike indicators that record collision events using sensors installed along the length of each blade (under development).

Effective monitoring technologies are critical for developing cost-effective mitigation approaches if offshore wind turbines result in significant risks to bats in the Gulf of Mexico. Avoiding effects requires the use of monitoring technologies to fill information gaps related to species presence and composition to inform offshore wind farm siting that avoids areas of high bat use. Curtailing wind turbines, or slowing the rotational speed of the blades, when collision risk is greatest is a commonly used minimization technique in land-based wind farms. Curtailment for bats has proven effective during low-wind conditions.

However, if offshore wind farms are in regions with relatively high average wind speeds (e.g., >10 meters per second, or 22 miles per hour), and risk of bat collision is low, then curtailment may not be necessary. Deterrents are an alternative minimization strategy under development that may be used to discourage bats from spending extended periods of time within the rotor-swept area. If impacts occur and cannot be avoided or minimized, compensation—whereby conservation actions such as protecting or restoring critical bat habitat—may be necessary.

KNOWLEDGE GAPS & RESEARCH NEEDS

The migratory habits of Mexican free-tailed bats suggest they may be at risk from offshore wind energy in the Gulf of Mexico during spatially and temporally isolated migratory periods. Other species may also be present in the Gulf of Mexico; however, there is a lack of direct evidence on the extent of their activity offshore and limited evidence that any other bat species occur in the Gulf of Mexico. It remains unknown whether the presence of offshore wind turbines may draw high-altitude flying bats out of migratory flights. To address these research gaps, the following work is needed:

- Collect additional baseline data, including offshore species compositions, distribution, activity rates, and flight behaviors such as flight heights
- Assess attraction or avoidance behaviors to understand the scale and associated mechanisms
- Develop integrated systems to monitor bat interactions at operating offshore wind energy facilities and determine if and when collision risk is a concern.

Chapter 6 References

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SEER

U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

7.0

FLYING INSECTS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Flying insects are known to occur at offshore wind farms and are known to collide with wind turbines at terrestrial wind farms.
- At least 150 species of flying insects, including monarch butterflies, occur offshore in the Gulf of Mexico.
- Monarch butterfly presence is typically associated with the fall migration period.
- There are significant knowledge gaps regarding the extent and nature of insect activity in the Gulf of Mexico, the potential effects of offshore wind turbines on insects, and how offshore wind farms in the Gulf of Mexico might affect insect populations.
- Various monitoring technologies exist for insects, but few have been applied to monitoring insects at wind farms. Existing knowledge about insect presence at offshore wind turbines comes from detecting them in monitoring technologies that target birds or bats, such as visible light and thermal cameras and opportunistic visual observations.

TOPIC DESCRIPTION

At least 10 orders, 50 families, and 150 species of flying insects occur offshore in the Gulf of Mexico. Flying insects in the Gulf of Mexico are primarily detected during the fall and spring migratory periods; dragonflies (order: Odonata) often contribute the greatest amount of captured insect biomass collected in surveys at offshore oil platforms [1]. Activity peaks late August through October in fall and from late March through May in spring. The presence of aerial invertebrates in the Gulf of Mexico coincides with bird migration and may represent a significant food resource for several species. Migrant songbirds have been observed foraging near oil platforms, and Russell [1] noted that foraging rates appeared greater at offshore platforms than those observed in onshore coastal habitats.

Monarch butterflies (*Danaus plexippus*) are of particular interest in the Gulf of Mexico because they are a U.S. Fish and Wildlife Service candidate species for listing under the Endangered Species Act. Monarch butterflies are known for their migrations. In eastern North America, monarchs travel north from Mexico to Canada in the spring, over two to three successive generations, breeding along the way. In the fall, the final generation makes the return trip to wintering sites in Mexico. Typically, these individuals are observed entering Mexico by traveling through Texas. However, researchers have observed hundreds of monarch butterflies annually flying across the Gulf of Mexico (Figure 7.1). The following key findings from monarch butterfly monitoring on oil and gas platforms in the Gulf of Mexico in the falls of 1994 and 1995 were noted by Ross [2]:

- Monarchs were observed in pairs or small groups (20–40 individuals).
- Monarchs were observed flying 30–130 feet above the water.
- Monarchs did not land until dusk or early darkness; they remained until dawn/morning (but some individuals remained through the following day and night).
- Movement was always in a south-southwest direction.

Where many smaller-bodied invertebrate species may be blown offshore unintentionally, monarch butterflies may use offshore routes to minizine the distance between their origin in the eastern United States and their overwintering grounds in Mexico. Yet, for all aerial invertebrates, it remains unknown what proportion of individuals survive flights over the Gulf of Mexico.

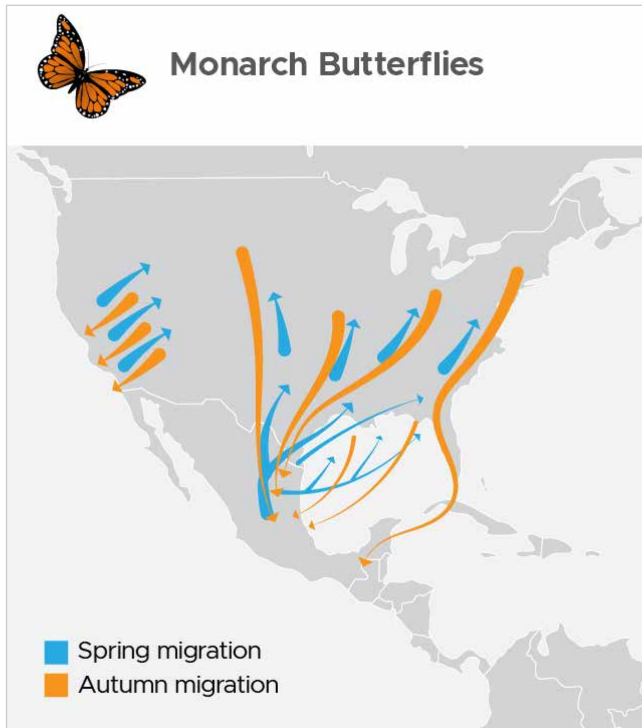

Figure 7.1. Migratory path of monarch butterflies. *Image from the Pacific Northwest National Laboratory, modified from Calvert and Wagner [3].*

MAIN RISKS & EFFECTS

Rotating Turbine Blades (Risk)/Collision (Effect)

Invertebrate turbine collision at land-based wind turbines is increasingly well documented. Voigt [4] estimated collision biomass to equate to thousands of tons per year at terrestrial wind farms. Although it is likely that significantly fewer individuals occur offshore in the Gulf of Mexico during migration compared to the spawning periods on terrestrial landscapes, individuals that encounter offshore wind turbines are at risk of collision.

Presence of Structures (Risk)/ Attraction (Effect)

Flying insects may view offshore anthropogenic structures as a refuge, particularly in inclement weather. Moreover, there is evidence suggesting that birds and bats comigrate with migrating insects [5] and that bird and bat interactions with wind turbines may coincide with insect presence onshore [6,7] and offshore [8] (Figure 7.2). Recent evidence from video monitoring at two offshore wind turbines off the coast of Virginia provides evidence that insect occurrence offshore coincides with the presence of migratory songbirds (Figure 7.2) [8]. Given these dynamics, insect concentrations at offshore wind turbines may, in part, drive behavioral changes in birds and bats in response to the presence of wind turbines by offering foraging opportunities that would otherwise not exist. The available food resource provides foraging opportunities for birds and bats that may increase collision risk for individuals that spend additional time at offshore wind turbines refueling.

Lighting (Risk)/Attraction (Effect)

It is unclear what affect offshore lighting might have on nighttime movement patterns of insects migrating over the Gulf of Mexico, as most observations have been made during the daytime. Although no information exists regarding their nighttime movements, there is some evidence of monarch butterflies arriving at oil platforms in small groups at dusk to rest on structures overnight [9].

Figure 7.2. Cape May warbler (left) chasing a moth (right) at the Dominion Energy offshore wind turbine, Virginia. *Image from Robinson Willmott et al. [8].*

Figure 7.3. Image of turbine blade leading edge with evidence of invertebrate body parts. *Image from Voigt [4].*

MONITORING & MITIGATION METHODOLOGIES

Various monitoring technologies exist to detect insects at varying spatial scales, such as light traps to collect local species and weather radar to track large swarms of insect biomass. However, few of these technologies have been applied to monitoring insects at offshore wind farms. There is some information about insect presence at offshore wind turbines. For example, monitoring insect activity rates may be accomplished with visual and thermal cameras used to record daytime and nighttime invertebrate activity (e.g., Figure 7.2) [8]. Monitoring collision effects is challenging offshore but may be most feasibly accomplished by visual surveys of wind turbine blades to look for evidence of invertebrate body parts stuck to the leading edge of the blade (Figure 7.3) [4].

KNOWLEDGE GAPS & RESEARCH NEEDS

There is limited information about the diversity of flying insect species presence and activity offshore. Further, it is unclear which species intentionally use the offshore environment (if any) and which may be inadvertently carried offshore during migration. To date, there have been no widescale, systematic monitoring efforts offshore for insects. Thus, little is known about the use of human-made offshore structures by flying insects and how activity rates surrounding existing oil and gas platforms and future wind farms will differ from the activity rates in open waters. Future studies can improve our understanding of insect activity patterns offshore by:

- Collecting additional baseline data during the day and night and throughout the annual cycle, including offshore species compositions, distribution, activity rates, and flight behaviors such as flight heights
- Assessing attraction or avoidance behaviors to understand the scale and associated mechanisms
- Investigating if occurrences coincide with migratory birds (and bats) that may be comigrating
- Developing integrated systems to monitor aerial invertebrate interactions at operating wind energy facilities to determine when collision risk is a concern.

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SEER

U.S. OFFSHORE WIND SYNTHESIS OF ENVIRONMENTAL EFFECTS RESEARCH

8.0

SEA TURTLES AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Sea turtles in the Gulf of Mexico are federally protected, highly migratory marine reptiles that rely on several important coastal and pelagic habitats throughout their long lifespans and within each stage of their life history.
- The primary risks of concern for sea turtles from offshore wind energy development in the Gulf of Mexico are the effects of electromagnetic fields, entanglement, habitat change, underwater noise, and vessel strikes.
- There are many efforts underway to monitor, recover, and conserve sea turtles in the Gulf of Mexico, but important data gaps remain and additional research is needed to better understand and mitigate potential risks from offshore wind energy development and other known threats.

TOPIC DESCRIPTION

Five species of sea turtles are commonly found in the Gulf of Mexico, all of which are listed as threatened or endangered under the U.S. Endangered Species Act: the loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*), leatherback sea turtle (*Dermochelys coriacea*), hawksbill sea turtle (*Eretmochelys imbricata*), and Kemp's ridley sea turtle (*Lepidochelys kempii*). These species are highly migratory and rely on several important coastal and pelagic habitats in the Gulf of Mexico throughout their lives, including nesting beaches, estuaries, barrier islands, seagrass beds, Sargassum mats, the Gulf Loop Current, and the Gulf Stream [1,2].

Sea turtles are long-lived reptiles that transition through several stages of development from hatchling to adult. After emerging from nests along coastal beaches, hatchlings enter the water, swim offshore to forage and grow for several years, and are often found in mats of Sargassum floating on the surface. Juvenile green, hawksbill, Kemp's ridley, and loggerhead sea turtles reside and forage in shallow coastal waters of the Gulf of Mexico, while juvenile leatherbacks spend their time in the open ocean, although less is known about their life history and distribution [3–5]. Adult sea turtles are found throughout the Gulf of Mexico and feed near the surface, within the water column, and near soft- or hard-bottom communities, depending on the species' preferred prey [1].

Once they reach sexual maturity, adult females return to land to lay their eggs on nesting beaches, often after migrating long distances. Nesting mainly occurs in the eastern and western Gulf of Mexico, along the coasts of Florida and Mexico, and less frequently along the coasts of Texas, Louisiana, Mississippi, and Alabama [2]. The Gulf of Mexico is particularly important for the Kemp's ridley sea turtle, which is considered critically endangered internationally, has the smallest geographic range, and whose primary nesting areas are along the coasts of Mexico and Texas [6,7].

The main threats to sea turtles worldwide include bycatch in fishing gear, illegal harvesting, loss and degradation of nesting habitat, vessel strike, ocean pollution, and climate change [8]. In the Gulf of Mexico, which is already heavily industrialized and highly trafficked, management efforts have primarily focused on reducing accidental capture by commercial fisheries (e.g., through the adoption of turtle excluder devices). As offshore wind energy development expands in the region, and elsewhere around the world, sea turtles may face additional pressures from site surveying, construction, operations, maintenance, and eventual decommissioning activities.

MAIN RISKS & EFFECTS

Electromagnetic Field Effects

Sea turtles use geomagnetic fields for orientation, navigation, and migration. As a result, they may be sensitive to changes caused by electromagnetic fields emitted from offshore wind subsea power cables [9,10]. Multiple studies have shown sea turtles' use of and sensitivity to magnetic fields [e.g., 11,12], but there are no empirical data on the effects of magnetic fields from subsea cables on sea turtles. The overall effect is expected to be minor because sea turtles typically rely on multiple sensory cues [10], but additional research is needed to better understand the potential risks [13].

Learn more about offshore wind and electromagnetic field effects in Electromagnetic Field Effects on Marine Life [14].

Entanglement Risk

Entanglement in active and derelict fishing gear is a primary threat to sea turtles in the Gulf of Mexico and can result in limited mobility, direct injury, and/or death [2]. If derelict fishing gear snags on floating offshore wind mooring lines, cables, or other infrastructure, it may pose an additional entanglement risk to sea turtles. However, because there are few data on marine debris in the Gulf of Mexico, the likelihood of this "secondary entanglement" occurring remains unknown, and additional research is needed to better understand the extent of the risk.

Learn more about offshore wind and entanglement risk in Risk to Marine Life From Marine Debris & Floating Offshore Wind Cable Systems [15].

Habitat Change

The Gulf of Mexico is a dynamic, highly developed region with a wide variety of construction, dredging, fishing, extraction, and other ongoing human activities that can affect benthic and coastal habitats and the sea turtles they support. Offshore wind energy activities (e.g., turbine installation, cable laying) may have negative effects on sea turtle habitat by disturbing or destroying existing foraging habitat along the seafloor, or positive effects via the introduction of new hard substrate and associated communities (i.e., "reef effect"). Coastal development (e.g., port expansion, vessel traffic) can also deter adult sea turtles from nesting or lead to the loss of nesting beach habitat. For example, artificial lighting from onshore facilities near nesting beaches may deter adult females from coming ashore to nest or disorient emerging hatchlings trying to find the water [16]. However, proper siting and protective measures can avoid or reduce impacts to sea turtles by distancing activities from key habitats and following best practices.

Learn more about offshore wind and effects on benthic and coastal habitats in Chapters 3 and 4.

Underwater Noise Effects

Sea turtles are low-frequency specialists with hearing ranging between 100 hertz and 2 kilohertz [1,17]. Sea turtles in the Gulf of Mexico are commonly exposed to numerous anthropogenic noise sources, including maritime activities and coastal development. Underwater noise generated from offshore wind activities (e.g., site surveys, pile driving) are typically short term and localized but can be chronic and lead to auditory masking, behavioral effects, changes in hearing sensitivity, and potentially injury or death. Research on the effects of pile driving and other sources of high-amplitude impulsive sound on sea turtles is lacking [18], but sound exposure guidelines are available [17], and a variety of protective measures can be applied.

Learn more about offshore wind and underwater noise in Underwater Noise Effects on Marine Life Associated With Offshore Wind Farms [19].

Vessel Strike & Collision

Vessel strikes are an ongoing threat to juvenile and adult sea turtles throughout their ranges, particularly in heavy traffic areas near ports, transit routes, and developed coastlines. Vessel traffic associated with offshore wind development in the Gulf of Mexico may increase sea turtles' risk of strike, which can result in injury or death. Diving behavior and time spent at the surface influence the likelihood of a vessel strike occurring and vary temporally, seasonally, spatially, by species, and in different environmental and oceanographic conditions [4,20,21]. Mitigation measures such as protected species observers, route restrictions, and vessel speed restrictions can reduce the risk of vessel strike.

Learn more about offshore wind and vessel collision risk in Presence of Vessels: Effects of Vessel Collision on Marine Life [22].

MONITORING & MITIGATION METHODOLOGIES

Sea turtles can be difficult to monitor due to their broad distribution, long life spans, migration patterns, time spent at sea, and diving behaviors. They are typically studied using aerial or vessel-based surveys, nesting beach studies, and satellite or acoustic tags. Additionally, remote camera installations, stranding studies, stomach content analyses, and molecular techniques (e.g., stable isotope and genetic methods) can be used to better understand sea turtle distribution and life history.

There are several efforts underway to monitor and study sea turtles in the Gulf of Mexico. For example, the Gulf of Mexico Marine Assessment Program for Protected Species is collecting broad-scale information on the distribution and abundance of sea turtles to inform seasonally and spatially explicit density estimates [20,21,23]. The National Oceanic and Atmospheric Administration recently published a strategic plan to support coordinated in-water sea turtle data collection in the Gulf of Mexico to better inform abundance and population trends [26]. Recently, several surveys and tracking studies have provided better understanding of sea turtle habitat use and behavior throughout the region [e.g., 25–28].

Many local, state, regional, federal, and international organizations are working together to recover, conserve, and protect sea turtles in the Gulf of Mexico. For example, the National Marine Fisheries Service and U.S. Fish and Wildlife Service, who share responsibility for the conservation and recovery of sea turtles in the United States, have jointly designated critical habitat for the northwest Atlantic population of loggerheads [29,30] and have proposed new critical habitat for the North Atlantic green turtle population [31,32]. The National Marine Fisheries Service also coordinates the Sea Turtle Stranding and Salvage Network, which collects data and rescues and rehabilitates stranded sea turtles in the Gulf of Mexico [33]. Generally, conservation and recovery efforts for sea turtles typically include protecting them and their habitats, reducing bycatch, minimizing entanglement, and reducing vessel strikes, as well as supporting research and rehabilitation.

As offshore wind energy development expands in the Gulf of Mexico, federal and state agencies may require additional monitoring and mitigation to further minimize potential risks to sea turtles. Various best practices and mitigation measures exist to avoid and reduce the potential effects from underwater noise, habitat change, vessel strike and collision, entanglement, and electromagnetic fields on sea turtles generally. For example, the National Marine Fisheries Service has issued vessel strike avoidance guidelines for sea turtles, which include speed restrictions to effectively minimize the likelihood of strikes.

KNOWLEDGE GAPS & RESEARCH NEEDS

Additional research is needed on sea turtle abundance, distribution, habitat use, migration patterns, and behavior in the Gulf of Mexico to better understand and mitigate the potential risks from offshore wind energy development, as well as other known threats (e.g., climate change, fisheries bycatch). Continued monitoring to fill remaining data gaps, such as those on sea turtle diving behavior and leatherbacks' spatial distribution [20], can inform future risk assessment and adaptive management.

Finally, as offshore wind development expands in the Gulf of Mexico, it is important to consider the potential cumulative effects of multiple environmental stressors from offshore wind as well as from other human activities (e.g., shipping, oil and gas), on sea turtles. In combination, these effects may result in impacts on sea turtles that should be examined within the context of the global climate change crisis.

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U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

9.0

MARINE MAMMALS AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- Twenty-one cetacean species (whales and dolphins) have been identified in the northern Gulf of Mexico; most species live in the ocean.
- Potential effects on cetaceans differ for floating and fixed offshore wind foundations.
- During the construction of fixed foundations, pile driving generates acute underwater noise, which can injure marine mammals or cause site avoidance.
- Mooring lines associated with floating foundations have the potential to ensnare marine debris or fishing gear which could create an entanglement risk for marine mammals. The likelihood of entanglement for a marine mammal is expected to be very low, but there is insufficient information to quantitatively evaluate this risk.
- Vessel collision is a persistent risk to cetaceans. Vessels used for offshore wind construction and operations should follow best practices to avoid and minimize any potential effects to marine mammals.
- Potential impacts to cetaceans from offshore wind energy development can lead to cumulative effects given existing industrial activities in the Gulf of Mexico.

TOPIC DESCRIPTION

The development of offshore wind energy in U.S. waters is highly regulated, and interactions with marine mammals must be avoided, minimized, and/or mitigated. In the Gulf of Mexico, whales and dolphins, collectively referred to as cetaceans, occur in offshore and coastal waters. This distribution creates the potential for them to interact with offshore wind construction, operations, and decommissioning activities. More than 20 species of cetaceans have been identified in the Gulf of Mexico. The only species known to inhabit inshore waters (i.e., bays, estuaries, lagoons, and inlets) is the common bottlenose dolphin (*Tursiops truncatus*). In coastal waters (ocean depths between 0 and 200 m), common bottlenose dolphins and Atlantic spotted dolphins (*Stenella frontalis*) have been observed. All other cetacean species are observed in offshore waters (ocean depths beyond 200 m) (Table 9.1) [1]. Marine mammal behavior, including foraging, diving, migrating, socializing, nursing, and resting, varies depending on the species, season, and time of day. Both the geographic location and behavior of cetaceans may affect their potential risks from offshore wind energy development, including underwater noise, entanglement, and vessel collision.

All cetaceans are protected under the Marine Mammal Protection Act [2]. In addition, two cetacean species are listed as endangered under the Endangered Species Act: the sperm whale (*Physeter macrocephalus*) and the Rice's whale (*Balaenoptera ricei*), which is the only baleen whale endemic to the Gulf of Mexico [3]. Marine mammals may interact with fixed or floating offshore wind foundations differently based on the location of the development and the type of infrastructure used. For example, in the Gulf of Mexico, fixed offshore wind foundations are likely to occur 50–80 km from the coast, whereas floating foundations are suited for deeper waters that can extend 290 km offshore. The type, location, and water depth of offshore wind development determines which species may be affected be the surveys, installation, operation, and/or decommissioning of the wind farm.

Potential impacts to cetaceans from offshore wind development can include increased underwater noise, vessel traffic, and habitat disruption. Combined with effects from existing industrial activities in the Gulf of Mexico, including oil and gas exploration, commercial shipping, and fishing, these effects can lead to cumulative impacts. These overlapping stressors from multiple sectors could exacerbate risks to cetacean populations, particularly in species already facing conservation concerns, by increasing the frequency and intensity of anthropogenic disturbances in their habitats.

Table 9.1. All Documented Cetacean Stocks in the Gulf of Mexico [1]

A check mark indicates species occurrence in the different habitats and depths they use.
Habitat Depths: Coastal (0–20 m), Continental Shelf (20–200 m), Continental Slope (200–3,000 m), Oceanic (>3,000 m). Species listed as Endangered under the Endangered Species Act are noted with a *.

Common Name	Habitat & Depth			
	Coastal Depth (0–20m)	Shelf Depth (20–200m)	Slope Depth (200–2,000m)	Oceanic Depth (>3,000m)
Common bottlenose dolphin (*Tursiops truncatus*)	✓	✓	✓	
Atlantic spotted dolphin (*Stenella frontalis*)		✓		
Spinner dolphin (*Stenella longirostris*)			✓	
Melon-headed whale (*Peponocephala electra*)			✓	
Rice's whale* (*Balaenoptera ricei*)			✓	
Pilot whale, short finned (*Globicephala macrorhynchus*)			✓	✓
Striped dolphin (*Stenella coeruleoalba*)			✓	✓
Pantropical spotted dolphin (*Stenella attenuata*)			✓	✓
Sperm whale* (*Physeter macrocephalus*)			✓	✓
Dwarf sperm whale (*Kogia sima*)			✓	✓
Pygmy sperm whale (*Kogia breviceps*)			✓	✓
Risso's dolphin (*Grampus griseus*)			✓	✓
Pygmy killer whale (*Feresa attenuata*)			✓	✓
Clymene dolphin (*Stenella clymene*)				✓
Rough-toothed dolphin (*Steno bredanensis*)				✓
Fraser's dolphin (*Lagenodelphis hosei*)				✓
Killer whale (*Orcinus orca*)				✓
False killer whale (*Pseudorca crassidens*)				✓
Goose-beaked whale (*Ziphius cavirostris*)				✓
Blainville's beaked whale (*Mesoplodon densirostris*)				✓
Gervais' beaked whale (*Mesoplodon europaeus*)				✓

MAIN RISKS & EFFECTS

Noise

Offshore wind site characterization surveys, construction, operations, and decommissioning all generate underwater noise (Figure 9.1). Exposure to high-intensity sound from fixed-bottom turbine installation or other construction activities can result in physical injury and/or changes to a marine mammal's hearing. These may include temporary reductions in hearing sensitivities, also known as temporary threshold shifts, or permanent reduction in hearing, known as permanent threshold shifts [4]. Additionally, underwater noise can mask vocalizations and cause short- or long-term behavioral changes that could affect survivorship [5]. Since sound dissipates over distance, the risk of injury or harmful effects generally decreases further away from the sound source.

Impact pile driving, also known as impact piling, is a construction process that drives vertical columns into the ocean floor to build foundations for fixed offshore wind turbines and has the greatest potential impacts on cetacean hearing. It produces high-amplitude broadband noise that can propagate long distances through the ocean, seafloor, and air. The greatest concern regarding noise from pile driving is the risk of hearing loss, particularly for cetaceans close to the sound source. Cetaceans most commonly respond to this noise by avoiding the pile driving area [6,7]; however, the magnitude of displacement varies depending on the species [8].

Vibratory pile driving, where the pile is vibrated into sediment using a vibratory hammer, is typically used for construction in coastal areas and sometimes during monopile installation to ensure pile stability [9,10]. Noise from vibratory pile driving is less likely to cause permanent hearing loss and injury in marine mammals than impact piling due to lower peak pressure levels. But because the distance threshold for behavioral disruption in marine mammals is typically further for continuous sound sources (such as vibratory piling) than for impulsive noise sources (such as impact piling), vibratory piling has the potential to result in behavioral disruption over a larger area [8].

More information about noise from offshore wind farms can be found in Underwater Noise Effects on Marine Life Associated With Offshore Wind Farms [11].

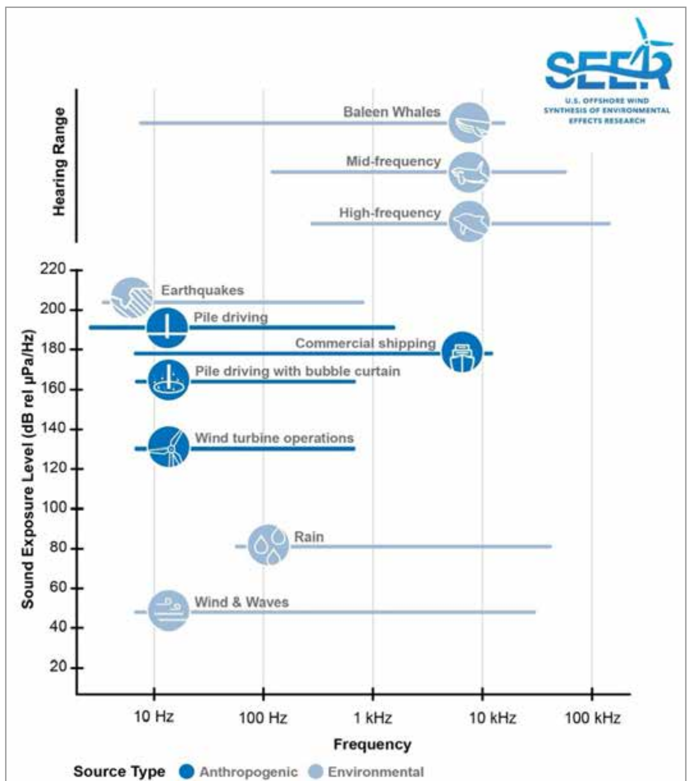

Figure 9.1. Hearing range of marine mammals (top) and sound exposure level of anthropogenic and environmental noise (bottom). *Image from Pacific Northwest National Laboratory.*

Vessel Collision

Vessel strikes are one of the primary causes of marine mammal mortalities worldwide [12]. The probability of a strike increases with vessel speed [12] and poor visibility conditions such as fog or darkness. Vessels operating in the Gulf of Mexico, which is highly industrialized, pose a risk to cetaceans. Increases in vessel traffic during offshore wind development activities (e.g., construction, maintenance) are a topic of concern, especially for the Rice's whale.

More information about vessel collision risk associated with offshore wind development can be found in Presence of Vessels: Effects of Vessel Collision on Marine Life [13].

Entanglement

Floating offshore wind foundations are anchored with mooring lines and connect to adjacent floating turbines with underwater cable arrays. Given the tension, larger diameter, and rigidity of these lines, direct or "primary" entanglement is unlikely. However, mooring lines and cables can potentially ensnare marine debris or derelict fishing gear. In turn, the ensnared debris may entangle marine mammals and other organisms (known as "secondary" entanglement) and therefore poses a risk [14]. Little is known about secondary entanglement probability. Model estimates, which use tides, currents, and winds to predict marine debris concentrations in the Gulf of Mexico, show the highest concentrations are likely to be within 30 km of the shore [15]. Floating offshore wind sites will be developed at least 50 km offshore, so it is expected that risk of secondary entanglement is low.

More information about entanglement risk from offshore wind energy development can be found in Risk to Marine Life From Marine Debris and Floating Cable Systems [16].

MONITORING & MITIGATION METHODOLOGIES

Best practices and lessons learned from offshore wind energy development in Europe and on the U.S. Atlantic coast can inform monitoring and mitigation strategies in the Gulf of Mexico. BOEM has issued guidelines for best management practices for floating offshore wind, including strategies to minimize impacts to wildlife from noise, vessel strikes, and entanglements [17]. Figure 9.2 highlights potential risks to marine mammals from offshore wind development and examples of associated mitigation measures.

Underwater Noise

NMFS has determined amplitude levels for the permanent and temporary hearing threshold shifts for all underwater noise sources. While these thresholds can be used to develop and guide strategies to mitigate noise-related risks posed to cetaceans, mitigation measures are not mandated [18]. One common mitigation measure is to avoid sound-generating activities at locations and times when cetaceans are expected to be present [19]. Information about the seasonal abundance/density and known behavioral patterns of marine mammal species in an offshore wind project area can be used to determine the degree of overlap with offshore wind activities and mitigation options. For example, during construction, trained protected species observers are required onboard vessels to reduce risks. Underwater passive acoustic monitoring with hydrophones can also be used to detect whales and dolphins so activity can be halted when an animal is nearby.

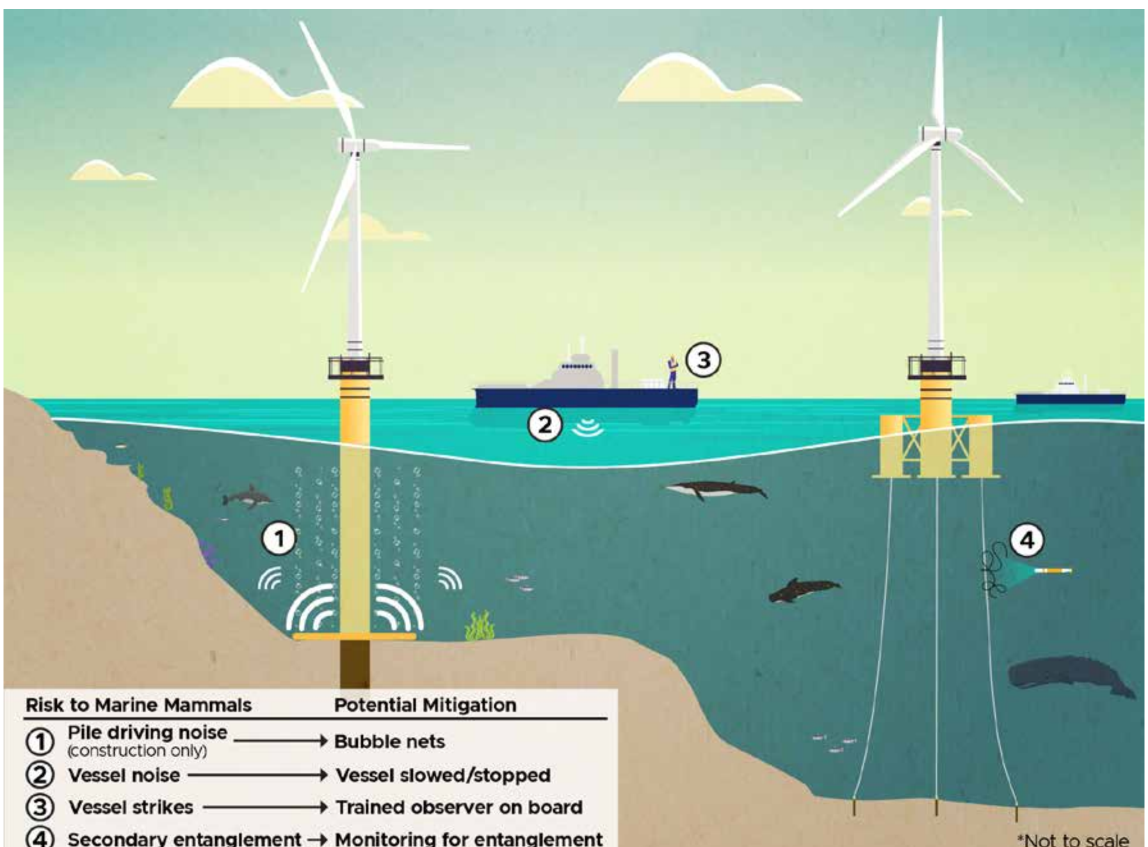

Figure 9.2. Risks and potential mitigation measures for marine mammals. *Image from Pacific Northwest National Laboratory.*

Reducing underwater noise can help mitigate potential effects on marine mammals. Alternative installation methods, like vibratory piling, may be quieter than driving piles. Additionally, there are other foundation types, such as suction buckets or gravity-based foundations, that do not require loud piling. If the production of high-intensity sound is a necessary part of the construction plan, deploying noise reduction or abatement technologies can reduce the intensity of noise emissions. Some examples include bubble curtains, resonator systems, and dampening systems, among others. Bubble curtains, which release bubbles from an air hose on the seafloor, can block a portion of the sound emitted during construction activity and have been used during the construction of fixed offshore wind foundations near Martha's Vineyard [20], Block Island, Rhode Island, and Virginia [21]. However, they do not reduce all low-frequency sounds within the hearing range of baleen whales. Advancing noise reduction technologies by improving efficacy, reducing costs, and developing measurement standards is expected to increase their use and applicability to the offshore wind sector [22].

Vessel Collision

Using best management practices for vessel operations, such as visual monitoring for marine mammals and reducing vessel speed, can reduce the risk of vessel collision. Vessels associated with offshore wind projects are typically required to operate at reduced speeds and have a qualified protected species observer onboard. When cetaceans are observed near the vessel, the vessel operator is required to adjust the course or place the engine in neutral until the animal(s) have passed. Vessel traffic can also be rerouted to circumnavigate areas with high marine mammal presence [23]. In addition to human observers, novel technologies can be used and deployed to improve awareness of nearby cetaceans and take appropriate actions. Beyond onboard detections, NOAA and other data service providers have mobile applications in the Atlantic that are used by vessel operators to receive marine mammal sighting alerts. Vessel operating procedures during site assessment, construction, and other relevant project phases are subject to review under the Marine Mammal Protection Act, Endangered Species Act, and National Environmental Policy Act prior to initiation of any offshore wind development activities.

Entanglement

To reduce the risk of entanglement, BOEM has issued mooring design guidelines for best management practices for operations; the guidelines include mooring designs that minimize cable length and use materials (e.g., rubber sleeves or chains) that prevent looping, wrapping, or entrapping cetaceans [17]. Mooring line monitoring is typically performed using underwater vehicles during periodic surveys, but advanced technology to allow real-time detection of marine debris with underwater offshore wind infrastructure would help reduce the risk for secondary entanglement of marine mammals.

KNOWLEDGE GAPS & RESEARCH NEEDS

Understanding the abundance, distribution, and behavior of cetaceans in the Gulf of Mexico is a complex and ongoing area of research. For example, recent studies have shown that the endangered Rice's whale mainly feeds during the day on a specific species of fish that occur on the upper continental slope in the northern Gulf of Mexico [24]. While more research on Rice's whale location and behavior is needed and underway [25,26], these findings can be used to help determine offshore wind farm siting as well as temporal and spatial restrictions during the development process. Knowledge gaps remain on hearing thresholds of baleen whales as well as species-specific responses to underwater noise.

In addition, advancement in the design, application, and standardization of mitigation and monitoring technologies and risk identification can reduce exposure of harmful effects to cetaceans. Specific technology needs include:

- Improving existing noise-quieting technologies and developing new types of fixed foundations that do not require pile-driving activity [22].
- Developing best practices and validation frameworks to design monitoring arrays that can detect the presence of cetaceans and inform maritime operators to alter or halt operations. For example, including passive acoustics or infrared detection to monitor cetacean presence in addition to onboard protected species observers has the potential to reduce vessel collisions with cetaceans and cetacean exposure to construction noise associated with the installation of fixed-bottom turbine foundations.
- Developing technology and models that can predict, detect, and prevent marine mammal secondary entanglement with mooring lines and underwater cable arrays attached to floating offshore wind foundations.

Overall, additional knowledge about how cetaceans in the Gulf of Mexico respond to stimuli (e.g., noise) and environmental changes will help inform the responsible development of offshore wind energy in the region. However, offshore wind development can still occur under the regulatory frameworks established in the United States to protect marine mammals with oversight, monitoring, and caution.

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U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

10.0

FISH AND INVERTEBRATES AND OFFSHORE WIND IN THE GULF OF MEXICO

MAIN TAKEAWAYS

- The Gulf of Mexico has a long history of human activities, and the potential effects from offshore wind energy development are likely to be similar to those from existing ocean industries.
- Addition of hard substrate and vertical structures in the water column may have the greatest potential effects on fish and marine invertebrate species.
- Bottom disturbance, underwater noise, electromagnetic fields, artificial light, and habitat alteration associated with offshore wind development have the potential to affect fish and invertebrates during various stages of the project life cycle.
- The legacy of oil and gas platforms in the Gulf of Mexico informs our understanding of how offshore wind development may influence the local ecosystem.

TOPIC DESCRIPTION

The Gulf of Mexico is renowned for its rich marine biodiversity. Its community structure is influenced by factors such as water temperature, depth, degree of light penetration, and substrate type, creating a diverse mosaic of habitats. These habitats support a rich array of both fish and marine invertebrate species in the Gulf of Mexico that are ecologically and economically valuable, including several federally protected species (Table 10.1). The fish community in the Gulf of Mexico is influenced by factors such as species movement and migration, life-history strategies, fishing pressure, and differences in hydrographic, oceanographic, and geographic conditions [1].

Within the Gulf of Mexico, coastal pelagic species inhabit sunlit waters from the coast to the continental shelf. Notable taxonomic families include menhaden (*Clupeidae*), anchovies (*Engraulidea*), and bluefish (*Pomatomidae*). The Gulf of Mexico is also home to a diverse array of coastal pelagic sharks that are vital top-level predators in the marine food web. Coastal demersal species primarily use benthic habitats rather than open water. Species of coastal demersal fish associated with soft-bottom habitats include penaeid shrimps and flatfishes, and those associated with hard-bottom habitats include snappers, groupers, and lobsters. Certain species, like drums, red grouper, red snapper, and octopus, can be associated with either type of substrate. Red drum, red snapper, and red grouper are ecologically and economically prominent coastal demersal within the Gulf of Mexico [2].

Waters seaward of the continental shelf become oceanic. Pelagic fish and invertebrates are found in the open ocean at varying depths along the water column. These organisms, although capable of traversing multiple depths, are described by their primary habitat depth, including epipelagic (surface to 200 meters [m]), mesopelagic (200–1,000 m), and bathypelagic (deeper than 1,000 m) [2]. Among the epipelagic species, tunas are an ecologically and economically important pelagic group in the Gulf of Mexico and yellow-fin tunas are top level predators [3]. Although the deep-sea zones of the Gulf of Mexico constitute approximately 91% of its volume [4], less is known about these mesopelagic and bathypelagic regions. Many fish species in the mesopelagic zone undergo vertical migrations to feed on plankton in the epipelagic zone at night, contributing to an important cycle of energy transfer [5,6].

Marine invertebrates constitute a diverse group of species, and some of the most common taxonomic groups include crustaceans (e.g., lobsters, crabs, shrimp), mollusks (e.g., shellfish, squid), and cnidarians (e.g., jellyfish, corals) [7]. These species rely on benthic habitats and may be impacted by activities from offshore wind energy development that disrupt benthic processes. The type of seabed

Definitions

- **Benthopelagic fish:** Fish that live in close association with the bottom of the sea but can move to the upper parts of the water column (cod, pouting)
- **Epifaunal organisms:** Organisms that grow on the surfaces of submerged structures, including stationary and mobile invertebrates (mussels, barnacles)
- **Demersal fish:** Groundfish (flounder, haddock) that spend most of their time living and feeding on or near the seafloor
- **Pelagic fish:** Fish that occupy middle depths and surface waters with the ability to perform daily vertical migrations (mackerel, sea bass)

substrate strongly influences benthic communities. Soft-substrate communities of mud and sand support communities of benthic infauna, or organisms that burrow into the seafloor. Hard-bottom habitats are associated more strongly with benthic epifauna (e.g., worms or clams), or organisms that live on the seafloor (e.g., crabs or mussels). Blue crab, eastern oyster, pink shrimp, brown shrimp, and white shrimp are some of the most recreationally and economically valuable species in the Gulf of Mexico.

Table 10.1. Federally Protected Fish and Marine Invertebrate Species Within the Gulf of Mexico

Species	Scientific Name	Protection	Description	Primary Stressors
Gulf sturgeon	*Acipenser oxyrhynchus desotoi*	Environmental Species Act (ESA) Threatened in 1991	Subspecies of the Atlantic sturgeon	Overfishing and habitat loss
Nassau grouper	*Epinephelus striatus*	ESA Threatened in 2016	Long-lived, moderately sized species	Overharvesting during spawning season
Oceanic whitetip shark	*Carcharhinus longimanus*	ESA Threatened in 2018	Large, pelagic shark species; vulnerable to exploitation, as they mature slowly and have low fecundity [8]	Bycatch and direct fisheries
Giant manta ray	*Manta birostris*	ESA Threatened in 2018	World's largest ray species; slow-growing filter feeders found throughout the globe; highly migratory [9]	Overfishing
Smalltooth sawfish	*Pristis pectinata*	ESA Endangered in 2003	Elasmobranch named for distinctive rostrum, a flat snout with a toothed edge	Habitat loss and degradation

MAIN RISKS & EFFECTS

Activities associated with offshore wind development in the Gulf of Mexico, including construction, operations and maintenance, and decommissioning, have the potential to directly and/or indirectly impact fish and marine invertebrate species.

Benthic Disturbance

The foundations, anchors, and cables required for offshore wind energy development may alter benthic habitats and associated benthic communities through bottom disturbance during construction and decommissioning. The primary stressors of seabed disturbance are potential physical damage to individuals, habitat loss, and changes to water quality or sediment and turbidity. Species associated with soft-bottom sediments are generally better adapted to disturbance and quicker to recover from this type of physical disturbance than those in hard-sediment habitat [10]. Overall, the physical footprint of this disturbance is expected to be small and localized. No lasting damages to these communities are expected [11].

Learn more about offshore wind and benthic disturbance in Chapter 4 and Benthic Disturbance From Offshore Wind Foundations, Anchors, and Cables [12].

Habitat Alteration

Given that the majority of the Gulf of Mexico coastal seabed is soft sediment, the addition of hard substrates (e.g., rock and concrete) has the potential to alter seabed habitat and marine invertebrate communities. The addition of platforms creates changes in the water column that last for several decades in areas that previously lacked any vertical structure. These new hard surfaces are rapidly colonized by species that attach to hard surfaces, also called epifaunal organisms, and the addition of vertical structures attracts fish. In this way, offshore wind development may create ecologically beneficial artificial reefs that support higher biodiversity than the surrounding areas [13].

Understanding of the impact of these habitat alterations is informed by the large body of evidence and research on offshore structures in the United States (e.g. see [2,14]), including over 1,300 active offshore oil and gas platforms in the Gulf of Mexico [15]. These submerged structures are rapidly colonized by invertebrates and fish, thereby creating artificial reefs and fish aggregation hotspots [16,17]. The direct effects on fish and marine invertebrate ecology are lower at floating wind turbines than at those with fixed-bottom turbines because floating turbines do not use a foundation that creates substantial hard-bottom habitat between the surface and the seafloor [18,19].

Offshore wind foundations may provide "stepping stones" across which non-native species are able to spread. Lionfish were first spotted in the Gulf of Mexico in 2010, and by 2013, the density of lionfish at artificial reefs was 2 orders of magnitude more than at natural ones; it is not possible to know whether this species would have spread even in the absence of artificial platforms [20]. Fouling communities—the semimobile marine invertebrate species that colonize hard surfaces—on oil and gas platforms differ from communities found on natural hard substrate. In the Gulf of Mexico, barnacles dominate nearshore platforms, whereas platforms farther offshore have a larger number of bivalves [21,22]. The rate at which benthic communities recover following disturbance depends on the area's connectivity.

In some offshore wind areas, fisheries exclusion can increase local species abundance by reduced mortality of both target and bycatch species and can benefit benthic species, particularly if bottom trawling is halted.

Learn more about offshore wind and habitat changes in Introduction of New Structures: Effects on Fish Ecology [23].

Underwater Noise

Underwater noise levels produced through offshore wind development will vary throughout the project life cycle. Noise produced during initial high-resolution geophysical surveys are short term, infrequent, and unlikely to cause negative effects [24]. During construction, high-intensity, impulsive noise associated with pile driving has the highest potential for negative effects. Non-impulsive sounds (e.g., background vessel traffic and operational noise) are continuous, stable over time, and are less likely to affect fish and invertebrate species. During operations and maintenance, underwater noise is unlikely to exceed ambient sound levels from other disturbance sources in the Gulf of Mexico, an area with chronically elevated marine noise [25]. During decommissioning, the soundscape may experience increased vessel traffic and noise associated with dismantling infrastructure. Both the pressure and vibration of underwater noise decrease with distance from the source (Figure 10.1) [26].

The primary effects of concern from underwater noise are damage to sensitive organs, disruption of natural behaviors, and masking of important biological signals. Fish and invertebrates can sense different variations of sound pressure, particle motion, or substrate vibration. Injury-causing noise levels likely only occur within close range to impact activities like pile driving, whereas lower sound levels causing behavioral impacts may extend across a wider range. While all fish are sensitive to particle motion, sensitivity to sound pressure is related to the presence of gas-filled organs such as swim bladders. Fish with swim bladders are at increased risk of injury from vibration from anthropogenic noise, and species with swim bladders located close to their inner ears are the most sensitive and suffer detrimental impacts at lower noise levels [27,28]. Sound is a critical mating strategy for some species in the Gulf of Mexico. Goliath grouper (*Epinephelus itajara*) at spawning sites in the Gulf of Mexico produce sounds around 60 hertz (Hz), which is within the range of several offshore wind activities [29]. Red drum (*Sciaenops ocellatus*) spawn in large aggregations where males produce low-frequency sounds around 140–160 Hz to attract mates; red drum call rates may decrease when nearby boat traffic levels reach a certain threshold, and high levels of traffic may potentially mask the calls [30].

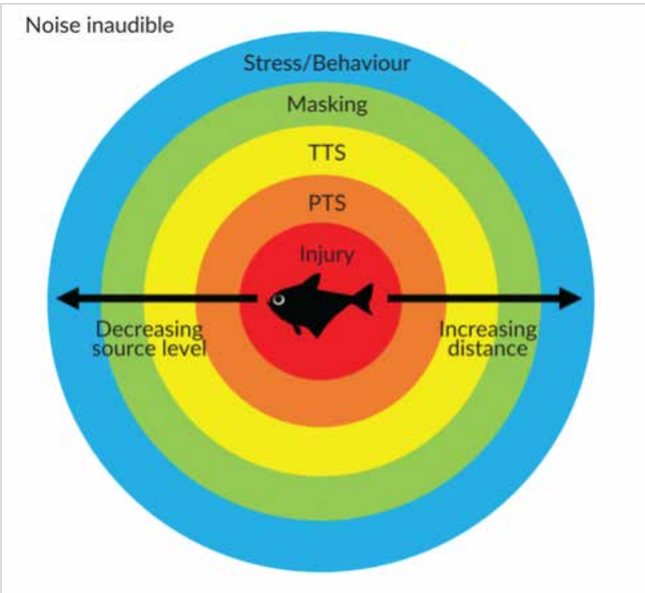

Figure 10.1. The potential for injury is highest with high noise levels and close distance. Behavioral effects are possible farther away. TTS stands for temporary threshold shifts and PTS for permanent threshold shifts. *Figure from Putland et al. [26].*

Less is known about the acoustic sensitivity in invertebrates although many species are sensitive to vibratory stimuli [31]. For example, hermit crabs (*Pagurus berhnardus*) exhibit locomotion in response to particle motion [32]. One study found that blue mussels (*Mytilus edulis*) increased rates of filtering suspended particles from the water in response to pile driving, potentially due to increased metabolic activity and stress [33]. Research investigating the sound reception of invertebrates is less clear, although prawns (*Palaemon serratus*) are able to hear sounds with a 500-Hz frequency [34]. Crustaceans are the only marine invertebrates known to actively rely on sound for communication. For example, some species of lobsters produce creaky frictional sounds reminiscent of a stringed instrument upon movement that may work to deter predators [35,36]. Statocysts, the internal sensory organs of cephalopods, showed physical damage consistent with massive acoustic trauma after exposure to low-frequency sound (~50–400 Hz) [37]. Additionally, these sounds can create behavioral changes; pile driving stimulated alarm behavior in longfin squid (*Doryteuthis pealeii*) [38]. Invertebrates lack swim bladders and are thus slightly less sensitive to physical injury to sound.

The overall risk of noise-related effects from pile driving is low because they are localized and short term. Mitigation options such as noise abatement systems will reduce the likelihood of negative impacts even further. The non-impulsive sounds associated with background operations and maintenance are likely too low to cause direct physical injury but may impact the behavior of species near turbines (although species may adapt to this noise through time). Under laboratory settings, groups of juvenile seabass (*Dicentrarchus labrax*) exposed to recordings of pile driving experienced less group cohesion and become more disordered [39]; some of these behavioral changes become less pronounced across trials, suggesting some degree of habituation over time [40].

Learn more about offshore wind and noise effects in Underwater Noise Effects on Marine Life Associated With Offshore Wind Farms [41].

Electromagnetic Fields

Electric power cables from offshore wind farms may add to or interact with electromagnetic fields (EMFs) naturally occurring in the marine environment. Overall, anthropogenic EMFs are not expected to have significant impacts on fish or marine invertebrate ecology, although more research is needed to increase overall understanding.

Although species' sensitivities are not fully understood, naturally occurring EMFs may influence several natural behaviors like navigation, orientation, and predator-prey interactions. Some species of fish (e.g., sharks, skates, rays, and sturgeon) and invertebrates (e.g., some species of snail, lobster, and crab) may be able to sense these fields. EMFs from subsea cables may disguise natural EMF-mediated behavioral cues, but more research is needed to assess if there is any negative impact to species or populations. Exact responses will vary depending on the role EMFs play in a specific natural history cycle (e.g., species that use EMFs for navigation may be disoriented when coming into close contact with cables). The American lobster (*Homarus americanus*) and the little skate (*Leucoraja erinacea*), two prominent species present in the Gulf of Mexico, exhibited altered behavior and movement patterns in response to EMFs in laboratory settings. These EMFs did not, however, pose a barrier to movements across the cable for either species [42].

Some examples of species in the Gulf of Mexico that may be sensitive to EMFs include the blue shark (*Prionace glauca*), blacktip shark (*Carcharhinus limbatus*), common thresher shark (*Alopias vulpinus*), clearnose skate (*Raja eglanteria*), roundel skate (*Raja texana*), longfin mako (*Isurus paucus*), Atlantic stingray (*Dasyatis sabina*), and cownose ray (*Rhinoptera bonasus*). Gulf sturgeon, a protected species in the Gulf of Mexico that is a subspecies of Atlantic sturgeon, use special sensory organs, called ampullae of Lorenzini, to detect electric fields, potentially for the purpose of prey detection and navigation. Laboratory studies found no evidence of behavioral changes to Atlantic sturgeon in the presence of EMFs [43]. Bottom-dwelling species are most likely to encounter EMFs from seafloor power cables, and the strength of an EMF is dependent on distance to the cable.

Learn more about offshore wind and EMF effects in Electromagnetic Field Effects on Marine Life [44].

Light

The potential for artificial light to impact species of fish or invertebrates is species-specific and limited overall due to the transient and localized nature of the impacted area. No substantial impact to finfish or pelagic invertebrates is expected.

However, artificial light does have the potential to cause behavioral reactions such as attraction or avoidance in fish and marine invertebrate species in a highly localized area. Artificial light can disrupt diel vertical migration patterns in some fish and potentially increase the risk of predation or disrupt predator/prey interactions [45]. In the northern Gulf of Mexico, fish abundance was greater in the upper water column during the day near illuminated oil and gas platforms than at unlit platforms. This relationship was less pronounced at night, which may suggest that fish are spending less time near illuminated surface waters to avoid predation, although the results had significant temporal and spatial variability [46]. Corals exposed to artificial light at night exhibited structural changes [47]. Blue mussels (*Mytilus edulis*) did not exhibit overall changes in feeding in response to the presence of artificial light [48].

MONITORING & MITIGATION METHODOLOGIES

A variety of methods and technologies can be used to monitor the distribution, abundance, and behavior of fish and marine invertebrate species in the Gulf of Mexico. Careful sampling and experimental design allow researchers to assess changes to fish or marine invertebrate ecology associated with offshore wind energy development. Two commonly used approaches are the before-after control-impact (BACI) approach and the before-after gradient (BAG) approach.

In the earliest stages of offshore wind development, careful siting can help minimize impacts by avoiding sensitive areas or populations. BOEM requires developers to conduct site characterization surveys; this preconstruction information can be used as a baseline from which developers can create site-specific decisions on how to assess and limit negative impacts. After leasing and as part of their construction and operations planning, wind energy developers are required to submit biological assessment and benthic habitat monitoring plans. These types of assessments inform micro-siting. Ongoing benthic monitoring includes acoustic sonar surveys, sediment samples, water quality samples, and video/photographic monitoring to look for changes or deviations from baseline surveys.

Specific monitoring and mitigation approaches are designed to mitigate effects from:

Noise

Ocean acoustic monitoring is performed using hydrophones. Mitigation measures like noise abatement systems can alleviate the impacts of noise associated with pile driving. Other strategies include temporal restrictions on pile driving and soft starts wherein the impact is gradually ramped up from an initial set of softer strikes.

Electromagnetic Fields

EMFs can be modeled using site-specific information to show how they spread within the water column. Cables should be sited away from important habitats for sensitive species. Cables are typically buried, although burial depth depends on several factors, and burial does not reduce impacts to benthic invertebrates on the seafloor.

Bottom Disturbance

The environmental review process requires benthic habitat surveys during siting. Benthic monitoring includes acoustic sonar surveys, sediment sampling, water quality samples, and video/photographic monitoring to look for changes or deviations from baseline surveys. Acoustic and optical backscatter sensors can be used to measure turbidity.

Habitat Alteration

There is ongoing research to develop nature-inclusive foundation designs. Scour protection layers, which are thick sediments placed around turbine foundations to limit erosion, can be designed to promote biodiversity and habitat. Properly burying cables and lines can strategically minimize the overall footprint of disturbance.

Light

Following best practices will minimize the number and intensity of lights. Strobing or flashing lights should be used, when possible, with careful attention to the direction of the beam to avoid direct illumination of the ocean.

KNOWLEDGE GAPS & RESEARCH NEEDS

As offshore wind energy development increases, there is a need for continued research into how it may impact fish and marine invertebrate species. Remaining knowledge gaps and areas for further research that would increase understanding of how these species interact with offshore wind farms include:

- Increased understanding of underwater noise on invertebrates; very few studies have explored the effects of noise on invertebrates on large scales or over longer periods of time
- More thorough examination and understanding of the role artificial platforms play in spreading non-native species and their impact on ecosystem function
- Further investigation into the potential for EMFs to mask behavioral cues in species
- Additional research linking effects to fitness consequences and how these interact with other stressors (i.e., artificial light and temperature)
- Further research into how specific facility and turbine designs can impact fish and marine invertebrates
- Continued exploration of the linkage between individual or population effects and ecosystem wide processes (e.g., trophic interactions).

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