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Review

Science priorities to evaluate the effects of offshore wind energy development on fish and fisheries in the Gulf of America

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ABSTRACT

Objective: Offshore wind (OSW) farms are slated for development in the Gulf of America (also known as the Gulf of Mexico), presenting a timely need to understand the potential effects of their construction and operation on marine ecosystems.

Methods: To help address this need, we convened a transdisciplinary working group of scientists, managers, and representatives of commercial and recreational fisheries to identify and assess research priorities and recommendations related to the effects of OSW farms on fish and fisheries in the Gulf of America.

Results: Here, we share these research priorities for shrimp, reef fishes, coastal migratory pelagics, forage fishes, oceanic pelagic fishes, coastal elasmobranchs, and invasive species. We then detail OSW research needs that are related to oceanographic and ecological processes, and we provide specific recommendations for fisheries management, marine spatial planning, and detection of social and economic effects. Our synthesis highlights three overarching considerations: (1) targeted data collection is needed to disentangle the effects of OSW from those of concurrent natural and anthropogenic stressors, (2) measuring the effects of OSW will require maintaining the integrity of

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long-term fisheries-independent surveys and augmenting such surveys with comprehensive before-after-control-impact or before-after-gradient research designs, and (3) there are differences in public participation processes for nascent OSW development versus established fisheries management that should be considered to allow meaningful societal participation.

Conclusions: Scientists and natural resource managers have a unique opportunity to address these priorities and recommendations, shaping the understanding of the effects of OSW.

KEYWORDS: artificial reefs, fisheries, fisheries management, Gulf of America, marine artificial structures, offshore wind, research priorities

LAY SUMMARY

Given the multisector (oil and gas, artificial reefs, fisheries) and multispecies fisheries nature of the United States Gulf of America, we summarize important research priorities for understanding the effects of offshore wind development on fish and fisheries.

INTRODUCTION

The rapid and global expansion of offshore wind (OSW) development presents pressing science and management opportunities and questions. Since the first OSW farm (Vindeby) was built in 1991 in the North Sea (Ørsted, 2019), OSW farms have been developed in northwest Europe (Ørsted, 2019; Wang et al., 2024), China (Wang et al., 2024), and the United States (Doty, 2023). Europe led the global development of OSW until 2022, when the Asia-Pacific region began producing over 34 gigawatts (GW) per year from OSW (Wang et al., 2024; Williams et al., 2023). As of 2022, U.S. OSW contributes to <1% of global OSW electricity generation (Williams et al., 2023). Over the past decade, the USA has set federal and regional plans to increase technological capacity, reduce production costs, and expand OSW infrastructure (The White House, 2021; Musial et al., 2023; U.S. Department of Energy, 2022); however, these plans have more recently been curtailed (The White House, 2025).

The Gulf of America (hereafter, abbreviated as GoA; also known as Gulf of Mexico) has been explored as a suitable region for development of OSW in the USA (Randall et al., 2022). The Bureau of Ocean Energy Management (BOEM), under the U.S. Department of the Interior, executed the first federal offshore wind energy lease sale in the GoA in 2023 and has prepared other wind energy areas (WEAs) in U.S. federal waters off Texas and Louisiana for potential auction in the future (Figure 1). Other GoA areas that are under consideration and review for OSW leasing have been identified (Musial et al., 2023), and two additional leases in Louisiana state waters have been designated and awarded (Baurick, 2023). Given an estimated timeline of approximately 8 years from leases being granted to the beginning of infrastructure installation (Figure 2; Bureau of Ocean Energy Management, 2024), the GoA may have operational OSW infrastructure in the early 2030s. Therefore, the time to anticipate the potential ecological impacts of OSW in the GoA, especially regarding fish and fisheries, and plan for their mitigation is now.

Offshore wind infrastructure in the U.S. GoA would join a constellation of oil and gas (O&G) platforms, pipelines, and intentionally placed artificial reefs in a heavily industrialized and immensely productive ecosystem. Collectively, the GoA has the largest footprint of artificial reefs in the USA (Paxton et al., 2024) and contains 49% of the global area of offshore O&G platforms (Bugnot et al., 2021). Thousands of O&G platforms have been constructed since the 20th century (Shipp & Bortone, 2009; Yergin, 1991), with about 2,100 platforms existing currently (Office for Coastal Management, 2024). Also, over 20,000 documented (and innumerable undocumented) artificial structures have been deployed on the GoA shelf (Gardner et al., 2022; Schulze et al., 2020; Shipp & Bortone, 2009). In addition, the GoA provides 17% of the U.S. national commercial fisheries landings, 35% of the U.S. national recreational fisheries catch, and 21% of the U.S. marine aquaculture production value (National Marine Fisheries Service [NMFS], 2024a). Artificial structures support commercial and recreational GoA fisheries (Gallaway et al., 2009, 2021), and fishermen in the GoA have traditionally targeted fishing on O&G platforms and artificial reefs (Brashier, 1988; Stanley & Wilson, 1989). The presence of multisector and multispecies fisheries in the GoA presents novel issues, research opportunities, and management scenarios to consider with respect to the potential effects of OSW on fish and fisheries.

Approach

We convened a transdisciplinary working group in 2023 (Impacts of Offshore Wind on Gulf of Mexico Fish and Fisheries, https://www.nceas.ucsb.edu/workinggroups/gei-data-synthesis-and-models-evaluate-cumulative-ecosystem-impacts-offshore-wind) to evaluate potential effects of OSW development on fish and fisheries in the GoA. The working group members represented academic, federal, and private research entities; federal and state natural resource management agencies; and recreational and commercial fisheries groups (Table 1). We used a coproduction process (e.g., Beier et al., 2017) to identify research priorities and rank them according to urgency and importance (Figure 3). Although our primary focus was on fish and fisheries, we also acknowledge the importance of identifying and addressing research priorities for other ecologically important and/or protected species (e.g., birds, sea turtles, and marine mammals). In addition, OSW in the GoA may become coupled with "green hydrogen" technology in the future (Hicks, 2024), as the GoA is one region where low costs of production could be achieved (Brunik et al., 2024); however, considering the effects of green hydrogen technology was outside the scope of our working group.

Here, we present the priorities and recommendations for GoA managers that were identified by the working group (Table 2). In section 2, we present research priorities for specific taxa and fisheries of interest in the GoA. In section 3, we more broadly discuss research priorities for oceanographic and

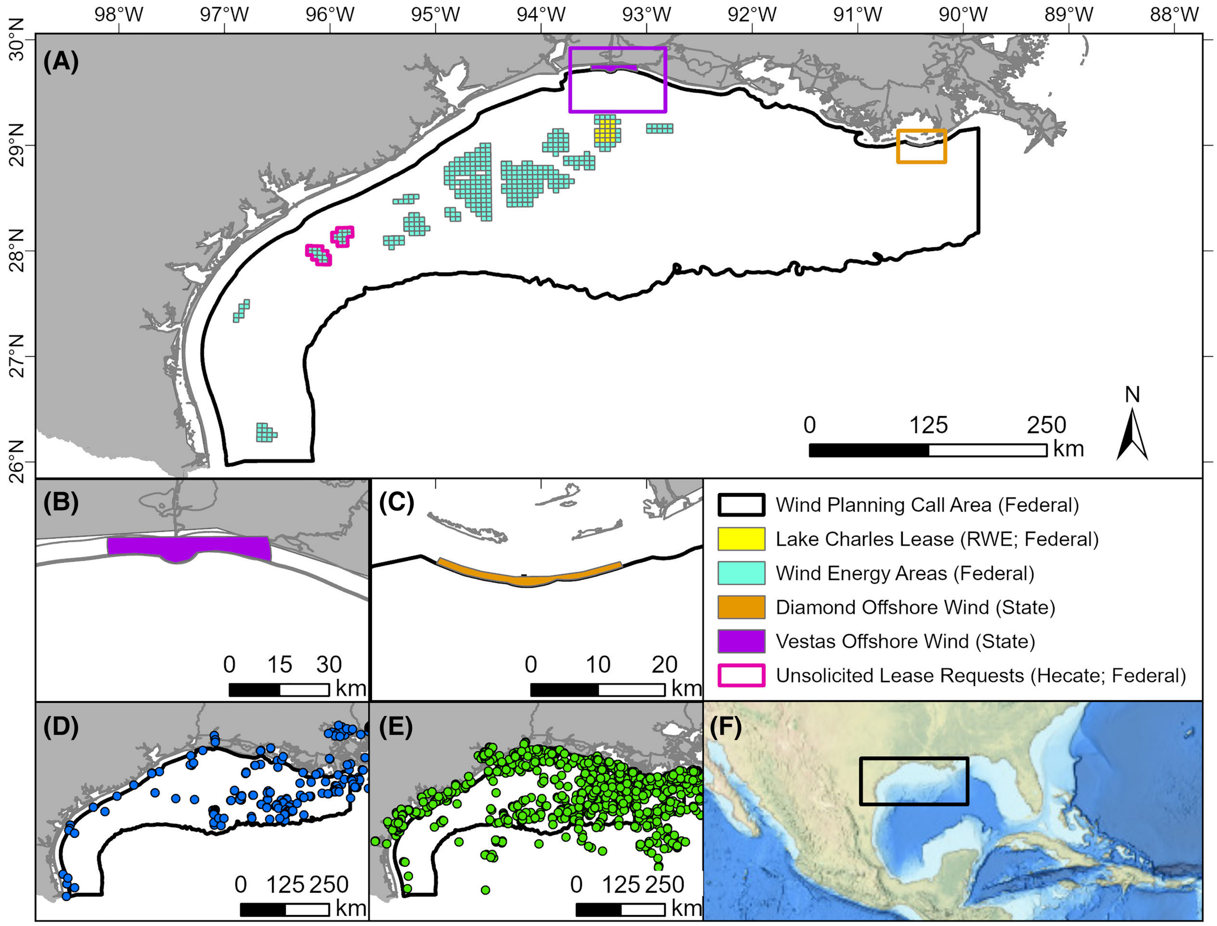

Figure 1. Current and proposed OSW development in the GoA for (A) federal waters and (B–C) state waters. (A) Federal offshore wind development activities, including the regional wind energy call area (gray outline), potential wind energy areas (teal polygons), proposed lease areas (pink outlines), and current wind lease (yellow polygon). Potential wind energy areas (teal polygons) denote options for wind energy development created by the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science. The current wind lease (yellow polygon) was awarded to RWE (Essen, Germany) in October 2023. The unsolicited lease requests (pink outlines) are from Hecate Energy (Chicago, Illinois), announced in July 2024. Extent indicators correspond to state leases (purple outline; orange outline) for (B) Diamond Offshore Wind (Boston, Massachusetts; purple polygon) and for (C) Vestas Offshore Wind (Aarhus, Denmark; orange polygon). Bathymetry map (inset) is from the General Bathymetric Chart of the Oceans (GEBCO); the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. The locations of other artificial structures, including (D) artificial reefs and (E) oil and gas platforms, are also provided. Artificial reef and oil and gas platform data were downloaded from Marine Cadastre (hub.marinecadastre.gov) on July 19, 2024.

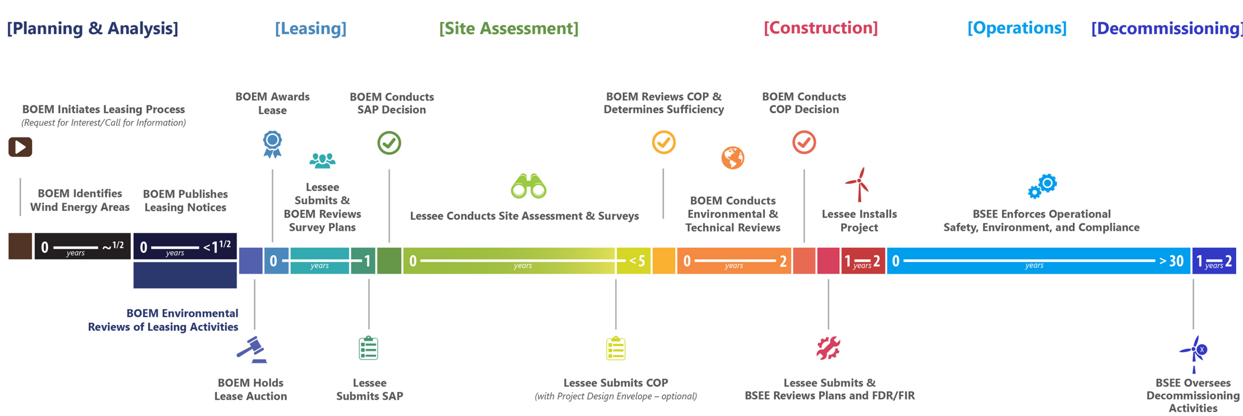

Figure 2. Timeline of offshore wind infrastructure development in the Gulf of America. The major phases include planning and analysis, leasing, site assessment, construction, operations, and decommissioning. The numbers indicate an estimated time frame in years for each phase. The image was provided by the Bureau of Ocean Energy Management (BOEM). Abbreviations in the image are as follows: SAP = site assessment plan; COP = construction and operations; BSEE = Bureau of Safety and Environmental Enforcement; FDR/FIR = facility design report/fabrication and installation report.

Table 1. Representation across scientific, management, and resource/fisheries sectors for members of the Impacts of Offshore Wind on Gulf of Mexico Fish and Fisheries Working Group.

Sector	Working group member affiliations
Academic research	• University of Florida • University of Miami Cooperative Institute of Marine and Atmospheric Sciences • National Center for Ecological Analysis and Synthesis • University of South Alabama
Federal research	• National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service • Bureau of Ocean and Energy Management
Private research	• LGL Ecological Research Associates • TwoSix Technologies • Intertidal Agency
Federal and state natural resource management	• Gulf of Mexico Fishery Management Council (GMFMC) • Texas Parks and Wildlife Coastal Fisheries Division • Louisiana Department of Wildlife and Fisheries • NOAA Office of National Marine Sanctuaries
Recreational and commercial fisheries	• Southern Shrimp Alliance • GMFMC as recounting interests of recreational and commercial fishers • Working group members as individual recreational anglers

ecological processes. In section 4, we discuss research priorities for understanding the social and management implications of OSW development. Finally, we highlight the importance of comprehensive assessment and management processes, as OSW development coincides with climate change and other existing stressors in this large marine ecosystem. The research priorities and recommendations that are presented here will help to ensure an evidence-based approach to understanding and evaluating potential effects of OSW on fish and fisheries in the GoA.

GULF OF AMERICA TAXA AND FISHERIES OF CONCERN WITH RESPECT TO OSW DEVELOPMENT

Myriad coastal and marine habitats in the GoA host an estimated 1,443 species of fish from 700 genera and 223 families (McEachran & Fechhelm, 2006). Many of these species associate with artificial structures, including O&G platforms, or otherwise occur in continental shelf waters that host energy extraction platforms. Approximately 50 finfish species and an additional 11 shellfish species support notable commercial or recreational fisheries (Ward & Tunnell, 2017). In this section, we identify research questions for taxonomic groups or fisheries as they relate to potential effects (and pathways for ecological and social impacts) of OSW (Table 3).

Penaeid shrimp (Table 3)

Commercial bottom trawling of penaeid shrimp—brown shrimp *Farfantepenaeus aztecus*, pink shrimp *F. duorarum*, and white shrimp *Litopenaeus setiferus*—collectively comprise the most valuable commercial fishery in the GoA, with more than $US300 million in dockside value in 2022 (National Marine

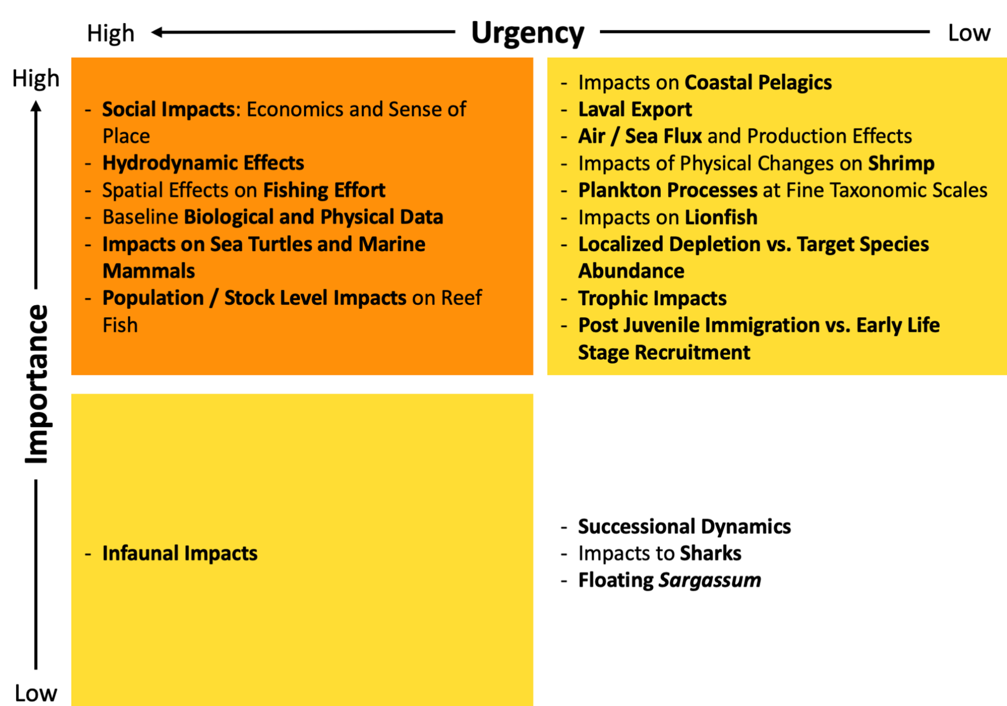

Figure 3. Eisenhower diagram with a horizontal axis of urgency from high to low (left to right) and a vertical axis of importance from high to low (top to bottom). Credit: Impacts of Offshore Wind on Gulf of Mexico Fish and Fisheries Working Group attendees, unpublished.

Table 2. Table of contents for remaining sections of this article. OSW = offshore wind.

Section	Topics
Section 2. Gulf of America taxa and fisheries of concern with respect to OSW development	• Penaeid shrimp • Reef fishes • Coastal migratory pelagic fishes • Forage fishes • Oceanic pelagic fishes • Coastal elasmobranchs • Invasive species

Section 3. Overarching oceanographic and ecological processes	• Oceanographic processes
	  • Wind
	  • Hypoxia and stratification
	  • Benthic and biogeochemical processes
	• Ecological processes
	  • Addition of new artificial hard-bottom and vertical habitat
	  • Succession
	  • Habitat
	  • Connectivity

Section 4. Management and human dimensions implications	• Fisheries management • Marine spatial planning • Social and economic impacts
Section 5. Discussion	• Disentangling OSW from concurrent environmental pressures • Importance of baseline data • Societal participation in the scientific process

Fisheries Service Office of Science and Technology). Catches of all three species occur on the GoA continental shelf, with brown shrimp catches being largest in federal waters off Texas (Tunnell, 2017; Williams et al., 2024) that coincide with the first GoA federal OSW wind energy areas. In these fishing grounds, OSW farms will create de facto spatial closures to the commercial shrimp fishery because trawling vessels may be unable to physically navigate trawlable bottom within the footprint of wind farms. Members of the shrimp fishery have expressed interest in collaborative efforts with researchers to collect in situ data for assessing the ecological impacts of OSW on GoA fisheries. Currently, the precise amount of trawling effort that would be displaced by OSW, the effects on income, and the collaborative research opportunities remain unknown. Future distributions of fisheries compensation funds would also benefit from a regional fund administrator to streamline and standardize the application and approval processes, similar to an effort that is currently underway in the northeast USA by the New York State Energy Research and Development Authority (South Atlantic Fishery Management Council, 2024; Special Initiative on Offshore Wind, 2024).

Penaeid shrimp species in the GoA feed on detritus, algae, and invertebrates, including polychaetes and amphipods (Cook & Lindner, 1970; Pattillo et al., 1997). The availability of these food items may increase near OSW structures due to enhanced biological production from colonizing sessile epifauna, providing a potential positive ecological effect of OSW on benthic macrofauna, including shrimp (Lefaible et al., 2023; Raoux et al., 2017). In the North Atlantic, Krone et al. (2017) estimated that OSW structures may increase the production of commercially important decapods (e.g., crabs *Cancer* spp.), although the role of food availability is unknown. Other researchers found that lobster *Homarus* spp. abundances do not change near OSW structures (Roach et al., 2022; Wilber et al., 2024). Differences in habitat requirements, among other characteristics (e.g., anatomical, physiological, and behavioral traits), of decapods may drive species-specific responses to OSW structures.

There is also potential for OSW development to cause negative habitat alterations for penaeids, including altered sediment composition and direct physical disturbances. Penaeids generally prefer open, soft sediment bottom habitat with relatively little hard structure present (Williams, 1958). Although Hutchison et al. (2020b) found no strong changes in sediment grain size within 90 m of OSW turbines in the northwest Atlantic, potential changes in sediment composition in the GoA cannot be ruled out. The negative effects of direct physical disturbances from OSW, such as electric and magnetic fields (EMF) and noise, on decapod behavior and physiology are relatively well documented (Harsanyi et al., 2022; Leiva et al., 2021; Scott et al., 2018). However, no investigations have tested such adverse outcomes for penaeid shrimp. Also, GoA penaeid shrimp exhibit species-specific traits and behaviors; for example, the burrowing behavior of brown shrimp differs from that of white shrimp (Osborn et al., 1969). This emphasizes the need for species-specific research to understand the effects of OSW-related physical disturbances on GoA penaeid shrimp. Additionally, there is concern that thermal emissions from cables (among other OSW activities) may affect shrimp, as penaeid growth, abundance, and distribution are temperature dependent (Arreguín-Sánchez et al., 2015; Montero et al., 2016; Zein-Eldin & Aldrich, 1965). Currently, it is unknown whether OSW cables produce localized temperature alterations; thus, benthic environmental monitoring may clarify this potential issue, among others.

Many study types are needed to evaluate shrimp responses to OSW development. Shrimp survival, growth, and behavior are largely tied to benthic environmental conditions (Haas et al., 2004; Zein-Eldin & Renaud, 1986); thus, monitoring before, during, and after operational phases of OSW development would aid in detecting changes. Collecting baseline benthic environmental conditions, including the presence of EMF and substrate temperature and condition, before OSW development would ideally include control sites to discriminate widespread change from changes caused by OSW development. Observational field studies may detect population-level changes (e.g., shrimp abundance) in response to potential changes in the benthic environment. Manipulative lab experiments may detect individual-level effects of physical disturbances (e.g., effects of noise on burrowing behavior in shrimp), which could identify potential mechanisms for observed population-level trends. Hybrid field experiments that quantify direct disturbances (e.g., EMF and heat from cables) and use cages to manipulate in situ crustacean exposure to such disturbances may be particularly useful in linking mechanisms to disturbances and population responses (Williams et al., 2023). Linking individual- and population-level responses may be important to assessing whether OSW development drives significant adverse outcomes for shrimp fisheries.

Table 3. Research questions for potential effects and pathways for effects of offshore wind (OSW) on taxonomic groups or fisheries in the Gulf of America (GoA). The taxonomic groups and fisheries include penaeid shrimp, reef fishes, coastal migratory pelagic (CMP) fishes, forage fishes, oceanic pelagic species, coastal elasmobranchs, and invasive species.

Taxa	Research questions
Penaeid shrimp	• Will shrimp habitat be affected, and at what scale, by direct disturbances from OSW, such as electric and magnetic fields (EMF), noise, and temperature? What are the physiological and behavioral mechanisms by which these direct disturbances may negatively affect shrimp? • How will benthic environmental conditions, including sediment composition and food availability, change through space and time and impact shrimp populations? • At what spatial scales of OSW development are shrimp fishing fleet behavior and profitability affected? What is the tipping point, regarding the number of wind farms and their spatial arrangement, for when the fleet needs to change how it operates? • Is it feasible for the shrimp fleet to supplement fishing-based income with collaborative efforts with researchers to collect in situ data relevant to assessing ecological OSW impacts?
Reef fishes	• To what extent does OSW infrastructure aggregate versus enhance productivity of reef fishes (i.e., growth, survival, reproduction)? How does the relative effect of aggregation versus production vary over space, time, and across reef fish taxa? • Will OSW serve as new spawning habitat for aggregating species? • How will OSW affect movement patterns, spatial distributions, and trophic ecology of reef fishes at local and seascape scales? • How will reef fish fisheries (commercial and recreational) target and exploit these new fish habitats? • What is the colonization trajectory of reef fishes at OSW sites? What factors affect the colonization trajectory (e.g., infrastructure spacing, depth, fishing pressure)? • How will sound, vibration, and EMF associated with OSW affect reef fishes? • How can OSW infrastructure, including scour protection and turbine foundations, be designed to maximize ecological benefits and minimize ecological risks to reef fishes? • How do reef fish community metrics (e.g., community composition, abundance, density, richness, diversity) on OSW sites compare with those at O&G, artificial reef, shipwreck, and natural reef sites (see Lemasson et al., 2024 for global meta-analysis)?
Coastal migratory pelagic (CMP) fishes	• Do the migratory patterns of CMP fishes currently coincide with planned OSW lease areas? Does the migratory behavior of CMP fishes change during different phases of OSW development (e.g., construction, operation, decommissioning)? • Will OSW change resource availability for CMP fishes via altered hydrodynamic regimes that affect pelagic food sources and floating structures (e.g., *Sargassum* spp.)? • To what extent does OSW infrastructure attract versus produce new biomass of CMP fishes? • What are the baseline levels of EMF, vibration, and sound within planned OSW lease areas? How do these conditions change with OSW development? How do any changes in these conditions affect CMP fishes related to their abundance, movement, temporal behavior, and other factors?
Forage fishes	• Could the presence of OSW in Louisiana state waters displace effort by the Gulf Menhaden *Brevoortia patronus* purse seine fishery? • Will OSW alter the spatial distribution and local densities of forage fishes? • Will OSW enhance production of forage fishes or aggregate them from nearby nonreef habitats?
Oceanic pelagic species	• To what degree do larvae of oceanic pelagic fishes interact with artificial structures and OSW?
Coastal elasmobranchs	• Will OSW increase interactions between humans and elasmobranchs, leading to novel or exacerbated effects? • Will EMF from OSW affect elasmobranch behavior and embryo development?
Invasive species	• Will OSW platforms serve as larval sources for Red Lionfish *Pterois volitans*, thereby exacerbating the Red Lionfish invasion? • Will OSW serve as stepping stones for invasive species range expansion? • What are the ecological impacts of Regal Damselfish *Neopomacentrus cyanomos* invasions, and will OSW mediate or exacerbate these impacts? • Will OSW serve as a critical habitat for fouling nonnative invertebrates? • Will OSW worsen jellyfish blooms, potentially disrupting fishing activity and/or forage fish that compete with jellyfish for planktonic food?

Reef fishes (Table 3)

In the GoA, reef fish communities are largely associated with hard-bottom, biogenic natural reefs or artificial structures. Small demersal reef fishes transfer energy via benthic and pelagic pathways to upper-trophic-level reef fishes, which support valuable recreational and commercial fisheries. Thirty-one GoA reef fish species undergo routine federal monitoring, assessment, and management (Gulf of Mexico Fishery Management Council [GMFMC], 2023). These are targeted by both recreational and commercial fisheries and are captured using a range of gears, including hook and line, vertical and bottom longlines, nets and traps, and spearfishing (data

Table 4. Reef fishes in the Gulf of America that are important to recreational and commercial fisheries and their stock status as of December 31, 2023 (NMFS, 2024b; SEDAR, 2024). An empty status indicates that the species is not experiencing overfishing and is not overfished. Overfished indicates that the stock biomass is below the management target; experiencing overfishing indicates that fishing mortality is higher than the management target.

Reef fishes	Stock status (as of December 31, 2023)
Gag Grouper *Mycteroperca microlepis*	Overfished; experiencing overfishing
Gray Snapper *Lutjanus griseus*	
Gray Triggerfish *Balistes capriscus*	
Greater Amberjack *Seriola dumerili*	Overfished; experiencing overfishing
Lane Snapper *Lutjanus synagris*	Experiencing overfishing
Red Grouper *Epinephelus morio*	
Red Snapper *Lutjanus campechanus*	
Scamp *Mycteroperca phenax*	
Vermilion Snapper *Rhomboplites aurorubens*	
Yellowedge Grouper *Hyporthodus flavolimbatus*	Experiencing overfishing

summarized in Berenshtein et al., 2021). Some of the managed reef fish species have poor stock statuses (Table 4).

The effects of OSW on reef fishes will depend on the degree to which OSW structures function as artificial reefs, as reef fishes are strongly associated with hard-bottom habitat. Researchers are starting to examine how different types of OSW foundations and their components (e.g., scour protection), as well as their spatial configuration and density, affect fish abundance in other regions (Glarou et al., 2020; Werner et al., 2024), which could inform their functioning as artificial reefs. Although a global meta-analysis indicates that OSW structures may have higher fish abundances than adjacent soft-bottom habitats do, there is not enough existing evidence to detect the effects on fish abundance, biomass, or diversity relative to that of natural reefs (Lemasson et al., 2024). There are many additional knowledge gaps, including how trophic ecology, community metrics (e.g., community composition, diversity), and spatial distributions of reef fish (e.g., vertical and horizontal distribution, residence time, home range, etc.) near OSW infrastructure differ from those in existing GoA reef habitats. Finally, the potential ecological effects of OSW on reef fish will span population-to-ecosystem levels and must be considered cumulatively.

Reef fishes may also be affected by localized disturbances that are caused by OSW. For example, fish may respond to sound and vibration associated with preconstruction, construction, and operation of OSW (e.g., vessels, pile driving, turbine operation; reviewed in Popper et al., 2022). In addition, EMF that is associated with OSW infrastructure may affect reproduction, migration, and other behaviors in reef fish (Gill et al., 2020; Hutchison et al., 2020a). Developing rigorous monitoring programs, especially by implementing before–after–control–impact (BACI) or before–after-gradient (BAG) designs, will be critical to detecting and better understanding how reef fish respond specifically to OSW and related activities.

It may also be possible to incorporate scour protection designs that are inspired by natural reefs and potentially other components associated with OSW turbine foundations to try to minimize the adverse effects (or optimize the beneficial effects) of OSW on reef fishes (Paxton et al., 2025).

Like other artificial structures, OSW infrastructure is expected to attract reef fish from nearby natural nonreef habitats (i.e., aggregation) and may enhance reef fish production as well (Bohnsack, 1989). Whether built structures ultimately yield net production gains is the topic of continued scientific research—that is, the "attraction–production" debate (e.g., Layman & Allgeier, 2020; Pickering & Whitmarsh, 1997). Evidence suggests that artificial reefs may enhance primary and/or secondary production (and therefore total reef fish biomass), although these effects are likely scale, place, and species specific (Claisse et al., 2014; Esquivel et al., 2022; Layman et al., 2016). Investigations in Europe, for example, demonstrate that small demersal, structure-associated fishes aggregate near OSW turbine foundations (Wilhelmsson et al., 2006), as do larger demersal piscivores (Bergstrom et al., 2013). However, enhanced production of reef fishes as a result of OSW has yet to be documented, but it will be critical to determine this for effective reef fish management (see Ecological processes for additional information).

Coastal migratory pelagic fishes (Table 3)

Coastal migratory pelagic (CMP) fishes in the GoA support important recreational and commercial fisheries, and there are some concerns over the health of these stocks. Gulf Cobia *Rachycentron canadum* are currently not overfished but are experiencing overfishing (NMFS, 2024b; SEDAR, 2020a). Although King Mackerel *Scomberomorus cavalla* and Spanish Mackerel *S. maculatus* were not estimated to be overfished or undergoing overfishing as of their last stock assessments (SEDAR, 2020b, 2023), individuals expressed concerns during recent GMFMC meetings about potential distributional shifts by these stocks in the GoA and changes in the availability of their prey. Dolphinfish *Coryphaena hippurus*, Wahoo *Acanthocybium solandri*, and Tripletail *Lobotes suirnamensis* also support fisheries, but they have not been assessed in the GoA. Stock assessments for CMP species in the GoA are made difficult by data limitations and by the fact that these species migrate across regional and national boundaries. As most CMP fishing is by hook and line near the surface, the development of OSW is unlikely to directly affect CMP fisheries, aside from the effects of artificial reefs or spatial exclusion management rules if they are implemented.

The reef effect of OSW development may have both positive and negative effects on CMP fish. We expect these effects to be less pronounced for CMP than those for reef fishes, given that CMP fishes spend time between fixed reef structures, floating structures (e.g., *Sargassum* spp., buoys, and floating inanimate objects), and the open ocean. Nevertheless, OSW structures are expected to provide habitat for larvae and juveniles (Hernandez et al., 2003; Lindquist et al., 2005), and turbine-induced wind wakes could increase productivity for earlier life stages of CMP species (Daewel et al., 2022). Adult CMP fishes typically rely on pelagic food sources (Finucane et al., 1990; Franks et al., 2008; Meyer & Franks, 1996; Oxenford & Hunte, 1999); however, OSW structures would provide high-relief habitat in the entire water column that CMP fishes use for shelter, food supply, spawning, and spatial reference (reviewed in Franks, 2000; Sinopoli et al., 2017). The effects of OSW structure will likely be similar to the reef effects from O&G structures that aggregate CMP fishes: These include altered movement and migration patterns, aggregation of prey and changes in their food web linkages, and increased vulnerability to fishing (reviewed in Snodgrass et al., 2020). As with reef fishes, understanding the relative strength of aggregation (and increased vulnerability to exploitation) versus production gains remains an area of active research.

How physical disturbances, including EMF, vibration, and sound, from OSW may affect CMP fishes and their migratory behavior remains unknown, as does the degree to which CMP migratory patterns and the fisheries that target them overlap with lease areas. Some indirect effects may occur from de facto exclusions from active fishing gear in the areas. The combination of aggregation effects and the exclusion of shrimp trawling could reduce the bycatch of CMP fishes. However, fishing gear can become entangled in vertical and off-bottom structures and cause tear-offs or abrasions (Barnette, 2001); thus, fouled gear around OSW structures could potentially cause ghost fishing interactions. Spatial modeling analyses, using O&G infrastructure in the GoA as a proxy, could be used to explore the effects of aggregation, reduced risk of bycatch, and occurrence of fouled gear on CMP fishes.

Forage fishes (Table 3)

Forage species are typically small, short-lived (<5 years), schooling, or demersal fishes. They occupy an intermediate trophic level and are preyed upon by larger fish species of commercial and recreational importance, along with marine mammals and seabirds. Of the over 75 forage fish species that occur in the GoA (McEachran & Fechhelm, 1998, 2006), only a few of these species support fisheries. Gulf Menhaden are targeted by an industrial commercial purse-seine fishery that can remove the largest volume of catch in the USA GoA, which totaled 75% of all GoA commercial landings by mass in 2020 (NMFS, 2023). The Striped Mullet *Mugil cephalus* is another forage fish that is harvested commercially in the nearshore GoA, although only in Louisiana (Louisiana Department of Wildlife and Fisheries, 2020) and Florida (Florida Fish and Wildlife Conservation Commission, 2014). The only other forage fish that was historically commercially targeted and harvested in the region is Gulf Butterfish *Peprilus burti*, which is targeted using otter trawls that are pulled at depths greater than 100 m (Mareska & Bellais, 2023). However, recently, commercial interest in this species has declined (GMFMC, 2024, meeting minutes, 201, lines 29–38). The trophic roles of all forage fish and economic importance of the species that are specifically targeted by commercial fishing may drive interest in assessing interactions between forage fish and OSW.

The spatial overlap between planned OSW in the GoA and forage fishes is presently assumed to be minimal based on current distributions of fishing efforts, but it may increase in the future. The positioning of OSW structures in GoA federal waters is >16 km (9 nautical miles) from shore for Florida and Texas or 5 km (3 nautical miles) for Alabama, Mississippi, and Louisiana, and thus, it does not overlap with the habitat or fishing grounds of forage species. For example, the Gulf Menhaden fishery harvests most of its catch (93%) from within 16 km of the shoreline (Smith et al., 2002). However, spatial overlap may increase between OSW and forage fish habitats and fishing grounds with the addition of OSW leases within GoA state watersfor example, in Louisiana's 2023 lease sale (Baurick, 2023). Spatial overlap between GoA OSW and forage fishes may also increase if these species are driven to cooler, deeper waters in response to warming ocean temperatures (Pinsky et al., 2013, 2021). An initial concern of increased spatial overlap is the creation of de facto fishing exclusion zones, as purse seines and other harvest gear may be difficult to use around OSW infrastructure. Therefore, it is necessary to assess scenarios of how future OSW development in nearshore areas and climate change may alter interactions with forage species and fishery activity.

Because most forage fish species are not targeted by fisheries, the potential effects of OSW structures on forage fish have received less attention than potential effects on species that support commercial and recreational fisheries. Nevertheless, there are some studies concerning OSW interactions with forage fish in the northwest Atlantic. Friedland et al. (2023) documented the potential for significant spatial overlap between OSW and forage fishes, including Atlantic Menhaden, as multiple species preferred habitat within potential OSW lease areas. Additionally, Wilber et al. (2022a) found no effect of OSW on forage fish abundance (e.g., Atlantic Herring *Clupea harengus* and Atlantic Butterfish *Peprilus triacanthus* 7 years postconstruction. Although not specifically documented in response to OSW, forage fishes can be displaced by noise from simulated pile driving (Hawkins et al., 2014), ships (De Robertis & Handegard, 2013; Vabø et al., 2002), and seismic investigations (Slotte et al., 2004). This suggests that noise from OSW construction and operation may also influence the behavior of forage fishes, but more research is needed because there is limited evidence regarding behavioral and population-level responses of forage fishes to OSW.

The trophic importance of forage fishes, specifically Gulf Menhaden, in the GoA is becoming more established (Berenshtein et al., 2023; Sagarese et al., 2016, and references within). Therefore, future studies may consider assessing how OSW structures influence predator–prey interactions and the nutritional value of forage fish, as fish feeding behavior and physiology may change near OSW structures (e.g., Wilber et al., 2022b). It is also important to consider the responses of forage fish to OSW in the context of the attraction–production debate, as increased production of forage fish may lead to increased production or attraction of forage fish predators. Therefore, research is needed to assess how OSW may alter community-level interactions and trophic flows that are mediated by forage fish.

Oceanic pelagic fishes (Table 3)

Oceanic pelagic fishes in the GoA include teleost and elasmobranch species within the broad taxa of tunas (Scombridae), pelagic sharks (various families, e.g., Lamnidae, Carcharhinidae), billfishes (Istiophoridae), and Swordfish *Xiphias gladius*. Oceanic pelagic fishes also include highly migratory species that are characterized by extensive

Table 5. Oceanic pelagic fishes in the Gulf of America that have stock statuses of concern and their stock status as of December 31, 2023 (NMFS, 2024b). Overfished indicates that the stock biomass is below the management target; experiencing overfishing indicates that fishing mortality is higher than the management target.

Oceanic pelagic fishes	Stock status (as of December 31, 2023)
Blue Marlin *Makaira nigricans*	Overfished; experiencing overfishing
White Marlin *Kajikia albida*	Overfished
Bigeye Tuna *Thunnus obesus*	Overfished
Dusky Shark *Carcharhinus obscurus*	Overfished; experiencing overfishing
Porbeagle Shark *Lamna nasus*	Overfished
Shortfin Mako Shark *Isurus oxyrinchus*	Overfished; experiencing overfishing

Table 6. Oceanic pelagic fishes in the Gulf of America that are prohibited from fisheries take and their status according to the International Union for Conservation of Nature (IUCN; Marshall et al., 2022; Pierce & Norman, 2016; Rigby et al., 2019).

Oceanic pelagic fishes	IUCN status
Giant Manta Ray *Mobula birostris*	Endangered
Oceanic Whitetip Shark *Carcharhinus longimanus*	Critically endangered
Whale Shark *Rhincodon typus*	Endangered

transoceanic movements and whose management necessitates international coordination. Many oceanic pelagic fishes have stock statuses of concern as of December 31, 2023 (NMFS, 2024b; Table 5). Some are prohibited from fisheries take and are on the International Union for Conservation of Nature Red List (Table 6). Given the current and expected locations of OSW development, we expect no or minimal interactions with Oceanic Whitetip Sharks *Carcharhinus longimanus*. Whale Sharks *Rhincodon typus* and Giant Manta Rays *Mobula birostris* could spatially overlap with OSW infrastructure, particularly in proposed development areas near the Flower Garden Banks National Marine Sanctuary (Stewart et al., 2018).

Siting options for OSW in the GoA are limited to shelf waters, and we expect them to have relatively minimal spatial overlap with most oceanic pelagic fishes that inhabit the open-ocean environment and typically occur offshore of continental shelf waters. This could change if future energy development extended farther offshore and employed the floating OSW infrastructure that is used in deepwater environments, in which case there are various concerns about its effects on these species, as summarized in Hendon et al. (2024). Offshore O&G structures affect pelagic longline fishing operations, which set main lines that can be 40 km long and drift for over 10 h. Such structures also attract both fish and fishermen, increasing vulnerability to fishing (Snodgrass et al., 2020). Although floating OSW is planned for other regions, the wide shelf area of the GoA provides more shallow-water leasing opportunities; also, floating OSW in the GoA is not expected within the near future. However, oceanic pelagic fishes may interact with OSW farms that are situated on the continental shelf because, similar to CMP, their larvae (e.g., Bluefin Tuna *Thunnus thynnus*) are found near O&G structures on the continental shelf (Hernandez et al., 2003). Continued telemetry tracking and spatial analyses will also be prudent for oceanic pelagic fishes given that climate change is expected to drive changing range distributions—for example, poleward shifts for Blue Marlin (Dale et al., 2022) and Bigeye Tuna (Erauskin-Extramiana et al., 2019).

Table 7. Coastal elasmobranchs, including inshore shark species and common northern Gulf of America batoids and, if applicable, their stock status as of December 31, 2023 (NMFS, 2024b). An empty status indicates the species is not experiencing overfishing and is not overfished. Overfished indicates that the stock biomass is below the management target; experiencing overfishing indicates that fishing mortality is higher than the management target.

Coastal elasmobranchs	Stock status (as of December 31, 2023)
Atlantic Sharpnose Shark *Rhizoprionodon terraenovae*	
Blacknose Shark *Carcharhinus acronotus*	Overfished; experiencing overfishing
Blacktip Shark *Carcharhinus limbatus*	
Bonnethead Shark *Sphyrna tiburo*	
Bull Shark *Carcharhinus leucas*	
Nurse Shark *Ginglymostoma cirratum*	
Sandbar Shark *Carcharhinus plumbeus*	Overfished
Sand Tiger Shark *Carcharias taurus*	
Scalloped Hammerhead Shark *Sphyrna lewini*	Overfished, experiencing overfishing
Southern Stingray *Dasyatis americana*	
Atlantic Stingray *Dasyatis sabina*	
Cownose Ray *Rhinoptera bonasus*	

Coastal elasmobranchs (Table 3)

Coastal elasmobranchs include inshore shark species and batoids, some of which have stock statuses of concern (Table 7). These species use coastal and nearshore habitats for various life stages, including nursery grounds, feeding, and some breeding activities (Chen, 2017, and references within). Their presence inshore makes them more accessible to coastal fisheries and increases their vulnerability to habitat degradation, bycatch mortality, and nearshore environmental stressors. Overexploitation has historically driven global declines in sharks and rays (Dulvy et al., 2014; MacNeil et al., 2020), which are particularly vulnerable due to their slow growth, late maturity, and production of few offspring. Such vulnerabilities and declines warrant strong consideration of the effects of OSW on coastal elasmobranchs.

Coastal elasmobranchs use electromagnetic-receptive sensory systems for many vital functions, such as foraging, predator avoidance, social communication, and navigation (Collin et al., 2015; Tricas & Sisneros, 2004). Therefore, specific research may be warranted to understand the interactions between elasmobranchs and EMFs produced by OSW. For example, Hutchison et al. (2020c) found that EMFs caused a demonstrable increase in exploratory and foraging behaviors in Little Skate *Leucoraja erinacea*. These effects will likely be specific to the OSW installment (i.e., scale, output) and relate to the placement of subsea power cables, the strength of EMF they radiate, and whether the cables transmit alternating or direct current (Hermans et al., 2024). Some shark species undergo precise long-distance navigation using the Earth's magnetic field, produced by direct current (e.g., Keller et al., 2021). Tagging studies and spatial mapping analyses should examine behavioral changes in habitat usage and migratory patterns. A particular concern worth investigating is the potential disturbances by EMF on elasmobranch embryonic development (Hermans et al., 2024), as these could have population-level consequences. Such research should be species-specific, as effects will likely differ based on reproductive physiology (e.g., oviparous or viviparous species) and, for oviparous species, the specifics of where they lay their eggs.

Invasive species (Table 3)

If OSW infrastructure functions similarly to other artificial structures (e.g., artificial reefs, O&G structures), it could facilitate the expansion of invasive fishes and invertebrates in the GoA. The GoA currently has established invasions for two species of nonnative fishes of concern: Red Lionfish and Regal Damselfish. Red Lionfish represent the species of greatest concern given their direct demonstrated effects on prey species (e.g., Ballew et al., 2016; Dahl et al., 2017) and indirect effects on food webs (e.g., Chagaris et al., 2017, 2020; Tuttle, 2017). In the northern GoA, high-relief artificial structures serve as preferred Red Lionfish habitat and Red Lionfish densities on artificial structures can be 10–100 times those on natural reefs in the region (Dahl & Patterson, 2014 ; Harris et al., 2019). Offshore wind structures could serve as larval sources to enable the expansion from areas with higher densities of Red Lionfish—for example, from the Flower Gardens Banks National Marine Sanctuary (Blakeway et al., 2022) or eastern GoA reefs (Dahl & Patterson, 2020; Harris et al., 2023)—to reefs in the western GoA (Johnston et al., 2017). Nonnative Regal Damselfish were first observed on O&G and artificial structures in the northern GoA, and like Red Lionfish, they have higher densities on artificial structures than on natural reefs (Bennett, 2019). The highest densities are observed on relatively shallow artificial structures, which would have depths similar to those in the areas proposed for OSW development. Regal Damselfish were observed to comprise approximately half of the damselfish community in the north-central GoA (Tarnecki et al., 2021); however, their ecological impacts remain poorly understood and should be an area for further study. Collectively, the strong association between artificial structures and Red Lionfish, as well as uncertainties of Regal Damselfish invasions, warrant consideration for research concerning how these two species may interact with OSW structures.

Offshore wind and other artificial structures may serve as available habitat for nonnative fouling invertebrates. In the northern GoA, these have largely been observed on O&G platforms, with current invasions documented for nonnative orange cup corals *Tubastrea* spp., Australian spotted jellyfish *Phyllorhiza punctata* (during its polyp stage), the tunicate *Didemnum perlucidum*, and acorn barnacles (including triangle barnacle *Balanus trigonus*, striped barnacle *Amphibalanus amphitrite*, reticulated barnacle *A. reticulatus*, and titan acorn barnacle *Megabalanus coccopoma*) (Schulze et al., 2020). Although the overall community effects of these species are largely unknown, evidence indicates that cup corals disturb native communities of sessile invertebrates that may function as important habitat for fishery species (Lages et al., 2011). Additionally, blooms of the pelagic stage of Australian spotted jellyfish (among other jellyfish species) can cause large economic losses to shrimp fisheries by clogging trawl nets (Graham et al., 2003). Increased blooms of invasive jellyfish may also increase interspecific competition with planktivorous forage fish, as jellyfish and forage fish in the GoA may have strong diet overlap (D'Ambra et al., 2018). Future studies could assess the degree to which OSW may exacerbate interactions between invasive invertebrates and fisheries.

The role of OSW, O&G, and other artificial structures in facilitating biological invasions in the GoA remains an area of considerable uncertainty and active research (Schulze et al., 2020). Predicting the dynamics of invasive species remains notoriously difficult, as our understanding only comes after a species is established and the natural experiment of an invasion generally lacks control comparators (Strayer et al., 2017). Offshore wind platforms are expected to interact with invasive species in at least some capacity, and the relative interaction between invasive species and OSW versus O&G or other artificial structures will be important to evaluate, as there are already many artificial structures in the GoA (Figure 1D, 1E) and the initial expected footprint of OSW structures is comparatively small. Nevertheless, relevant pre- and post-OSW installation data collected at large temporal and spatial scales may elucidate these interactions, as there is a unique opportunity to "predict" and then validate the locations at which invasive species may arrive. Such data may allow for assessing the degree to which OSW platforms serve as stepping stones for range expansion by invasive species.

OVERARCHING OCEANOGRAPHIC AND ECOLOGICAL PROCESSES

Although different taxonomic groups require individualized attention, in terms of OSW effects, many (if not all) taxa will be affected by similar (if not the same) environmental processes. In this section, we consider broader oceanographic and ecological processes and how they may be affected by OSW. This is not intended to be a comprehensive review, as other studies have reviewed the effects of OSW on oceanographic and ecological processes (Gill et al., 2020; Reubens et al., 2014; van Berkel et al., 2020). Rather, we emphasize specific processes of interest to the GoA and provide context with representative examples from other regions (Table 8).

Oceanographic processes (Table 8)

Oceanographic processes and their inherent properties are important determinants of primary production, which supports secondary production of many fishery species via trophic pathways. Specifically, wind fields, stratification, and the effects of river discharge (hypoxia and turbidity), sediment

Table 8. Research questions for potential effects and pathways for effects of offshore wind (OSW) on oceanographic and ecological processes in the Gulf of America.

Processes	Research questions
Oceanographic processes	• How will OSW affect wind fields and related physical oceanographic processes, such as turbulence, stratification, vertical/horizontal mixing, and upwelling/downwelling? • How will the physical effects of OSW affect biological processes and primary production? • Will OSW alter oxygen concentrations and at what temporal and spatial scales are those changes observable? • How will OSW affect benthic sediment dynamics, organic matter depositions, and thermal microhabitats, and will such changes affect benthic taxa, such as shrimp? • How do these oceanographic effects vary based on relative position to turbines (e.g., upwind versus downwind)?
Ecological processes	• To what degree will OSW enhance fish production, and will it be offset by aggregation from nearby habitats to OSW structures where they are more easily captured? • What are the successional dynamics of OSW structures, and how do they compare to O&G (or other artificial) structures and natural reefs? • How do fishes use the habitat created by OSW compared with O&G (or other artificial) structures and natural reefs? • Does the vertical relief of OSW turbines offer refuge from harmful environmental conditions, such as hypoxia? • How will OSW affect the physiology, behavior, and populations of reef fishes, forage fishes, and pelagic fishes? How will these interact with and influence trophic and community dynamics? • How will OSW affect connectivity and larval dispersal? • What are the fishery implications of changes in ecological processes?

transport, and deposition of particulate organic matter are often linked and important for fish and fisheries in the GoA (Bianchi et al., 2010; Coates et al., 2015; Hazen et al., 2009; Nagel et al., 2018). Because of their bottom-up effects on fish and fisheries, monitoring these abiotic, oceanographic processes will be important to help understand potential effects of OSW in the GoA.

Wind

The transport and retention of nutrient-rich surface waters that drive pelagic primary production is largely tied to wind, particularly in offshore waters where federal lease areas will occur (Muller-Karger et al., 2015). At local scales, changes in wind fields can lead to increased turbulence and mixing in turbine-adjacent waters (Carpenter et al., 2016). At larger scales, OSW farms can reduce wind stress within and downstream of OSW farms (referred to as a “wind wake”) and can cause upwelling–downwelling dipoles (Broström, 2008; Christiansen & Hasager, 2005; van Berkel et al., 2020). The directionality and magnitude of primary production responses to such wind changes depend on location, depth, and scale. For example, at local scales, OSW may increase chlorophyll production and lead to chlorophyll aggregation, potentially due to increased upwelling and turbulence, but such signals may change at larger scales (Lu et al., 2022; van Berkel et al., 2020). To date, larger-scale (>100 km^2 from OSW farms) oceanographic effects from OSW have been evaluated for cool, nutrient-rich, North Atlantic waters (van Berkel et al., 2020), but further research is needed to understand its effects for subtropical systems, such as those in the GoA. Changes in wind and turbulence that are induced by OSW may also directly affect fish and fisheries through changes in the growth rates of larval fish due to turbulence-induced, altered predator–prey encounter rates (Kiørboe & MacKenzie, 1995). Fisheries ecologists and physical oceanographers should work together to coproduce study designs to monitor and detect these effects in the GoA.

Hypoxia and stratification

The GoA has the largest areas of hypoxia in the Western Hemisphere (Rabalais et al., 2001). The water column generally becomes highly stratified (unless mixed by tropical cyclones) during late summer, with lower water-column respiration depleting oxygen to levels that can form expansive hypoxic or anoxic areas that are hundreds of km^2 in size. Offshore wind structures can induce hypoxia due to increased respiration of higher levels of turbine-associated biomass, depending on spatial scale (Janßen et al., 2015). Stratification changes and thermocline shoaling induced by OSW can also directly affect the abundance and distribution of biota, including phytoplankton and zooplankton (Floeter et al., 2017). Mississippi River discharge largely affects hypoxia, stratification, and turbidity in the GoA. Offshore wind farms may increase or decrease turbidity, with such directionality changes potentially dependent on baseline conditions (van Berkel et al., 2020). In the GoA, it will be important for future work to separate the effects of OSW farms on the physical and chemical properties of the ecosystem from those of other drivers, such as the Mississippi River. These processes are very much intertwined, as OSW farms can simultaneously increase turbulence, nutrient transport, and chlorophyll production (Floeter et al., 2017).

Benthic and biogeochemical processes

Benthic oceanographic and biogeochemical processes may be disrupted by OSW construction (e.g., dredging) and operations (e.g., wind wakes; Coates et al., 2015; Nagel et al., 2018). For example, one study indicated that sediments directly adjacent to OSW scour protection zones exhibited lower grain sizes, potentially resulting in higher macrobenthos biomass (Coates et al., 2011). Biofouling of OSW turbines can also lead to organic enrichment of the benthos (Hutchison et al., 2020b). For example, biofouling mussels can produce strong fecal pellet rain that increases benthic organic matter deposition by 50% up to 5 km away from turbines (Ivanov et al., 2021). Thus, oceanographic effects are possible at relatively large spatial scales, and biological hot spots may be generated by OSW invertebrate communities. Additionally, power cables from OSW farms may elevate the temperatures (~2.5°C) of the benthic boundary layer that is directly adjacent (within 1 m) to cables (Taormina et al., 2018). Although occurring at relatively small spatial scales, these effects may be important for smaller benthic fishery species, such as brown shrimp. Research assessing the effects of OSW on oceanographic and biogeochemical processes in the GoA will thus need to occur at variable scales, dimensions, and depths.

Ecological processes (Table 8)

Addition of new artificial hard-bottom and vertical habitat

The infrastructure for OSW has some similarities to existing artificial reefs and O&G platforms in the GoA, but it also has important differences that will influence our understanding of how OSW functions as an artificial hard-bottom and vertical habitat. Scour protection around OSW turbine foundations can be designed to function similarly to that of artificial reefs (Glarou et al., 2020). Also, OSW infrastructure is similar to O&G infrastructure in that it provides broad benthic cover and has a vertically extensive nature. Compared to monopile foundations, OSW jacket foundations, which have a lattice framework, will be especially similar to O&G platforms. Despite these similarities, OSW will differ from O&G in terms of spatial configuration and density. Although O&G platforms are irregularly arranged and spaced at varying distances apart, multiple OSW turbines will be placed at regular, gridded intervals within a lease area, separated by at least 1.85 km (1 nautical mile) for the purpose of navigational safety (U.S. Coast Guard, 2020). Because of the differences between OSW and existing human-made structures in the GoA, it is necessary to directly evaluate OSW as novel artificial habitat both at the seafloor and extending throughout the water column.

Given the foresight and the ability to collect data from pre- and postinstallation at appropriate spatial scales, OSW development presents a natural and large-scale opportunity to evaluate contributions from production and emigration to regional-scale fish populations. Carefully designing and implementing scientific studies (sensu Osenberg et al., 2002) could inform ecological questions, such as the attraction–production debate surrounding artificial structures and reef fishes. For example, greater relative abundance of Red Snapper has been observed on artificial structures (Gallaway et al., 2009), but whether this contributes to population-level changes remains debated and controversial (Cowan et al., 2011; Gardner et al., 2022; Karnauskas, Walter, et al., 2017; Szedlmayer & Shipp, 1994). By attracting fish, artificial structures can become hot spots for fishery removals by aggregating both fish and fishermen (i.e., ecological traps; Bohnsack, 1989; Gardner et al., 2022; Karnauskas, Walter, et al., 2017; Powers et al., 2018; Streich et al., 2017). Artificial structures may also increase production by providing additional settlement habitat (i.e., increased secondary production) for new recruits, thereby potentially increasing fishing opportunities (Bohnsack, 1989; Cowan et al., 2011). A large-scale, multidecade, and multiprong research and monitoring plan should use this opportunity to assess how OSW platforms affect fish production.

Succession

Biofouling organisms will rapidly colonize new hard substrate from OSW (Kerckhof et al., 2019). Over time, biofouling communities provide resources (e.g., food, habitat) for higher trophic levels. The composition of these biofouling communities may depend on construction materials (Petersen & Malm, 2006), timing of installation (Kerckhof et al., 2010, 2012), and location (Zupan et al., 2023). Benthic communities may also differ by the type of OSW turbines that are installed, as the type of foundation (jacket vs. monopile) and scour protection (rocks vs. sandbags) differ in surface area and structural complexity (Rumes et al., 2013). Biofouling communities on OSW turbines will go through successional stages, with early stages dominated by opportunistic species, intermediate stages being highly diverse, and climax stages dominated by a few species (e.g., Kerckhof et al., 2019). Climax communities on GoA O&G platforms and OSW infrastructure in the North Atlantic typically have high abundances of sponges, bryozoans, cnidarians (anemones, hydrozoans), and bivalves (Degraer et al., 2020; Gallaway & Lewbel, 1982). Full succession to a climax community can take at least 10 years for OSW communities (Kerckhof et al., 2019); thus, studies that are conducted at limited temporal spans may make misleading comparisons. Long-term monitoring will be required to assess the successional dynamics of benthic communities on OSW structures and to effectively compare OSW benthic communities with those found on other human-made structures (e.g., O&G, shipwrecks, artificial reefs) and natural reefs.

Habitat

Offshore wind structures often positively affect invertebrates and fishes (Galparsoro et al., 2022), but the quality of habitat that is provided by OSW infrastructure for a given species will depend on its use of the structure—for example, for foraging, shelter, navigation, or reproduction. Researchers who study feeding behavior found that fish obtain food resources from the hardened habitat created by OSW, but not all species use OSW as feeding grounds (reviewed in Hogan et al., 2023). Fish reproduction is less studied for OSW specifically, and findings are variable for O&G. Fish reproduction on O&G platforms was observed to be higher (Claisse et al., 2019), similar (Downey et al., 2018), or lower (Glenn et al., 2017) than that on natural reefs. Also, species may use the benthos-to-vertical structure of OSW to avoid environmental disturbances, such as moving higher up in the water column and avoiding hypoxic conditions (e.g., Carver, 2023; Reeves et al., 2018). Similarly, species vary in whether they remain present on or move from artificial structures during storm events, and it is hypothesized that fish are more likely to remain on larger, more stable structures, such as O&G and OSW structures during severe weather events, such as hurricanes (Topping & Szedlmayer, 2011). Overall, numerous metrics (e.g., diets, reproductive condition, movement, etc.) will need to be evaluated to obtain a comprehensive picture of the habitat quality of OSW for species and how it compares to that of natural reefs and other human-made structures in the GoA.

Habitat use of OSW structures will influence community dynamics (e.g., abundance, biomass, diversity). Demersal, structure-associated fishes and larger demersal piscivores can aggregate near OSW turbine foundations (Bergstrom et al., 2013; Wilhelmsson et al., 2006). Generally, OSW increases adjacent fish abundance relative to reference sites (Lemasson et al., 2024; Methratta & Dardick, 2019), although this can be negated if fishing is allowed (Methratta & Dardick, 2019) and is inconclusive for fish biomass and diversity (Lemasson et al., 2024). Fish community structures around OSW will be influenced by intra- and interspecific interactions, which are typically difficult to study, especially for mobile species (Hogan et al., 2023). Therefore, it will be important to design research studies that can tease apart community interactions at OSW farms to provide a mechanistic understanding of fish community metrics (e.g., abundance, biomass, diversity).

Whether OSW habitat quality influences regional population dynamics of fishery species in the GoA will depend on the scale of OSW development. Even with over 20,000 known artificial reefs estimated to exist in the GoA (Gardner et al., 2022), artificial reefs cover a very small proportion (2%) of the total reef habitat, with the majority consisting of natural reefs (Gardner et al., 2022; Karnauskas, Walter et al., 2017). Also, researchers found that only 5% of GoA Red Snapper are located on artificial reefs (Stunz et al., 2021), only 1.2% of northern GoA Red Snapper biomass is found on O&G platforms (Osowski & Szedlmayer, 2022), and Red Snapper abundances on artificial structures only contribute 8% of the total population biomass (Karnauskas, Walter, et al., 2017). These studies suggest that OSW artificial habitat has a low probability of contributing to regionwide population-level increases in fish production. Nevertheless, OSW artificial habitat may function differently from other GoA artificial structures, so comparative (OSW versus O&G) and regionwide studies will be critical to elucidate the role of OSW in regional population dynamics of GoA fishery species.

Connectivity

Artificial structures can serve as connectivity corridors that fish use to move from one habitat to another within the seascape (Adams et al., 2014) and as stepping stones for larval dispersal of less motile taxa (Galaiduk et al., 2024). Whether this provides a net benefit to populations or the ecosystem remains uncertain (McLean et al., 2022). The potential positive effects of adding artificial reefs via OSW development include facilitating the movement of fish at their climate range edges (Paxton et al., 2019) or providing larval subsidies for nearshore reef fish as they undergo latitudinal migrations (Nishimoto et al., 2019). These connectivity corridors may, however, facilitate the spread of invasive species (see Invasive species [section 2] for further discussion of this topic).

Site fidelity to structured habitats may influence connectivity within populations, communities, and ecosystems (Lowerre-Barbieri et al., 2021; Patterson, 2007; Portnoy et al., 2022). Fish may exhibit high site fidelity to OSW farms (Reubens et al., 2013), O&G platforms (Everett et al., 2020), and other artificial reefs (Tharp et al., 2024; Topping & Szedlmayer, 2011). It is important to monitor a network of artificial structures when assessing fish movement, as single-point evaluations might falsely indicate low site fidelity to a single site when fish are in fact moving among various structured habitats within an area (e.g., Topping & Szedlmayer, 2011). Thus, the uniform spatial arrangement of OSW turbines within a lease area may be an interesting element that influences fish movement and site fidelity compared with arrangements in other artificial structures, which are typically more haphazardly distributed. It will also be important to monitor fish over long periods, as the presence and site fidelity of fish at OSW infrastructure can vary seasonally or due to spawning migrations (Reubens et al., 2013).

Offshore wind structures may also affect connectivity via larval dispersal. Fish movement between and site fidelity to OSW farms will influence larval dispersal, especially if OSW installations become spawning aggregation sites (Heyman et al., 2019; Perry & Heyman, 2020). Offshore wind structures can serve as sources of larvae for surrounding natural habitats, as modeled for O&G platforms in southern California (Nishimoto et al., 2019). However, larval movement patterns may be disrupted by changes in turbulence and stratification from OSW infrastructure (Ajmi et al., 2023; Chen et al., 2024). For example, simulation studies predict that OSW will displace larval dispersal and settlement of Atlantic sea scallops *Placopecten magellanicus* in the northeastern USA (Chen et al., 2024), in part due to enhanced turbulence and weakened stratification. Larval movement and survival are crucial for not only connectivity but also recruitment and other population-level effects (White et al., 2019, and references within). Larval movement, survival, and recruitment around OSW and surrounding natural and artificial habitats should be assessed to inform individual species' population dynamics and the functioning of the entire ecosystem. Understanding connectivity, site fidelity, and dispersal should constitute high-priority research topics, as they have direct implications for fisheries management.

IMPLICATIONS FOR MANAGEMENT AND HUMAN DIMENSIONS

Beyond anticipated physical, chemical, and biological effects of OSW maturation in the GoA, there will be potential effects on natural resource management and society. More than 15.8 million people live in U.S. coastal counties that are adjacent to the northern GoA (National Oceanic and Atmospheric Administration, 2023), and fishing is an important source of recreation and income. Here, we seek to identify the potential effects of OSW development on the human dimensions of the GoA, including fisheries management, fishing communities, and fisheries economies (Table 9).

Fisheries management (Table 9)

A concern accompanying OSW development is that it will affect scientific surveys that are used to monitor population trends. Using simulation analysis, Borsetti et al. (2023) found that excluding Atlantic surfclam *Spisula solidissima* assessment surveys from the regions designated for OSW development in the northeastern USA negatively affected the stock assessment reference points and increased uncertainty in estimates of spawning stock biomass and fishing mortality up to 17% and 7%, respectively. Standardized, long-term, fisheries-independent surveys track changes in abundance and population metrics over space and time for fish, invertebrates, and protected species (reviewed in Grüss et al., 2018) and provide critical data inputs for fisheries stock assessments. In the

Table 9. Research questions for potential effects of offshore wind (OSW) development on human dimensions in the Gulf of America, including fisheries management, marine spatial planning (MSP), and social and economic effects.

Human dimensions	Research questions
Fisheries management	• How will the creation of OSW structures affect our ability to monitor and assess fisheries resources? • How will OSW change fishing behavior, in terms of number of trips, locations, and exploitation rates?
Marine spatial planning	• What fish and fisheries data layers are most critical for MSP, and how should these data layers be weighted relative to one another? • Can ecosystem models be used in MSP to account for dynamic ecological and fisheries interactions? • Can OSW be optimally co-sited with other ocean activities so that future ocean space is available for other ocean industries (e.g., aquaculture, tidal and wave energy, carbon capture, marine carbon dioxide removal, green hydrogen, transit, ecotourism)? • How should future OSW transmission and decommissioning be incorporated into the MSP process?
Social and economic effects	• What are the perceived and actual effects of OSW on the livelihoods of fishing communities, including commercial and recreational fisheries? • What are the potential effects on local economies if access to certain fishing grounds is lost or reduced? • What platforms and technologies can be leveraged to enable dialogue among scientists, managers, fishermen, and other resource users so that local concerns and knowledge properly inform research efforts and subsequent decision-making processes? • How do the social and economic impacts of OSW development vary across different sectors and communities at various timescales, and what options exist to mitigate them?

southeast Atlantic and GoA, a mitigation strategy was developed for fisheries-independent surveys (Hanisko et al., 2025). It will be important to minimize the effects of OSW development on fisheries-independent surveys and the metrics (e.g., mortality rates) that they produce (Haase et al., 2023).

The interplay between O&G infrastructure and the recreational fishing sector is a unique aspect of the GoA, as fishing activities are generally allowed on and immediately surrounding O&G platforms. Fishermen in the GoA have traditionally used O&G platforms as preferred fishing spots because they attract recreationally targeted species (Brashier, 1988; Stanley & Wilson, 1989). The use of O&G platforms in the GoA for fishing has been ubiquitous for over half a century and holds significant cultural importance (Dugas et al., 1979). Although existing and anticipated OSW development in the U.S. Northeast and Pacific is expected to restrict fishing activities around turbines, it is expected that OSW infrastructure generally will be open to fishing during operation in the GoA. The only expected restrictions are lack of access during the construction stage and that fishermen may be precluded from tying off to OSW structures. However, many anglers can lock on to sites using automated vessel positioning systems. As long as fishing access is not lost while OSW farms are operational, there has been general support for OSW development among charter captains that target reef fish (Klajbor et al., 2025). This general culture of openness to fishing on OSW infrastructure in the GoA presents novel considerations, research opportunities, and management implications. The potential effects of OSW development on economic and fishing behavior should also be considered. The addition of hardened benthic and vertical substrate may represent increased fishing opportunities for recreational and for-hire fishing operations. However, simulations for Atlantic surfclam fishermen in the northeastern USA predicted that OSW led to slightly increased fishing costs (<1–5%) and reduced revenues for fishing vessels and processors (∼3–15%; Scheld et al., 2022). Also, OSW structures will present navigation hazards and will effectively exclude commercial trawlers from areas that have been fished historically, as discussed in previous sections. Broadly, different fisheries will be differentially affected such that the behavior and responses of various commercial and recreational fisheries should be continuously monitored as OSW development evolves in the GoA.

Marine spatial planning (Table 9)

Marine spatial planning (MSP) is a comprehensive, ecosystem-wide process that assesses new ocean uses and reconciles them with existing ocean uses and conservation of natural resources. In the GoA, regional MSP was conducted by the National Oceanic and Atmospheric Administration (NOAA) in partnership with BOEM to develop regional spatial models that identified areas of the ocean with the least spatial conflict and thus

Table 10. Submodel data categories and fisheries data layers incorporated into the marine spatial planning regional spatial models for evaluating the development of offshore wind (OSW) in the GoA (Randall et al., 2022).

Submodel data categories	Fisheries data layers
• Natural and cultural resources—e.g., sensitive habitats, protected resources • National security—e.g., military operation areas, special use airspace • Economics—e.g., OSW resource potential • Industry—e.g., vessel traffic, seafloor infrastructure, buoys • Logistics—e.g., distance from shore • Fisheries—see Fisheries data layers column • Constraints—e.g., military zones, coral, and hard bottom	• Commercial shrimp electronic logbook data • Highly migratory species pelagic longline gear observer data • Menhaden fishery data • Reef fish bandit gear fishing data • Reef fish longline gear fishing data • Southeast region headboat survey data

the highest opportunity for OSW development (Randall et al., 2022). The identified ocean areas (WEAs) were developed by aggregating 200 regional spatial data layers into a model. More specifically, each data layer was assigned to a submodel that was designated based on the data type (e.g., fisheries, industry, natural resources; Table 10). The seven resulting submodels were unweighted (i.e., the submodel from fisheries data had weight equal to that of the other six submodels of other ocean industries). Specific guidelines were also developed to resolve potential adverse effects on 23 species groups that are listed under the U.S. Endangered Species Act or the Marine Mammal Protection Act (Farmer et al., 2023). The final model applied a specific constraint for Rice's Whale *Balaenoptera ricei* and excluded the 100–400-m isobath.

Continued MSP research and communication will be critical to informing science-based wind energy development in the GoA, particularly within the wider context of changes in climate and ocean use. The current MSP tool does not incorporate ecosystem and fishery dynamics, which may lead to unanticipated consequences. Ecosystem modeling applications, such as Ecopath with Ecosim and Ecospace (EwEE), have been used for European OSW (Alexander et al., 2016; Püts et al., 2023) and MSP that may capture ecological feedback (Steenbeek et al., 2020). There are several EwEE models in the GoA that could be adapted to simulate MSP and OSW scenarios (Shaffer et al., 2023; Vilas et al., 2023). Ultimately, it will be necessary to balance wind energy development with both current (e.g., fisheries, O&G, mineral extraction, shipping, aquaculture) and potential future uses, such as tidal and wave renewable energy, marine carbon dioxide removal, carbon capture, and green hydrogen.

Social and economic effects (Table 9)

Although OSW in the GoA serves to address general societal values through energy independence and clean energy production, its development has the potential to disproportionately affect specific sectors and people. This may include immediate loss of fishing access and increased fuel costs to avoid traversing through OSW areas (Gray et al., 2016; Samoteskul et al., 2014), and disruptions to cultural ecosystem services like aesthetics, traditional heritage, and sense of place. As marine resource management alone fails to sufficiently address the equitability of such disruptions (Klain et al., 2014), the public should be engaged throughout the scientific process.

The primary effect of OSW on commercial fisheries will be the de facto exclusion of some active fishing gears (e.g., trawls) that will be unable to operate near OSW structures (Gray et al., 2005; Gray et al., 2016; Kirkpatrick et al., 2017; Mackinson et al., 2006), and the resulting loss of livelihood and fishing heritage (Alexander et al., 2013; Mackinson et al., 2006). Some pelagic gear fisheries may still be able to operate (Methratta et al., 2020). However, there are further concerns for potential crowding in remaining areas outside of OSW farms (e.g., Mackinson et al., 2006; ten Brink & Dalton, 2018), which may cause safety issues and increase interactions with protected species (Methratta et al., 2020; Schupp et al., 2021). Hook and line fishermen (both commercial and recreational) often support OSW development due to real or perceived abundance increases from the "artificial reef effect" of new structures (Methratta et al., 2020; Smythe et al., 2021; ten Brink & Dalton, 2018). In the northeastern USA, anglers have demonstrated general support for OSW development, but they have also stated that it detracts from the natural beauty and wilderness image of the sea (Bidwell et al., 2023; Hooper et al., 2017; Smythe et al., 2021).

Sense of place describes the meaning, or attachment, that a person or group ascribes to a specific geographical setting (Jorgensen & Stedman, 2001) and is a multidimensional concept consisting of feelings, associated memories, sensory perceptions, social connections, cultural rules, and the perceived relationship between self, others, and the place (Gustafson, 2001; Tuan, 1974; van Putten et al., 2018). Thus, sense of place is linked to a community's health and vulnerability to disturbances (Conley & Diamond, 2024). Place-based research where OSW development is already occurring globally reveals that communities may struggle to adjust to changes in their use of the ocean (Firestone et al., 2018), and individuals with strong place attachment tend to oppose OSW development (Bidwell, 2017). For example, the construction of the Block Island Wind Farm in the northeastern USA negatively affected residents' sense of place, even for individuals who supported the project (Russell et al., 2020), due to sentiment that the OSW turbines were unattractive, appeared industrial, and detracted from the overall character of the Rhode Island coast (Firestone et al., 2018; Russell et al., 2020). Sense of place is geographically specific; therefore, we expect that sentiments may differ in the GoA, as infrastructure developed for the O&G industry is already well established (Ditton & Auyong, 1984; Hooper et al., 2017). Studies of sense of place typically only commence after an adverse event has occurred. For example, coastal residents that depended on natural resources for their livelihoods (e.g., fisheries) experienced a loss of cultural heritage and a diminished sense of place and spiritual connection to the environment following the *Exxon Valdez* and Deepwater Horizon MC252 oil spills (Gill et al., 2014; Lee & Blanchard, 2012). Baseline data on sense of place and community health are needed (Sandifer et al., 2021). Such data, if available before OSW development, would enable developers and managers to better address the public's concerns and identify trade-offs (van Putten et al., 2018).

Engaging affected parties, including fishermen, OSW developers, and state and federal managers, early in the scientific process can align research priorities with societal values and address institutional biases (Voinov et al., 2014). Special efforts are needed to include underrepresented populations, such as racial, ethnic, or gender minorities and low-income groups who have often been disproportionately affected by and historically disenfranchised in environmental decision making (Bennett et al., 2023; Furman et al., 2023). To date, research on the social and economic effects of OSW on the commercial fishing industry and its communities remains relatively limited (Chaji & Werner, 2023). Participatory modeling can be employed in conjunction with other methodologies (e.g., ethnographic research and quantitative analysis of fishing effort and landings data) to elicit and integrate community knowledge to fill such gaps (Voinov et al., 2018)—for example, to support spatial planning in fisheries (Blake et al., 2017) and connect fishing effort data with shoreside communities (NOAA National

Marine Fisheries Service, Southeast Fisheries Science Center, personal communication, 2024). The use of participatory modeling increases management transparency, reduces uncertainty (Röckmann et al., 2012), defines management objectives (Hobbs et al., 2002), and facilitates social learning (Li et al., 2016). Qualitative modeling tools can approximate scientific knowledge through crowdsourcing diverse perspectives, leveraging a "wisdom-of-crowds" approach for developing hypotheses or predictions (Aminpour et al., 2020). There are ample opportunities to apply such methods to leverage traditional and contemporary local ecological knowledge related to fisheries in the GoA to guide research directions that are related to OSW development.

DISCUSSION

The primary goals of OSW development in the USA are to produce decarbonized energy, advance national energy security, and support U.S. technologies and economies (The White House, 2021). In the GoA, a long history of industrial development has fostered a unique social, ecological, and regulatory environment among developers, managers, and members of the fishing industry, including commercial, recreational, and charter for-hire fishermen. Although BOEM has ongoing efforts to assess such effects, conducting additional and complementary research across all stages of OSW development is essential.

Disentangling OSW from concurrent environmental pressures

The GoA is already experiencing human and environmentally driven stressors and disturbances, such as ocean warming, ocean acidification, hypoxia, and harmful algal blooms. The introduction of OSW infrastructure has the potential to interact with these stressors and disturbances, and their interactions require further examination for responsible management and planning. There is little evidence suggesting potential alleviation of the adverse effects of climate change in the near future (Chagaris et al., 2019), and thus, it will be important to disentangle those effects from those driven by OSW development. Cumulative and interactive effects (e.g., additive, synergistic, antagonistic) of OSW development and other anthropogenic disruptions are expected and will need to be considered. For example, OSW structures support high biomasses of suspension-feeding invertebrate communities that increase the removal of organic matter from the water column, which is expected to increase more under ocean warming and acidification (Voet et al., 2022). These interactions may affect fishery species that rely on trophic pathways based on pelagic organic matter. Ultimately, the spatial and temporal extent of these interactions may determine the degree to which fisheries are affected, highlighting the need for regional scale, cumulative studies in the GoA.

Different perturbations are more prevalent in different regions of the GoA. For example, inner midshelf waters are more prone to hypoxia than offshore waters (Rabalais et al., 2001). Additionally, *Karenia brevis* or "red tide" blooms are more prevalent in southern GoA waters offshore Florida and Texas than in more northern and central GoA coastal states (e.g., Mississippi and Alabama; Soto et al., 2018). These spatial differences should be considered when evaluating the effects of forthcoming OSW structures and when disentangling these effects from those of other anthropogenic stressors. Relatedly, it will be important to disentangle and distinguish between the effects of OSW and other anthropogenic stressors to avoid mischaracterization of causal relationships. This issue is already present in the northeastern USA, where there is a public perception of linking OSW development to increased strandings of marine mammals, despite the current lack of a scientific link between OSW farms and these strandings (Thorne & Wiley, 2024).

Examining scale will be crucial for evaluating the effects of OSW. Although localized effects of OSW infrastructure on fish and fisheries can be studied at the turbine, cable, or even lease scale, regionally specific monitoring and science priorities are necessary due to the potential for cumulative or compounding effects (e.g., those associated with climate change) that cannot be identified at finer spatial and temporal scales (Methratta et al., 2023). An example of a program that addresses OSW at an ecosystem scale is NOAA's Gulf of Mexico Integrated Ecosystem Assessment (IEA) program, which summarizes and reports ecosystem-scale information in Ecosystem Status Reports (ESRs). These compile and generate ecosystem, biological, and social indicators, including climate drivers, physicochemical pressures, habitat changes, trophic states, ecosystem services, and human dimensions. To date, two ESRs for the GoA have been published by NOAA (Karnauskas, Keible, et al., 2017; Karnauskas et al., 2013). The data compiled for the ESRs enabled critical hypothesis testing on the linkages among drivers, pressures, and ecosystem states in the GoA (Karnauskas et al., 2015; Kilborn et al., 2018, 2024). Thus, the Integreated Ecosystem Assessment program and ESRs can inform empirically based assessments of concurrent environmental pressures in the GoA to help disentangle these from the effects of OSW farms.

Importance of baseline data

A central theme of the working group meeting was the importance of collecting comprehensive baseline data (biotic and abiotic variables) prior to the construction of OSW structures. Although there are several long-term monitoring surveys in the GoA (reviewed in Grüss et al., 2018), many of these surveys were designed to provide relative abundance indices for target marine resources across a wide spatial area for use in fisheries stock assessments. Therefore, most of these surveys do not have the statistical power to detect the effects of disturbances on finer-scale habitats (Powers et al., 2017). For example, the lack of baseline data prior to the Deepwater Horizon MC252 oil spill prevented a full assessment of the long-term effects on some marine resources and communities in the GoA (Powers et al., 2017), although population-level effects were more apparent for taxa with substantial prespill baseline community data (Patterson et al., 2023). The foresight from this working group can enable strategic plans for data collection in the proposed OSW lease areas before construction to help monitor responses using BACI or BAG sampling designs. Baseline data could be collected by supplementing ongoing monitoring surveys or by conducting new surveys that target specific habitats (e.g., benthic core grabs).

Societal participation in the scientific process

In the GoA, science to inform federal fisheries management has a long history of meaningful public participation, not only in developing and vetting scientific products but also in public involvement in management advice based on this science. The U.S. Department of Commerce oversees this public participation through the Magnuson–Stevens Fishery Conservation and Management Act (1976). Specifically, the Magnuson–Stevens Fishery Conservation and Management Act created structures for public, interagency discussions, and decision-making processes for fisheries science and management in the USA with the establishment of eight Regional Fishery Management Councils, including the GMFMC. These councils include academic scientists, fishing industry members, and members of the public, and their long-standing existence and processes established expectations for transparency and engagement around fisheries issues (Wilson & McCay, 1998).

Alternatively, OSW development (specifically siting and permitting) is managed by the Department of the Interior under different legislation: the Outer Continental Shelf Lands Act (1953) and the Energy Policy Act (2005). These laws do not require a similar, comprehensive public engagement process for OSW decision making. Department of Interior agencies, such as BOEM and the Bureau of Safety and Environmental Enforcement, engage with fisheries constituents at their own discretion. To date, BOEM's GoA region has participated in council discussions, organized public outreach events, and held one-on-one meetings with fisheries constituents. However, because this is an ad hoc and voluntary process, as opposed to the Fishery Management Council system, the differences in how public input is gathered and used between the two resource management processes may exacerbate mistrust and hamper meaningful societal participation. Given the intersection between OSW, fisheries, and the GoA ecosystem, meaningful public participation throughout OSW development, installation, operations, and decommissioning is essential in the GoA and expected by the public. Improving public engagement in the GoA may be driven by individual states using their positions as decision makers to facilitate and support additional public participation processes. Additionally, regionwide public engagement could be supported by creating an independent regional science advisory body that includes agencies, scientists, the fishing community, and developers, similar to the Responsible Offshore Science Alliance and the Responsible Offshore Development Alliance in the Atlantic.

CONCLUSIONS

In the mid-20th century, O&G exploration began in federal and state waters of the GoA, altering the anthropogenic relationship with the region forever. The environmental impacts of this development became subject to assessment and consideration during the advent of national environmental policies like the National Environmental Policy Act of 1970. Although there are similarities between O&G and OSW development, it is wholly unlikely the O&G industry would have matured and developed in the GoA as it has if we had the scientific body of knowledge, regulatory environment, and assessment capabilities that we do now. This speculation, considered in the context of OSW development in the same region, begs the question: What would we have done differently if we knew then what we know now about the potential effects of offshore energy development? This type of opportunity in which society can anticipate and plan for a major intrusion into the natural environment with years of advance notice is unprecedented and underscores the importance of codeveloping scientific and monitoring priorities.

The timeline of OSW development provides scientific and natural resource management communities in the GoA region with a unique opportunity to shape the course of OSW development. Such efforts should encourage novel and applied science and sustainable development opportunities while mitigating for known (and potential) adverse effects and fostering positive effects, thereby maximizing sustainable ecological and economic benefits for all sectors and communities involved. Such research could help inform responsible and equitable construction, operation, and decommissioning of OSW infrastructure (precradle to postgrave) to support the coexistence of environmental and economic prosperity.

DATA AVAILABILITY

There are no new data associated with this article.

ETHICS STATEMENT

This research met the ethical guidelines and legal requirements of the country in which it was performed.

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CONFLICTS OF INTEREST

None declared.

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