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# Protected species considerations for ocean planning: A case study for offshore wind energy development in the U.S. Gulf of Mexico

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## Abstract

**Objective:** Ocean planning provides opportunities for managers to evaluate trade-offs among environmental, social, economic, cultural, and management considerations in the development of place-based activities. Early integration of mobile protected species considerations into ocean planning reduces the likelihood of future resource conflict. Transparency and problem solving with potential conflicts in mind during the early planning stages can help to minimize contention and increase efficiency in permitting and may also minimize litigation challenges during project design and implementation. Starting with a large area, such as the Bureau of Ocean Energy Management's (BOEM) initial 12.1-million-ha call area in federal waters of the U.S. Gulf of Mexico, provided substantial geographic scope

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for identifying suitable areas for eventual offshore wind lease sales that also aim to minimize conflict across multiple resources and uses.

**Methods:** To support ocean planning for this large-scale activity, a generalized scoring system for protected species status and trends that facilitates relative comparison between species was developed. Spatial data for species listed under the U.S. Endangered Species Act or the Marine Mammal Protection Act were assembled. Species layers were scored based on species status and trend. The cumulative vulnerability for 23 species groups whose distributions overlap suitable areas proposed for eventual lease sales, termed wind energy areas (WEAs) by BOEM, was calculated.

**Result:** Integrating this combined protected species data layer into the broader Gulf of Mexico WEA ocean planning process helped to reduce potential protected species conflicts by 70%.

**Conclusion:** This generalized approach is directly applicable to other WEAs under consideration within the United States and is transferable to a variety of ocean spatial planning applications.

KEYWORDS

management, marine offshore, multispecies interactions, risk assessment, risk perception and communication, threatened and endangered species

# INTRODUCTION

Ocean planning provides opportunities for managers to visualize interactions and evaluate tradeoffs among environmental, social, economic, cultural, and management considerations in the development of spatially explicit activities. Ocean planning approaches are particularly useful when attempting to balance the introduction of new anthropogenic stressors into complex marine environments (Lester et al. 2018; Spijkerboer et al. 2020; Farmer et al. 2022a). Ocean planning (if properly applied) can be a useful tool for minimizing conflict between user groups, reducing environmental impacts, and increasing transparency in the management decision-making process (Ehler 2021).

Ocean planning informs intelligent siting for offshore development. In the United States, substantial increases in offshore aquaculture and wind energy development are anticipated. United States Presidential Executive Order (EO) 13921 (May 7, 2020) called for the expansion of sustainable seafood production in the United States through the identification of areas suitable for potential commercial offshore aquaculture development (Executive Office of the President 2020). Similarly, EO 14008 (§207; January 27, 2021) called for a doubling of the nation's offshore wind (OSW) renewable energy production to 30 GW by 2030 while ensuring robust protection of lands, waters, and biodiversity (White House 2021). To date, there are 29 OSW leases (27 commercial leases and 2 research leases) in active development. Additionally, nine states have set procurement goals totaling over 45 GW by 2035 through legislation, conditional targets, or EOs (American Clean Power 2022). The Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA), as amended, require the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) to apply science-based decision making to conserve and

**Impact statement**

This collaborative work provides a foundation for early engagement and strategic marine spatial planning for offshore wind energy to reduce potential adverse effects to protected species. It also provides a reference for work conducted to inform this process and a template for other regions as these efforts expand.

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recover protected species.[1] The Outer Continental Shelf Lands Act (OCSLA), as amended, gives the Bureau of Ocean Energy Management (BOEM) the authority to authorize and oversee responsible OSW energy development.[2]

Offshore wind energy development activities may include pre- and postconstruction geotechnical and geophysical surveys; pre- and postconstruction biological surveys; construction, operation, maintenance, and decommissioning of the OSW facility; running cables among the turbines within a lease area and from the lease area to a shoreside facility; and the potential for shoreside infrastructure needs, such as port expansions and channel deepening. Offshore wind activities may affect protected marine species both in nearshore and open-ocean environments through increased underwater noise; an increased risk of vessel strike; an increased risk of pollution, including air emissions; long-term (i.e., project duration) habitat disturbance and modification due to foundation installation, scour protection, cable installation, dredging, and vessel anchoring; hydrodynamic modifications of horizontal flow and turbulence, vertical mixing and destratification, and ocean–atmosphere interactions; disrupted scientific surveys; potential displacement of commercial and recreational fishing effort; electromagnetic fields from cables; project lighting; and entanglement (Blair et al. 2022 and references therein). Many of these effects have the potential to disrupt biologically important behaviors of protected species, such as foraging, migrating, resting, and reproduction, and also may cause changes in abundance and distribution for the protected species and their prey (Rolland et al. 2012; Taormina et al. 2018; Farr et al. 2021; Jacobs Engineering Group 2021; NOAA 2021a; Blair et al. 2022).

In 2021, BOEM announced that it was considering OSW leasing in federal waters of the Gulf of Mexico within a 12.1-million-ha “call area” encompassing waters beginning west of the Mississippi River and stretching to the Texas–Mexico border, with a seaward boundary following the 400-m depth contour line (BOEM 2022a, 2022b).[3] To leverage ocean planning early in BOEM's renewable energy process,[4] NOAA's National Centers for Coastal Ocean Science (NCCOS), in collaboration with BOEM, developed an ocean planning model to identify potential wind energy areas (WEAs) in the Gulf of Mexico call area. Wind energy areas are considered by BOEM to be areas suitable for OSW development and are used to inform the siting of OSW lease areas. The goal of this ocean planning exercise was to balance data-based analysis of wind resources and industry interest with potential impacts to commercial and recreational fisheries, sensitive biological habitat, protected species, archeological and cultural resources, and other ocean users (e.g., commercial shipping industry, oil and gas industry, carbon sequestration areas, military use areas, and federal fisheries surveys).

In this study, we present our approach to compiling, scoring, and combining NMFS protected species data layers to guide ocean planning for OSW energy development. Finally, we discuss integration of the NMFS combined protected species data layer into the broader NCCOS/ BOEM

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[1] The NMFS applies science-based decision making to maximize fishing opportunities and resource development, ensure sustainability of fisheries and fishing communities, and conserve and recover protected species. The conservation and recovery of protected species are implemented through the ESA of 1973, as amended (16 U.S. Code §1531 et seq.), and the MMPA of 1972 (16 U.S. Code chapter 31 §§1361–1423h) and 1994 amendments. The ESA requires federal agencies to ensure that any action that they authorize, fund, or carry out is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat. The MMPA and its implementing regulations (50 Code of Federal Regulations 216) provide protection to all marine mammals regardless of their listing status under the ESA and allow NMFS to authorize the incidental take of marine mammals under specified statutory and regulatory circumstances.

[2] The OCSLA, as amended, gives the Secretary of the Interior, through the BOEM, the authority to issue leases, easements, or rights-of-way on the outer continental shelf for the purpose of facilitating the leasing of U.S. offshore mineral and energy resources, including renewable energy resources. The Energy Policy Act of 2005, an amendment to the OCSLA, delegated BOEM the authority to oversee renewable energy developments in federal waters (43 U.S. Code 1337). Through these regulations (30 Code of Federal Regulations 585), BOEM oversees responsible OSW energy development.

[3] On June 11, 2021, BOEM announced that it was considering OSW leasing in federal waters of the Gulf of Mexico (BOEM 2022a). The initial request for interest (RFI) area under consideration encompassed BOEM's entire central and western planning areas. By November 1, 2021, the RFI area was narrowed to a 30-million-acre call area encompassing waters beginning west of the Mississippi River and stretching to the Texas–Mexico border, with a seaward boundary following the 400-m depth contour line (BOEM 2022b).

[4] As part of the early planning and leasing process, BOEM evaluated potential environmental consequences from site characterization activities (i.e., biological, archeological, and geotechnical, as well as geophysical surveys) and site assessment activities (i.e., installation of meteorological buoys) associated with the possibility of issuing OSW development leases in the Gulf of Mexico call area. The issuance of a lease would eventually allow for the submission of site assessment plans, which describe how lessees will conduct resource assessment activities, and construction and operation plans, which describe how lessees will construct, operate, and ultimately decommission a commercial OSW project on a particular lease, including easements (i.e., export cable corridors), for BOEM's consideration and approval (see 30 Code of Federal Regulations 585.620). The first lease auction in the Gulf of Mexico is proposed for early 2023. Site characterization and assessment activities are expected to occur within 5 years after a lease is issued; therefore, those activities could be conducted during 2023–2028. In its renewable energy process, BOEM refers to this as the site assessment and construction and operations stage.

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WEA siting model. The approach is conceptually simple (i.e., to guide OSW development to areas having fewer anticipated conflicts with protected species); however, in practice, it was challenging to determine an integrated approach for the many protected species existing in the U.S. Gulf of Mexico. The generalized approach presented here is directly applicable to other WEAs under consideration within the United States and is transferable to a variety of ocean planning applications.

## METHODS

The WEA siting model aggregated regional spatial data across 200 spatial data layers relevant to informing wind energy planning in the Gulf of Mexico. In the siting model, a score of 1 reflects an area with no siting conflicts and a score of 0 reflects an area that is unsuitable for the proposed activity (Riley et al. 2021). The data layers informing the siting model are combined using an unweighted geometric mean. Final WEA options are selected from clustered locations with high suitability scores. For this study, our goal was to generate a protected species data layer that would be informative to the WEA siting model by providing spatial suitability scores within this 0–1 range, accounting for overlap of protected species. First, we assembled protected species distribution layers from available data. Next, we applied a generalized scoring system that measured protected species vulnerability based on species status under the ESA or MMPA, population size, and population trajectory, as determined from stock assessments (NOAA 2021c) or the NMFS report to Congress (NOAA 2022), to inform relative risk in spatial modeling (Table 1). Finally, we combined the layers mathematically to generate a single combined protected species data layer to inform the WEA siting model.

Protected species distribution layers were assembled and evaluated across the entire U.S. Gulf of Mexico from state shorelines out to the U.S. exclusive economic zone boundary. Farmer et al. (2022a) developed and described the protected species data layers for eight ESA-listed species. For the present application, we evaluated 10 ESA-listed species (including two ESA-listed whales) and 12 MMPA-listed species groups (Table 2). Hawksbill sea turtles *Eretmochelys imbricata* were not included in this analysis because their primary documented high-use habitat in the Gulf of Mexico is a narrow migratory corridor through the Straits of Florida that is well isolated from the proposed WEA (Farmer et al. 2022b). All analyses and images were generated in R version 4.2 (R Core Team 2022) or ArcMap version 10.8 (ESRI Ltd.) in the Universal Transverse Mercator projection (zone 17N, North American Datum of 1983).

The species considered had vastly different types of data available to inform their distribution and the identification of high- and low-use areas. Data layers for the Gulf Sturgeon and Oceanic Whitetip Shark were generated by combining federally defined management areas (e.g., critical habitat or essential fish habitat [EFH] layers and consultation range maps). Data layers for Rice's whale and the Smalltooth Sawfish (U.S. Distinct Population Segment [DPS]) were generated by combining designated critical habitat and/or biologically important habitat layers with high-use areas identified from sightings, acoustic detections, and relocations of tagged animals. Data layers for 13 marine mammals, the adults of four sea turtles, and the Giant

**TABLE 1** A generalized scoring system for endangered and threatened species data layers, as modified from Farmer et al. (2022a); ESA, Endangered Species Act; MMPA, Marine Mammal Protection Act; n/a, not applicable.

| Status | Trend | Converted score for model |
|---|---|---|
| Endangered | Declining, small population,[a] or both | 0.10 |
| Endangered | Stable or unknown | 0.20 |
| Endangered | Increasing | 0.30 |
| Threatened | Declining or unknown | 0.40 |
| Threatened | Stable or increasing | 0.50 |
| ESA-listed low-use area | n/a (default score for ESA-listed species in low-use areas) | 0.50 |
| MMPA strategic[b] | Declining or unknown | 0.60 |
| MMPA listed | Small population[a] or unknown/declining | 0.70 |
| MMPA listed | Large population or stable/increasing | 0.80 |
| MMPA-listed low-use area | n/a (default score for MMPA-listed species in low-use areas) | 0.90 |

[a] Small population equates to a population of 500 individuals or less (Franklin 1980).

[b] A strategic stock is defined by the MMPA as "...a marine mammal stock for which the level of direct human-caused mortality exceeds the potential biological removal level; which, based on the best available scientific information, is declining and is likely to be listed as a threatened species under the ESA within the foreseeable future; or, which is listed as a threatened or endangered species under the ESA, or is designated as depleted under the MMPA."

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**TABLE 2** Scores assigned to protected species in the U.S. Gulf of Mexico based on species status and trend. Species are sorted by the type of data layers available; DPS, Distinct Population Segment; ESA, Endangered Species Act; MMPA, Marine Mammal Protection Act.

| Species or taxon | Status | Trend | Score | Trend source | Data layer(s) | Data layer source(s) |
|---|---|---|---|---|---|---|
| Management areas | | | | | | |
| Gulf Sturgeon *Acipenser desotoi* (formerly *Acipenser oxyrinchus desotoi*) | ESA threatened | Increasing | 0.5 | U.S. Fish and Wildlife Service and NOAA (2022) | Critical habitat, range | NOAA (2003, 2021b) |
| Oceanic Whitetip Shark *Carcharhinus longimanus* | ESA listed | Declining | 0.4 | NOAA (2023) | Essential fish habitat, range | NOAA (2017, 2021b) |
| Field observations | | | | | | |
| Smalltooth Sawfish *Pristis pectinata* (U.S. DPS) | ESA listed | Increasing | 0.3 | NOAA (2018) | Critical habitat, tag relocations, sightings | Simpfendorfer and Wiley (2006), Carlson et al. (2014), Graham et al. (2021, 2022), Florida Museum of Natural History (2021) |
| Rice's whale *Balaenoptera ricei* | ESA listed | Small population | 0.1 | Hayes (2021) | Sightings, tag relocations, passive acoustic monitoring, habitat suitability modeling | Rosel and Garrison (2022), Soldevilla et al. (2022) |
| Distribution models | | | | | | |
| Atlantic spotted dolphin *Stenella frontalis* | MMPA listed | Unknown | 0.7 | L. P. Garrison (unpublished data) | Density model | Rappucci et al. (2021) |
| Beaked whales *Ziphius* spp./*Mesoplodon* spp. | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Blackfish (false killer whale *Pseudorca crassidens*, pygmy killer whale *Feresa attenuata*, and melon-headed whale *Peponocephala electra*) | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Clymene dolphin *S. clymene* | MMPA strategic | Unknown | 0.6 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Common bottlenose dolphin *Tursiops truncatus truncatus* (coastal and shelf waters) | MMPA listed | Unknown | 0.7 | L. P. Garrison (unpublished data) | Density model | Rappucci et al. (2021) |
| Common bottlenose dolphin (oceanic waters) | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |

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**TABLE 2** (Continued)

| Species or taxon | Status | Trend | Score | Trend source | Data layer(s) | Data layer source(s) |
|---|---|---|---|---|---|---|
| Kogia *Kogia* spp. (dwarf sperm whale *K. sima* and pygmy sperm whale *K. breviceps*) | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Pantropical spotted dolphin *S. attenuata* | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Pilot whales *Globicephala* spp. | MMPA listed | Unknown | 0.7 | NOAA (2021c) | Density model | Rappucci et al. (2021) |
| Risso's dolphin *Grampus griseus* | MMPA listed | Unknown | 0.7 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Sperm whale *Physeter macrocephalus* | ESA listed | Unknown | 0.2 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Spinner dolphin *S. longirostris* | MMPA strategic | Unknown | 0.6 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Striped dolphin *S. coeruleoalba* | MMPA strategic | Unknown | 0.6 | Hayes (2021) | Density model | Rappucci et al. (2021) |
| Giant Manta *Mobula birostris* (formerly *Manta birostris*) | ESA threatened | Declining | 0.4 | NOAA (2020) | Habitat suitability model | Farmer et al. (2022b) |
| Leatherback sea turtle *Dermochelys coriacea* | ESA listed | Declining | 0.1 | NOAA (2022) | Density model | Rappucci et al. (2021) |
| Distribution + dispersal models | | | | | | |
| Green sea turtle *Chelonia mydas* | ESA listed | Unknown | 0.5 | NOAA (2022) | Density model, dispersal model | Rappucci et al. (2021) |
| Kemp's ridley sea turtle *Lepidochelys kempii* | ESA listed | Unknown | 0.2 | NOAA (2022) | Density model, dispersal model | Rappucci et al. (2021) |
| Loggerhead sea turtle *Caretta caretta* | ESA threatened | Unknown | 0.4 | Ceriani et al. (2019), NOAA (2022) | Density model, dispersal model | Rappucci et al. (2021) |

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Manta were developed from species distribution models (SDMs) fitted to aerial (continental shelf) or vessel (oceanic) line transect survey data (Rappucci et al. 2021; Farmer et al. 2022b). Additional data layers for juveniles of the green, Kemp's ridley, and loggerhead sea turtles were developed from dispersal models accounting for animal behavior and hydrodynamic forcing to simulate pelagic dispersion of small turtles from nesting beaches (Putman et al. 2013).

## Species data layers

### Management areas

Distribution models across the entire Gulf of Mexico have not been developed for the Gulf Sturgeon or Oceanic Whitetip Shark. For Gulf Sturgeon, high-use areas and the overall range of the species were approximated using the boundary of its defined critical habitat (NOAA 2003) and the NMFS Southeast Regional Office Section 7 Mapper (NOAA 2021b) consultation layer, respectively. The Section 7 Mapper[5] is a public-facing tool that allows federal action agencies or their representatives to determine whether ESA Section 7 consultation is required based on the occurrence of ESA-listed species or critical habitat within the project area. The NMFS has jurisdiction over Gulf Sturgeon in marine waters; thus, the consultation layer encompassed marine waters extending from coastal shorelines and bays with documented occurrences of Gulf Sturgeon to 50 m (i.e., the deepest recorded depth of Gulf Sturgeon encountered in the Gulf of Mexico). For Oceanic Whitetip Sharks, the high-use area and overall range were defined by the federally recognized EFH for the species (NOAA 2017) and the Section 7 Mapper consultation layer, respectively. The consultation layer for Oceanic Whitetip Sharks encompassed the shallowest documented occurrence of the species (148 m) out to the boundary of the U.S. exclusive economic zone.

### Field observations

The development of the Smalltooth Sawfish (U.S. DPS) data layer was described by Farmer et al. (2022b). Briefly, location data were obtained from three point sources: (1) U.S. Sawfish Recovery Encounter Database reports for 1999–2017 (Simpfendorfer and Wiley 2006; Florida Museum of Natural History 2021), (2) acoustic tag relocations from 43 animals tagged from 2016 to 2019 (Graham et al. 2021, 2022), and (3) maximum likelihood positioning estimates generated by Wildlife Computers GPE3 positioning software for 15 satellite-tagged Smalltooth Sawfish (Carlson et al. 2014; Graham et al. 2021, 2022). A 95% kernel density estimate around the merged point data was used to delineate a high-use area in the U.S. Gulf of Mexico using the kernelUD function in the adeHabitat package within R version 4.1.2.

The development of the Rice's whale data layer was also described by Farmer et al. (2022b). Briefly, a core area determined from visual sightings and the movements of tagged animals (Rosel and Garrison 2022) was joined to a suitable habitat layer supported by passive acoustic monitoring (Soldevilla et al. 2022) and habitat distribution modeling. The habitat model predicted potential occurrence (at varying densities) throughout areas of the northern Gulf of Mexico bounded by the 100- and 400-m isobaths.

### Distribution models

Data layers for marine mammal species other than Rice's whale and for adult sea turtles were derived from the final products of the Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS; Rappucci et al. 2021). Briefly, three line-transect aerial and vessel surveys were conducted over the continental shelf and oceanic waters, respectively, during 2017 and 2018. Mark–recapture distance sampling methods employing the independent observer approach (Laake and Borchers 2004) were used to estimate detection probability within the survey strip and to account for perception bias, and tag data were used to account for availability bias. Data were combined with those from prior aerial (2011 and 2012) and vessel (2003, 2004, and 2009) surveys to develop spatially explicit density models (Miller et al. 2013) with environmental predictors describing oceanographic conditions derived from remotely sensed data and hydrographic models. Environmental predictors included sea surface temperature, chlorophyll-$a$ concentration, sea surface height, geostrophic surface current fields, and bathymetric variables (Litz et al. 2022).

Farmer et al. (2022a) integrated three decades of sightings and survey effort data from multiple sources in a comprehensive species distribution modeling framework to evaluate the distribution of Giant Mantas off the eastern United States, including the Gulf of Mexico. Environmental drivers of sighting patterns were evaluated in a mark–recapture distance-weighted SDM, which was subsequently validated by both intra- and extra-survey observations. The best predictive model combined observations from surveys conducted by NMFS, the North Atlantic Right Whale Consortium, Normandeau Associates, Inc., and APEM Ltd.

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[5] https://www.arcgis.com/home/item.html?id=b184635835e34f4d904c6fb741cfb00d.

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## Dispersal models

Data layers for green, loggerhead, and Kemp's ridley sea turtle juveniles that were too small (<40 cm) to be detected by GoMMAPPS aerial surveys were modeled as described by Putman et al. (2019). These models simulated the dispersal of sea turtle hatchlings by using a hindcast ocean circulation model. Dispersal predictions were weighted by estimates of annual hatchling production and stage-specific mortality rates. Spatially explicit estimates of juvenile sea turtle population sizes were provided across 3 years (2015–2017) for three different oceanic survival levels (i.e., 0.250, 0.817, and 0.940).

## Scoring and combining data layers

Under the generalized scoring system presented in Table 1, scores for MMPA- and ESA-listed species data layers ranged from 0.1 (most vulnerable species based on their biological status) to 0.9 (least vulnerable species). Species and stocks were ranked according to factors that are more or less likely to affect their ability to withstand mortality, serious injury, or other impacts on the species' ability to survive and recover. Where species were ubiquitous within the area of interest, high- and low-use areas were identified to create spatial contrast in scoring. High-use areas were defined on a species-specific basis as described below and were scored in accordance with Table 1. Scores of 0.5 and 0.9 were applied to low-use areas for ESA-listed species and MMPA-listed species, respectively.

Management areas for the Gulf Sturgeon and the Oceanic Whitetip Shark were combined and scored as follows. Because the Gulf Sturgeon is listed as threatened under the ESA, with an increasing trend based on the most recent 5-year review (U.S. Fish and Wildlife Service and NOAA 2022), the critical habitat and consultation range were combined in ArcMap and assigned the same score of 0.5 (Table 2). The combined Oceanic Whitetip Shark layer was developed in a non-overlapping union as described above; a score of 0.4 was then assigned to the EFH, and the default score of 0.5 was assigned to the non-overlapping portion of the Section 7 layer (Table 2).

Field observations for Smalltooth Sawfish and Rice's whale were combined and scored as follows. The high-use area for Smalltooth Sawfish was joined to the boundary of its defined critical habitat and the Smalltooth Sawfish Section 7 Mapper consultation layer in a non-overlapping union in ArcMap using the "Analysis>Overlap>Erase" tool to erase high-use areas from the consultation layer and then using "Analysis>Overlap>Union" to combine the high-use areas with the erased layer. The high-use area and critical habitat were assigned a score of 0.3; the remaining non-overlapping consultation layer was assigned a score of 0.5 (Table 2). Given that there are likely fewer than 100 Rice's whales remaining (Hayes 2021), a conservative approach to scoring was taken, wherein the non-overlapping union of the core area and habitat suitability range was assigned a score of 0.1 (Table 2).

For marine mammals other than Rice's whale, SDMs were used to predict species density in each month during 2015–2018 over a hexagonal grid (cell area = 40 km$^2$) encompassing the U.S. waters of the Gulf of Mexico. Predictions were restricted to U.S. waters to ensure accurate representation of spatial utilization within the area of potential wind energy development. Observations from distance-weighted aerial surveys were used to develop continental shelf distribution models within the aerial survey domain. Similarly, observations from vessel surveys were used to develop oceanic distribution models within the vessel survey domain. In this analysis, the maximum across all predicted monthly densities was selected for each spatial cell. Each spatial cell was then coded as being above or below the median of the distribution of these maximum densities to identify high- versus low-use areas, respectively. High-use areas were scored according to Table 2. Low-use areas were scored as 0.5 or 0.9 depending on whether the species was listed under both the ESA and the MMPA or listed exclusively under the MMPA.

The habitat suitability model for the Giant Manta was fitted to monthly averaged environmental data from January 2003 to December 2019 across a 10- × 10-km grid within the U.S. Gulf of Mexico. The maximum observed probability of occurrence across this time period was retained for each grid cell. Following the method of Farmer et al. (2022b), the grid cells above the median maximal probability of occurrence were defined as high-use areas and assigned a score of 0.4; the areas below the median were assigned a score of 0.5 (Table 2).

For adult sea turtles, high- and low-use areas were defined using distribution model-estimated median maximum densities as described above for marine mammals. For juvenile sea turtles, the maximum number of surviving turtles across years at the middle survival level (e.g., 0.817) was summed within spatial grid cells. The spatial cells were then coded as above or below the median of population size across grids to indicate higher versus lower use areas, respectively. To avoid the double counting of sea turtle species by having separate scores for adult and juvenile distribution layers, the juvenile and adult layers for green, loggerhead, and Kemp's ridley sea turtles were spatially joined in ArcMap, yielding single scored layers for each species that reflected both low- and high-use areas for juveniles and adults. High-use areas were scored according to Table 2; low-use areas were scored as 0.5.

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A combined score was assigned to each cell in the hexagonal Gulf of Mexico-wide grid developed for the SDMs for each species using custom functions in Python to select the minimum nonzero score. Next, all layers for all species were spatially joined in sequence to the hexagonal grid such that a single column score remained for each species with a merge rule of minimum score, resulting in a single score per species per 40-km$^2$ cell. Cells without scores for a species were assigned a score of 1 (i.e., “suitable”). Following the procedures of Farmer et al. (2022b), protected species data layers across species were combined using both the product ρ (equation 1) and lowest scoring layer $l$ (equation 2) methods:

$$\rho = x_1 \times x_2 \times \ \dots \ \times x_n \qquad (1)$$

$$l = \min(x_1, x_2, \ \dots \ , x_n), \qquad (2)$$

where $x$ represents scores based on status and trend (Table 1) for species 1 to $n$ within a given cell in the model domain. The product method was used to provide broader marine planning guidance; the lowest scoring layer method was used to identify the primary species driving site-specific scores.

# RESULTS

## Species data layers

### Management areas

Gulf Sturgeon critical habitat is focused on natal rivers and associated estuarine habitats in the northeastern Gulf of Mexico; however, adults are found out to approximately the continental slope from Tampa Bay to eastern Louisiana (Figure 1A). Oceanic Whitetip Sharks are found in offshore waters throughout the Gulf of Mexico but primarily offshore of Texas and Louisiana (Figure 1B).

### Field observations

Sightings and tagging data for Smalltooth Sawfish (U.S. DPS) suggested high use of the southwest Florida coastal and continental slope waters (Figure 1C). Sightings, combined with passive acoustic monitoring, tagging, and habitat suitability modeling, suggested a core area for Rice's whale near DeSoto Canyon in the northeastern Gulf of Mexico, with a broader suitable habitat between 100 and 400 m throughout the Gulf of Mexico (Figure 1D).

### Distribution models

Non-overlapping coastal (aerial) survey and oceanic (vessel) survey SDMs were developed from GoMMAPPS data (Figure 1). The Atlantic spotted dolphin was sighted in both survey domains, with higher densities on the offshore edge of the coastal domain and nearshore edge of the oceanic domain (Figure 1F). For common bottlenose dolphins, density was highest nearshore in the shelf domain and also highest on the nearshore edge of the oceanic domain (Figure 1J). Beaked whales, blackfish, the Clymene dolphin, the pantropical spotted dolphin, and the striped dolphin were all concentrated in the offshore edges of the oceanic model (Figure 1H,I,L,N,S). The Atlantic spotted dolphin and the spinner dolphin were most concentrated on the continental shelf (Figure 1F,R). Leatherback sea turtle adults were generally found in offshore environments (Figure 1Z).

### Dispersal models

Juvenile green, Kemp's ridley, and loggerhead sea turtles were fairly ubiquitous throughout the Gulf of Mexico (Figure 1T–Y); however, both juvenile and adult sea turtles had areas of highest density in nearshore waters. Areas of highest density varied by species. Green sea turtle juveniles were most concentrated near the Louisiana–Texas border, with adults most concentrated off southwestern Florida (Figure 1T,U). Kemp's ridley sea turtle juveniles were heavily concentrated off coastal Texas; adults were concentrated nearshore throughout the Gulf of Mexico but especially off coastal Louisiana (Figure 1V,W). The highest predicted densities for loggerhead sea turtle juveniles and adults were in coastal waters off the Florida panhandle (Figure 1X,Y).

## Scoring and combining data layers

Data layers with generalized scores for each species are presented in Figure 2. The Gulf Sturgeon (Figure 2A) and green sea turtle (Figure 2T), due to their equal scoring for high- and low-use areas, provided no contrast for ocean planning. The data layer for Smalltooth Sawfish (U.S. DPS) did not intersect the call area (Figure 2C). The species with the highest potential for conflict in marine planning were Rice's whale (Figure 2D) and the leatherback sea turtle (Figure 2W). Oceanic Whitetip Sharks (Figure 2B), blackfish (Figure 2I), oceanic stocks of Atlantic spotted (Figure 2G) and common bottlenose dolphins (Figure 2K), and sperm whales (Figure 2Q) had the

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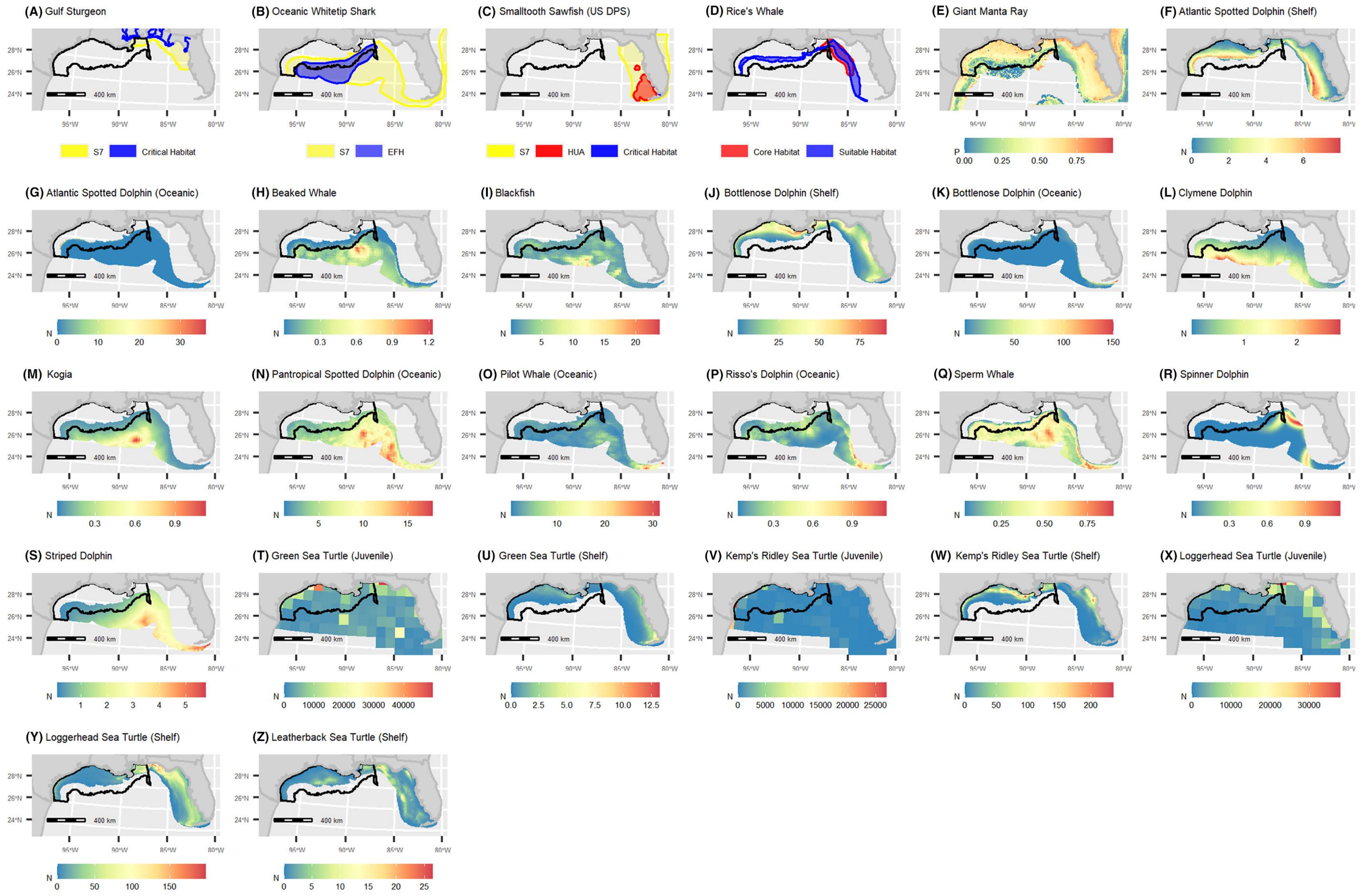

**FIGURE 1** Distributions of all protected species considered for potential wind energy development spatial planning in the Gulf of Mexico: (A) Endangered Species Act Section 7 (S7) consultation layers and critical habitat for the Gulf Sturgeon; (B) S7 and essential fish habitat (EFH) layers for the Oceanic Whitetip Shark; (C) S7 consultation layer, high-use area (HUA) from 95% kernel density estimates around tag relocations, and critical habitat for the Smalltooth Sawfish (U.S. Distinct Population Segment [DPS]); (D) core habitat from sightings and suitable habitat from passive acoustic monitoring, sightings, and habitat suitability modeling for Rice's whale; (E) maximum probability of occurrence (January 2003–December 2019) for the Giant Manta (from Farmer et al. 2022a); and (F)–(Z) estimated abundance of other marine mammals and sea turtles in the Gulf of Mexico based on species distribution models fitted to distance-weighted aerial (shelf) and vessel (oceanic) surveys with environmental and bathymetric covariates. Panels T, V, and X depict modeled distributions of juvenile sea turtles from Putman et al. (2019). The black polygon denotes the Gulf of Mexico wind energy development call area.

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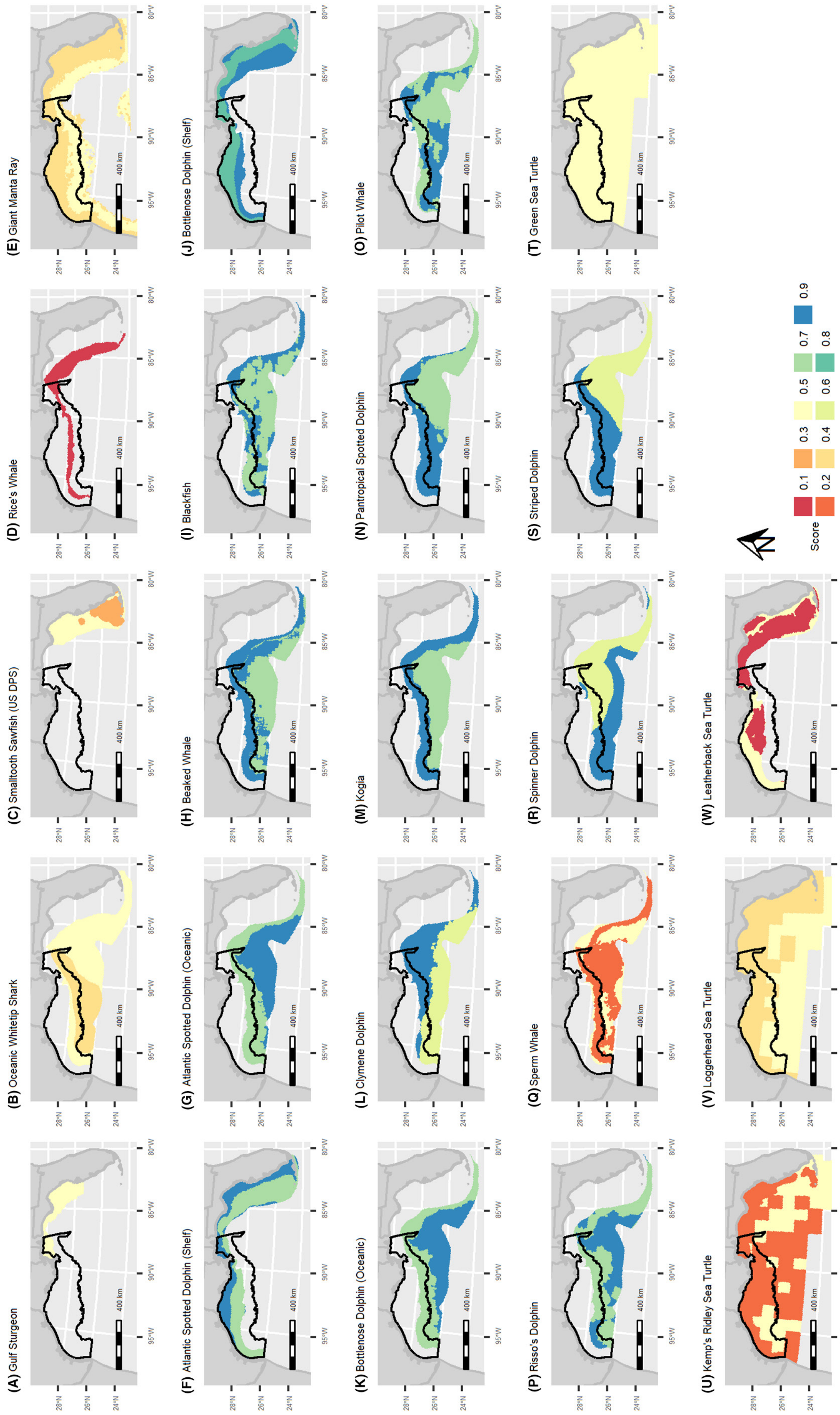

**FIGURE 2** Scores across all 23 protected species data layers. Scores for all species were calculated following Table 2. The black polygon denotes the Gulf of Mexico wind energy development call area; DPS, Distinct Population Segment.

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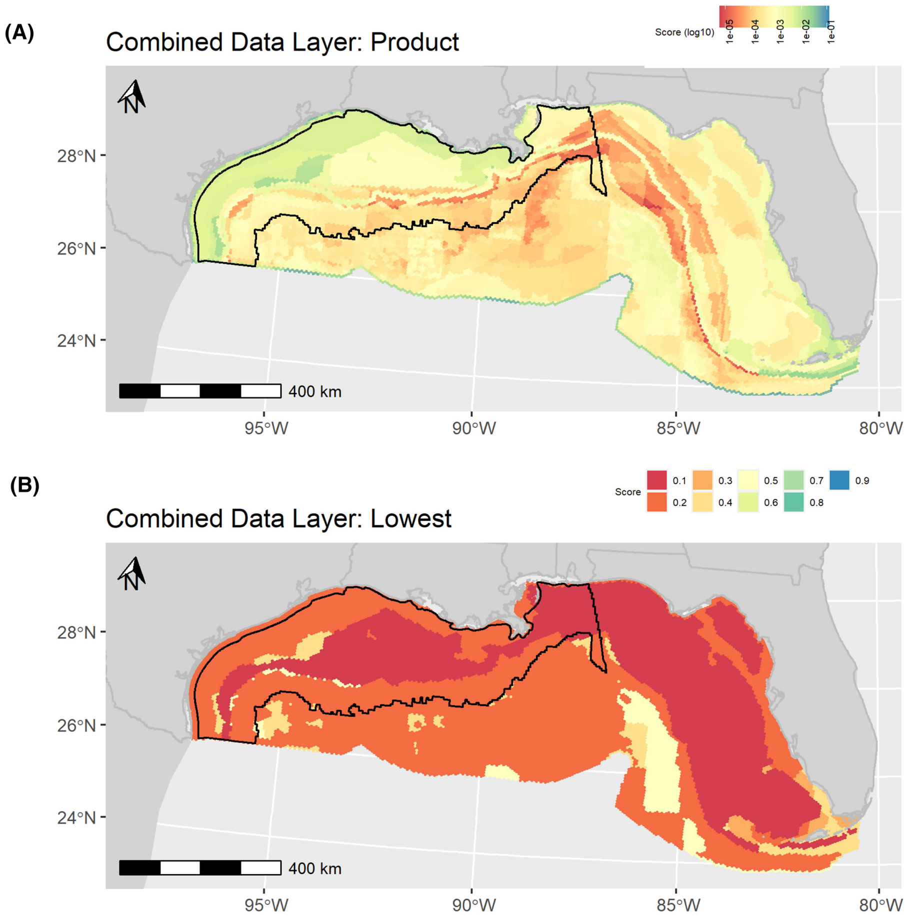

**FIGURE 3** Final combined protected species data layers for the Gulf of Mexico. Spatial distribution of consultation risk for protected species was based on vulnerability and trend, with layers combined using two different approaches: (A) the product of risk scores across all 23 protected species data layers and (B) the lowest scoring layer within a given cell. Note that the latter approach does not consider the cumulative risk associated with overlapping protected species concerns.

highest potential for conflict on the offshore edge of the call area. The call area primarily intersected with low-use areas only for beaked whales (Figure 2H), *Kogia* spp. (Figure 2M), the pantropical spotted dolphin (Figure 2N), and the striped dolphin (Figure 2S).

The final combined protected species data layer generated using the product method indicated that the highest potential vulnerabilities across all protected species evaluated are located in the shelf environments of the eastern Gulf of Mexico and the offshore (>100-m depth) environments of the western Gulf of Mexico (Figure 3A). The lowest vulnerabilities are in the very nearshore environments off Texas and Louisiana and the mid-shelf environments off Texas. The final combined protected species data layer generated using the lowest scoring layer method indicated that the highest single-species conflicts are located in the middle of the proposed call area (Figure 3B). Both results (Figure 3) were primarily driven by the Rice's whale data layer (Figure 2D), with the lowest scoring layer approach also strongly influenced by the leatherback sea turtle data layer (Figure 2W).

## DISCUSSION

Stationary protected resources, such as seagrass, corals, or marine protected areas, are often considered in spatial planning models (Perez et al. 2005; Longdill et al. 2008; Lester et al. 2018). However, spatial use by mobile or transient protected species, such as marine mammals, is generally excluded from ocean planning. Failure to consider mobile species is often attributed to uncertainty regarding species distributions and habitat requirements, coupled with uncertainty about the impacts of ocean industry activities during the early planning stages, when ocean planning is most useful. However, early integration of mobile protected species considerations into the planning process reduces the likelihood of future resource conflict (Young et al. 2007; Petruny et al. 2014; Farmer et al. 2022b; Ménard et al. 2022). Transparency and problem solving with potential conflicts in mind during the early planning stages can help to minimize contention and increase efficiency during permitting and can hopefully also minimize litigation challenges during project design and implementation.

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Spatial data from megafauna have been used to inform decisions regarding regulations and marine protected area boundaries (Dawson et al. 2017; Hays et al. 2019). In Redfern et al. (2013), the distributions of three large whales were evaluated in the context of ship strike risk. Petruny et al. (2014) evaluated the relative risk of ship strike and OSW farm planning relative to sightings of endangered North Atlantic right whales *Eubalaena glacialis*. In a study by Augé et al. (2018), 36 species distribution layers of seabirds and pinnipeds were combined into a single composite megafauna layer using a weighted arithmetic mean to inform spatial planning around the Falkland Islands. Ménard et al. (2022) employed a variety of sighting data sets to identify vessel routes supporting acoustic tranquility areas for endangered beluga whales *Delphinapterus leucas*. In Farmer et al. (2022b), eight species distribution layers were combined into a single protected species layer using the product approach to inform spatial planning for Gulf of Mexico aquaculture activities. In the present study, we integrated across 23 protected species data layers that were developed using a variety of available data to inform the Gulf of Mexico WEA siting effort. Across the U.S. Gulf of Mexico, we found generally lower risk of protected species conflict in the west (see Figure 3). Within the call area, we found generally higher conflict along the continental shelf, with a substantial portion of the combined model risk being driven by the distribution of Rice's whales within the 100–400-m bathymetry. Nearshore areas off Louisiana and Texas were found to have relatively low potential for siting conflicts. Our approach is generalized such that it is portable across species and ocean planning considerations.

This generalized scoring approach does not consider risk associated with specific OSW energy-related activities. This was deliberate, as the WEA siting models are intended to inform wind energy planning prior to lease sales taking place. Under the ESA, federal managers are required to avoid, minimize, or mitigate any federally permitted activity that might jeopardize the continued existence or recovery of ESA-listed species. Similarly, the MMPA prohibits "take," which is defined as "to harass, hunt, capture, or kill… any marine mammal," with limited exceptions. The WEA siting models provide a transparent, public-facing tool with which to inform the siting of OSW energy activities in U.S. federal waters in a manner that reduces ocean space user conflicts to the greatest extent practicable. In this context, the combined protected species layer (see Figure 3) is more analogous to a map of management consultation risk, with the final product helping to avoid conflict by reducing the likelihood of substantial investment in OSW energy planning, design, and development in areas where protected species overlap is high. A general principle of ocean planning is to preemptively avoid user conflicts through early engagement (Young et al. 2007). Our method provides a transparent process to illustrate where any action requiring federal permitting may face regulatory challenges due to high co-occurrence of vulnerable species.

The availability and quality of data used to develop scoring layers varied by species. The Section 7 Mapper consultation layers (e.g., Gulf Sturgeon and Oceanic Whitetip Shark) were highly generalized and conservative; as such, they were assigned the generalized score of 0.5, denoting that consultation for the species would be anticipated in that area. Critical habitat (e.g., Gulf Sturgeon and Smalltooth Sawfish) and EFH (e.g., Oceanic Whitetip Shark) were previously defined by NOAA based upon scientific knowledge of physical and biological features that are necessary for the species' life history. These management areas, while useful for identifying conflicts that may arise, lack temporal specificity.

High-use areas for species without formal surveys or with surveys of limited scope (e.g., Smalltooth Sawfish) were represented by tag relocation data. However, acoustic and satellite telemetry data were biased in terms of focal species, life stages, and regions. Tagging locations were biased by capture location, the size-classes capable of carrying tags, and tag retention or track duration. Additionally, movements and spatial use by juvenile animals may differ substantially from those exhibited by adults. Rice's whale is the only species of baleen whale that is exclusively found in U.S. waters (Rosel et al. 2021). The population is estimated at fewer than 100 individuals, with mean estimates of fewer than 50 individuals remaining (Rosel et al. 2021). For Rice's whale, multiple lines of evidence from ship-based sightings, passive acoustic monitoring, and habitat suitability modeling were used to delineate the scored area. Given the long life span, low reproduction rates, declining population trend, and very small population size of this species, the death of a single Rice's whale poses an extremely high risk to population viability (Franklin 1980; Rosenfeld 2014). As such, overlap with the range of Rice's whale should be a key consideration when evaluating potential sites for OSW development.

Density models derived from the GoMMAPPS aerial and vessel surveys controlled for both perception bias and availability bias that may be especially problematic for small, cryptic, or diving animals. The two-team recapture approach taken with the GoMMAPPS surveys helped to control for perception bias, and the distribution models accounted for underlying aerial and vessel survey effort. The SDM framework linked sightings per unit effort to environmental and bathymetric drivers of distribution, providing an adaptive, statistically robust predictive framework for species distribution (e.g., Farmer

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et al. 2022a). Density models for marine mammals and adult sea turtles were corrected for both availability bias and perception bias. The habitat suitability model for the Giant Manta (Farmer et al. 2022a) was not corrected for availability bias; further efforts should be made to integrate tagging data and upgrade this to a density model. It should be noted that SDMs for marine mammals occurring primarily in waters deeper than the continental shelf break (primarily from vessel surveys) were developed separately from those for species occurring over the continental shelf (primarily from aerial surveys). The region of low risk scores (see Figure 3A) along the shelf break is partly an artifact of this separation between the models. Future modeling efforts should attempt to close this gap by generating continuous scored layers for species sighted in both domains. Similar to the efforts made to model the distribution of juvenile green, Kemp's ridley, and loggerhead sea turtles, ancillary data sources may be needed to better capture the offshore space use of juvenile and adult leatherback sea turtles, which are not easily sighted with shipboard surveys but are known to occur in deeper water (Aleksa et al. 2018). Inclusion of this layer would potentially have a large impact on model outcomes given the low score for the leatherback sea turtle (see Table 2).

For species with SDMs, we provided generalized guidance for ocean planning by predicting the maximum abundance or probability of occurrence within a given model cell across time (Giant Manta: January 2003–December 2019; others: January 2015–December 2019). As such, the final maps were designed to represent the multiannual generalized distribution of a species across an array of possible environmental conditions rather than any seasonal concentrations at any given point. Given that the overall ocean planning effort is intended to cover impacts across the entire timeline of OSW operations, this approach emphasized the area having the highest probability of occurrence or abundance. Locations above the median prediction of the distribution model were assigned the "high-use area" score associated with Table 2; the areas below the median were assigned the generalized score for the species (e.g., 0.5 for ESA-listed species and 0.9 for MMPA-listed species). This facilitated necessary contrast between high- and low-use areas for SDMs covering the entire call area. Data layers based on SDMs provide siting guidance superior to that obtained from layers based on management areas or field observations because SDM-based layers are more geographically comprehensive and control for underlying effort, environmental variability, perception bias, and availability bias.

For a long-term ocean planning exercise, the primary limitations of all approaches are spatial and temporal in nature. We chose to define high- and low-use areas at the scale of the U.S. Gulf of Mexico. Future analyses should evaluate the influence of different spatial windows for defining medians for the distribution and dispersal data layers and kernel density estimates for the sighting and tag relocation data layers. Evaluating geographic data at multiple scales in the development of a combined model may provide a reasonable compromise where broad-scale trends are revealed (e.g., western Gulf of Mexico being of lower relative concern; see Figure 3), but more fine-scale information is provided to the ocean planning siting model by creating greater scoring contrast within the call area.

The primary temporal limitation of our approach is that the outputs are static. For mobile megafauna, the use of real-time tagging may facilitate the identification of periods of reduced risk for various human activities (Sequeira et al. 2019). Similarly, for species with distribution model data layers, robust seasonal or monthly models could be used to provide refined site-specific guidance during the planning and design phases. In particular, environmentally driven distribution models can be used to identify spatiotemporal windows for different stages of wind energy development to minimize site-specific conflicts with protected species (Ward et al. 2015; Farmer et al. 2016). Changing environments may lead to shifts in species distributions (Davis et al. 2020); as such, both the data layers and the resultant WEA siting model guidance should be updated through time. A retrospective analysis of management strategies for reducing lethal ship collisions with endangered blue whales *Balaenoptera musculus* found significant improvements in expected whale protection from daily and seasonal management as compared to fixed management strategies because the species' distribution exhibited changes in response to changing environmental conditions (Hausner et al. 2021). Continuing systematic broad-scale aerial and vessel surveys in the Gulf of Mexico at regular intervals is critical for providing additional, updated data needed for model refinement to ensure that predictive models for protected species encompass the variety of oceanographic conditions that these species experience, thus providing the latest science for environmental impact assessments.

## Integrating the combined data layer into the wind energy area spatial model

A collaborative BOEM/NCCOS WEA spatial modeling process was created to identify potential lease areas for OSW energy development within the area under consideration in the Gulf of Mexico (Figure 4). The WEA siting process integrates spatial data across seven submodels: (1) National Security, (2) Industry and Operations, (3)

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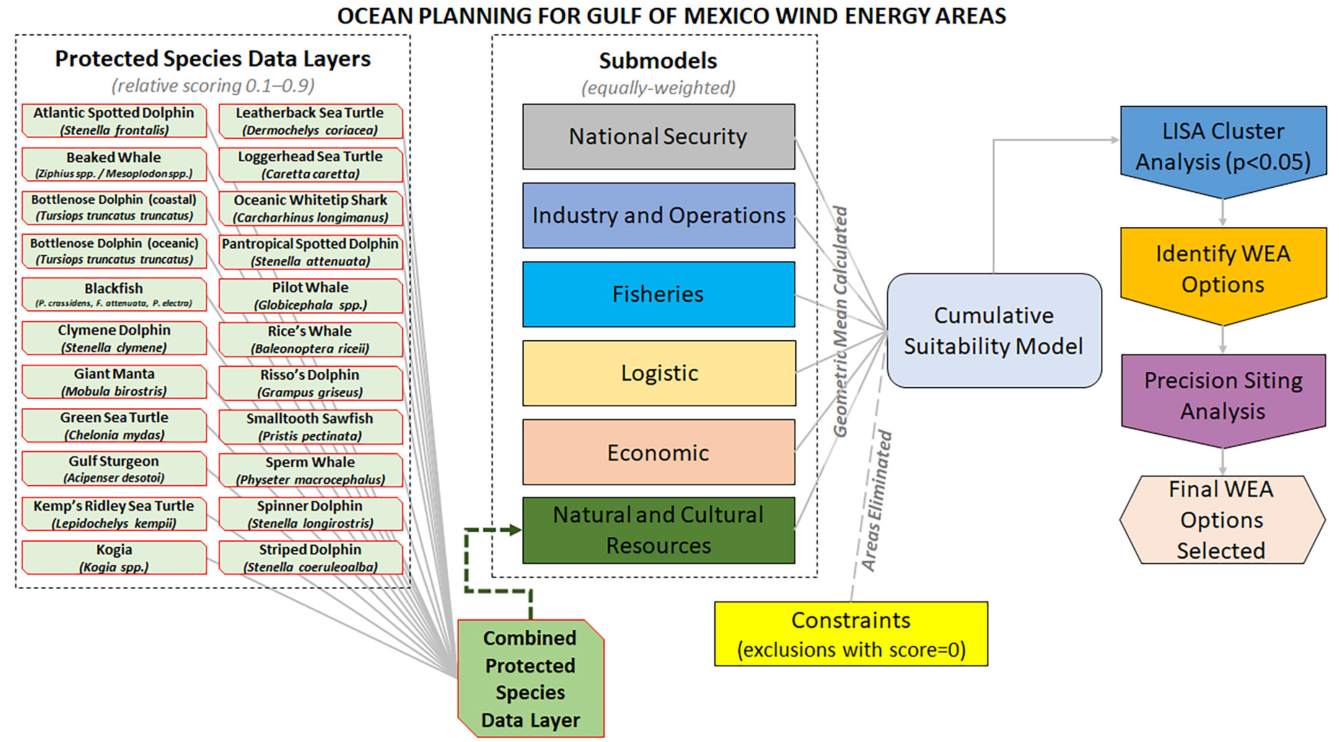

**FIGURE 4** The ocean planning process for the Gulf of Mexico wind energy area (WEA). The flow chart illustrates this study's protected species data layer inputs and integration of the combined protected species data layer (red outlines) into the broader ocean planning process used to identify the most suitable potential areas for offshore wind energy development within the Gulf of Mexico area under consideration for potential leasing. Note that equal relative weighting is imposed when combining the submodels, including the Natural and Cultural Resources submodel. LISA, local indicator of spatial association.

Fisheries, (4) Logistic, (5) Economic, (6) Natural and Cultural Resources, and (7) Constraints. The National Security submodel included military operating areas and special use airspace. The Industry and Operations submodel included Automatic Identification System vessel traffic maps by industry, navigational aids, anchorage areas, oil and gas leases and infrastructure, shipping fairways, and submarine cables. The Fisheries submodel included commercial shrimp, reef fish bandit and bottom longline, menhaden purse seine, and pelagic longline activity as well as headboat fishing and live rock aquaculture locations. The Logistic submodel included distance to shore, distance to the principal port, and depth. The Economic submodel included BOEM's competitive lease blocks and the National Renewable Energy Laboratory's OSW energy potential net value assessment for the Gulf of Mexico (i.e., areas where wind speeds are the greatest). The Natural and Cultural Resources submodel included the sensitive biological features in and around the Flower Garden Banks National Marine Sanctuary (including expansion areas), Coral Habitat Areas of Particular Concern, fish havens, Louisiana and Texas artificial reef boundaries, U.S. Fish and Wildlife Service GoMMAPPS combined pelagic bird species habitat suitability, BOEM's Potentially Sensitive Biological Features hardbottom data layer, and the NMFS combined protected species data layer that is the subject of this case study. A key additional component of the ocean planning approach used was the identification of constraints—that is, grid cells to be removed entirely from consideration as suitable for the particular purpose. The Constraints submodel included activities and occupied areas that were unsuitable for OSW siting (e.g., military zones, coral, and hard bottom; Riley et al. 2021) and were assigned a score of 0. The final modeling approach for OSW in the Gulf of Mexico applied a constraint specifically for Rice's whale whereby the 100–400-m isobath was excluded from consideration, thus providing additional consideration for Rice's whale that was not quantitatively reflected in the scoring model described above.

Based on an earlier draft of this analysis, BOEM and NCCOS included the protected species data layer using the product method in the Natural and Cultural Resources submodel (Figure 4). This submodel and five other equally weighted submodels were combined by NCCOS using a geometric mean approach to generate a cumulative suitability model. Any cells in the Constraints submodel were excluded from further consideration. Next, a local indicator of spatial association (LISA) method was implemented on the cumulative suitability model output for all study areas to identify

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statistically significant clusters ($p < 0.05$)—the grid cells with the highest suitability relative to others—within a given study area (Anselin 1995). Finally, potential WEA options were identified through a multi-criteria ranking approach and then filtered through a precision siting analysis that was modified from the technique for order of preference by similarity to ideal solution (TOPSIS) modeling approaches (Hsu-Shih et al. 2007; Singh et al. 2017; Díaz and Soares 2021). This approach identified the most suitable potential WEA options in each study area by ranking the "suitable" locations closest to an ideal solution based on distances (Sindhu et al. 2017; Konstantinos et al. 2019). The final WEA options selected represented less than 2% of the overall call area, and only 7 (30%) of 23 species in the combined protected species data layer were potentially affected: the Giant Manta, common bottlenose dolphin (shelf), Atlantic spotted dolphin (shelf), green sea turtle, Kemp's ridley sea turtle, loggerhead sea turtle, and leatherback sea turtle (Figure 4).

A general principle of ocean planning is that a comprehensive, model-based approach can integrate across multiple data layers to identify areas that are suitable to specific applications while preemptively reducing major user conflicts (Lombard et al. 2019). Inclusion of the combined protected species data layer in the Gulf of Mexico WEA siting modeling reduced potential conflict in the OSW energy development process. The WEA siting models are intended to become living data sources and reference guides. Integration of new data will allow the models to be used most effectively for future projects or siting efforts to reduce potential conflict between competing ocean uses to the greatest extent practicable. The WEA siting models will also be useful for furthering the understanding of the long-term effects of OSW development on protected species. Our method provides a transparent process to illustrate where any action requiring federal approval could face numerous challenges due to high co-occurrence with vulnerable species. By 2050, over 350,000 $\text{km}^2$ of ocean space may be developed to cultivate seafood and produce wind energy, compared to just 40,000 $\text{km}^2$ in 2018 (a ninefold increase; DNV 2021). Since submission of this article, the present approach has already been applied to inform WEA planning in the central Atlantic and Gulf of Maine call areas. Ocean planning that considers the overlapping needs of protected species is essential to ensure conservation of our planet's most sensitive species and habitats while stabilizing the seafood supply and building a clean energy economy in the United States. It is important to note that habitat utilization is dynamic, particularly in a changing environment. Ongoing surveys and updated models will be important for facilitating effective adaptive management, thereby ensuring that ocean planning tools such as this combined protected species data layer reflect current conditions.

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## CONFLICT OF INTEREST STATEMENT

The authors state they have no conflict of interest.

## ETHICS STATEMENT

All ethical guidelines were followed and no animals were handled in the development of this study.

## DATA AVAILABILITY STATEMENT

Aggregated data were provided in the Supplement. Additional data are available upon request to the lead author.

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