Field	Study Information
Title	Offshore Wind Farm Impacts on the Hydrodynamics and Biogeochemistry in Puerto Rico and the U.S. Virgin Islands (NT-25-06)
Administered by	Office of Environmental Programs
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Procurement Type(s)	Cooperative Agreement
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Final Report Due	TBD
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Problem	Offshore wind (OSW) has the potential to alter local and regional hydrodynamic and biogeochemical processes in Puerto Rico and the U.S. Virgin Islands (PRVI).
Intervention	A coupled hydrodynamic-biogeochemical modeling study is proposed to evaluate the impact of future OSW on hydrodynamics and biogeochemistry (including primary productivity and larval transport) in the PRVI.
Comparison	The model will be used to demonstrate oceanographic conditions prior to OSW construction, post-installation of a single facility, and post full build-out of OSW, in the context of the strong interannual and decadal variability.
Outcome	The study will provide BOEM with quantitative estimates of the impacts of future OSW on hydrodynamics and biogeochemistry in the PRVI, which is necessary for future NEPA analyses and for guiding future PRVI coastal monitoring efforts.
Context	Modeling efforts will cover the coastal region of PRVI.

BOEM Information Need(s): To support the sustainable development of OSW over the Outer Continental Shelf, BOEM must estimate the environmental impacts of OSW. BOEM needs to comprehend potential changes in physical oceanographic processes, both local and regional, that may affect nutrients, phytoplankton, and larval transport patterns. This modeling study aims to help BOEM estimate OSW impacts on primary productivity (which supports fisheries, seabirds, and marine mammals), assure stakeholders, and guide discussions on potential mitigations.

Background: BOEM is a resource management agency and conducts scientific research for managing OCS energy and mineral resources. The Inflation Reduction Act expanded BOEM's geographic scope to include the territories of Puerto Rico, U.S. Virgin Islands, Guam, Northern Mariana, and American Samoa. The federal government has set ambitious goals for renewable energy development. BOEM needs to assess the environmental impacts of OSW for energy planning and to make leasing and management decisions (NASEM 2023).

OSW draws energy from the surface winds, thereby creating a "wake" of reduced wind speed (Raghukumar et al. 2022). OSW structures alter oceanic turbulence and vertical mixing of currents flowing past the turbine structures (Dorrell et al. 2022). Both of these effects may alter local and regional ocean circulation enough to impact the marine ecosystem. As OSW development is still in early stages in the U.S., BOEM has relied on computer modeling experiments to assess OSW impacts on ocean circulation and larval dispersal (Chen et al. 2016; Johnson et al. 2021).

The coastal region of PRVI is characterized by diverse and dynamic oceanographic features. It is influenced by several major hydrodynamic features, causing complex and dynamic water movement patterns. PRVI experiences mixed semi-diurnal tides, with both diurnal and semi-diurnal tidal components. Several major currents influence the region, including the North Equatorial Current, the Antilles Current, and the Caribbean Current. These currents transport heat, nutrients, and larvae, playing a crucial role in the region's ecology. Winds blowing across the Caribbean Sea can drive upwelling events, bringing nutrient-rich water to the surface. This upwelling is important for supporting phytoplankton blooms and primary productivity. Locally, wind-driven currents and wave-driven currents are also important, particularly in shallower coastal areas. Local upwelling and downwelling events occur along the coasts, mainly driven by winds and variations in bottom topography. These events impact water temperature, nutrient availability, and overall water quality in coastal areas (e.g., Richardson 2005; Solano et al., 2018, Rueda-Roa and Muller-Karger 2013).

Potential concerns arise regarding to the alteration of oceanographic transport patterns in the coastal PRVI region as a result of OSW projects. To address these concerns, BOEM needs to accurately assess potential changes in hydrodynamic flows resulting from the build-out of one or multiple offshore wind energy facilities. Evidence shows that offshore structures change local current velocities and flows, as well as wind velocities and their effect on the water surface and vertical motions. Less understood are the cumulative impacts of large and multiple projects on regional circulation patterns. This is especially important concerning how changes in flow may impact the transport of juvenile fish and larvae to and from habitats used at different life stages and the transport of nutrients and phytoplankton throughout the region. This study will address an important knowledge gap for BOEM, namely OSW impacts on hydrodynamics and biogeochemistry in PRVI. Results will help inform potential mitigations (if necessary).

Objectives: The primary objective of this study is to determine, via computer modeling experiments, the impacts of OSW on hydrodynamics and biogeochemistry in the PRVI region, including nutrient availability and primary productivity, and therefore the vulnerability of marine species. The results from this study will be used to evaluate the need for and the formation of mitigation measures.

Methods: A regional computational modeling approach will be used. The spatial domain will cover the coastal region of PRVI. Experiments with simulated wind impacts from OSW will be compared to a control scenario without OSW. The model will simulate hydrodynamical and biogeochemical aspects of the PRVI region response to OSW. An established ocean model in this region should be a good candidate for this effort. One goal of this study is to support open source modeling tools. Open source means that the model codes are publicly available. BOEM would be able to rerun the model simulations internally in the future or provide the code base and model configuration to future vendors/contractors to build upon. Open source modeling therefore provides greater value to the taxpayer, while aligning with the concept of Open Science, which aims to make the fruits of scientific investment available to the wider public (The White House 2022).

This study will include a review of previous publications. This study will also incorporate seasonal conditions, improve upon the particle release and tracking methods, and examine new scenarios involving realistic layouts of multiple facilities. Three model segments will be necessary to address the objective: wind wake, ocean circulation, and biogeochemical processes. The wind wake model will be used to estimate the change in surface wind velocities for input into a high resolution, three-dimensional ocean circulation model capable of resolving small-scale physical processes throughout the water column. The small-scale processes include, but are not limited to, interactions between the structure of individual turbine and currents, the reduction of wind forcing due to turbine structure, and wind wave-turbine interactions. The biogeochemical model describes the evolution of nutrients (N), phytoplankton (P), zooplankton (Z) and detritus (D), which will also be used to release and track particles representing larvae (e.g., Cerco and Cole 1994; Powell et al. 2006).

Example scenarios include an initial condition absent any OSW facilities, a realistic layout of a single project, and a realistic layout of multiple projects. Additional scenarios may include layouts of varying turbine sizes with appropriate number and spacing, and varying particle characteristics. This study will assess the scale of change of offshore wind development on particles traveling through and near to the facilities. The model will also assess the impacts on biogeochemistry in the region as a result of OSW construction and operation. Models should utilize measured data in the region, such as acoustic Doppler current profiles, wind measurements, and geophysical data, which should be available from existing partners/projects.

Specific Research Question(s): This study focuses on different levels of questioning. The first focus is on understanding the hydrodynamic effects—how to estimate the effects of OSW on local hydrodynamics and the key parameters to be included in a model. The second main question is, given estimated changes to the hydrodynamics, what the potential local and regional effects on the ecosystem will be. More specifically:

1. Recent modeling experiments (e.g., Raghukumar et al., 2023) indicate offshore wind farms could result in a modest reduction in upwelling in the vicinity of OSW. How will these changes in upwelling impact biogeochemistry, including nutrient availability and primary productivity?
2. What are the magnitude, spatial footprint, and seasonal expression of OSW-induced changes in biogeochemistry?
3. How does the magnitude of the simulated OSW-induced changes to biogeochemistry compare to the large interannual variability in this region? (Option: How does it compare to projected climate change scenarios?) Would OSW-induced changes to biogeochemistry be detectable given the large interannual variability in the region?
4. How can the hydrodynamic and biogeochemical monitoring efforts around OSW be optimized to detect potential changes to the hydrodynamics and biogeochemistry in this region?

Current Status: N/A

Publications Completed: N/A

Affiliated WWW Sites: N/A

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