Technical Summary

Study Title	Offshore Wind Impact on Oceanographic Processes: North Carolina to New York
Report Title	Offshore wind impact on oceanographic processes: North Carolina to New York - RPS
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Sponsoring OCS Region or Office	Atlantic Region
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Keywords	Offshore wind energy, wind turbines, Mid-Atlantic Bight, scenario modeling, Delft3D-FM, SWAN, hydrodynamics, waves, currents, bed shear stress, sediment mobility, turbulent mixing, stratification, cold pool, habitat, larval transport, Ichthyop, Atlantic sea scallop, Atlantic surf clam, black sea bass

ABSTRACT: Proposed offshore wind development on the U.S. North Atlantic Ocean shelf from North Carolina to New York has raised concerns among stakeholders about changes to environmental conditions. The study objective was to determine effects of offshore wind energy facilities on coastal and oceanic environmental conditions and habitat by examining how oceanic characteristics will change after turbine installation, particularly for bottom stress, turbulent mixing, along and cross-shelf transport, wind-wave interactions, and larval transport. We treated three scenarios for the two-year period from February 2018 through January 2020, inclusive: baseline conditions without wind energy areas, partial buildout (five clusters, some partially occupied) of proposed wind energy areas, and complete buildout (8 clusters, fully occupied) of BOEM-specified wind energy lease blocks. We modeled effects of individual turbines and wind farm areas using PyWake for 15 megawat turbines with fixed-bottom monopiles. We constructed winds affected by wind energy arrays across the entire domain by superposing on unmodified winds the spatially and temporally varying wind reductions, which can overlap, computed for multiple clusters of turbines. These winds, together with effects of turbine foundations simulated by enhanced bottom drag, forced surface wave and hydrodynamic models. The waves model is Simulating WAves

Nearshore (SWAN), driven by surface meteorology and boundary waves from an operational meteorological model. The hydrodynamic model is Delft3D-FM, with boundary forcing from a validated data-assimilative operational ocean model, and the same meteorological model and grid as for SWAN.

Results quantify reductions to climatological winds at 10 m height, for complete buildout, that reach or exceed 20% within some wind energy areas and 10% at their downwind edges. Reductions weaken sharply with further distance but reach as far as 100-200 km. Effects on surface waves are mostly local to where weaker winds occur and include reduced wave heights and longer wave periods. Currents are more strongly affected by reduced winds than flow interactions with turbine foundations, which were simulated by enhanced bottom drag. Weaker winds shift the dynamical balance of the southward alongshelf mean general circulation making it stronger. They also cause higher water temperatures over most of the domain and shoaling and strengthening of the thermocline, likely due to suppressed vertical mixing, but changes to seasonal cold pool evolution are minor. Wind farms cause statistically significant changes in annual- and seasonal-mean winds; surface heat fluxes; surface and bottom temperatures; surface, bottom, and vertical-mean currents; water column stability; and thermocline depth. Weekly-mean impacts on most of these parameters are comparable to or stronger than baseline variability. Effects of weaker winds on bed shear stress and sediment mobility generally consist of modest reductions within turbine arrays and farther inshore.

We assessed larval connectivity of Atlantic sea scallop, Atlantic surf clam, and black sea bass using a biophysical larval dispersal model with literature-based species-specific inputs. Baseline results for all species with passive larvae showed general larval transport from north to south and higher larval connectivity in the north. Key differences between complete buildout and baseline were decreased retention in the north and longer larval dispersal distances. With diurnal vertical migration behavior included, dispersal distances and mean connectivity increased, and with temperature-dependent mortality larval connectivity decreased due to high mortality. Overall, the main effects of wind energy areas that have sufficient magnitude to potentially alter the population dynamics of Atlantic sea scallop, Atlantic surf clam, and black sea bass are changes to the hydrodynamics. This includes warming temperatures, which may accelerate the ongoing northward migration of species driven by climate warming.

BACKGROUND: We build on two previous BOEM-funded studies (#M14PC00011, #140M0120C0004) to examine a large geographic region, use a different suite of models, and treat different larval species.

OBJECTIVE: Determine the effects of offshore wind energy facilities on coastal and oceanic environmental conditions and habitat by examining how oceanic characteristics will change after turbine installation, particularly for bottom stress, turbulent mixing, along and cross-shelf transport, wind-wave interactions, and larval transport.

METHODS: We used PyWake with resolution 250 m, Turbo Gaussian wake deficit model, and an All to All Iterative engineering wind farm model. Turbine speed, generator power, and thrust coefficient are for the reference 15 MW turbine with 150 m hub-height and 240 m rotor diameter. The surface waves model is Simulating WAves Nearshore (SWAN) forced using winds over the domain surface, and waves at the offshore open boundary, from the fifth generation European Center for Medium Range Weather Forecasts reanalysis (ERA5). The hydrodynamic model is Deltares Delft3D Flexible Mesh (Delft3D-FM), with increased resolution in the wind energy installation areas, and hybrid vertical grid. Forcing includes water level and temperature and salinity profiles from the Doppio data-assimilative operational coastal model, and ERA5 wind and meteorological conditions. We calibrated and validated models using skill metrics and extensive observations of water level, currents, temperature, salinity, surface meteorology, and waves from tide gauge, mooring, satellite, high frequency radar, and glider sources. We identified the three species for larval modeling through a literature review and consultation with BOEM and NOAA colleagues. To model the larval dispersal of the three species of interest (Atlantic sea scallop, Atlantic surfclam, and black sea bass), a biophysical larval dispersal model was developed using the individual-based Lagrangian model Ichthyop coupled with Delft3D-FM. Biological parameters included in the model were spawning location, spawning depth, spawning time, larval dispersal duration, larval temperature tolerance (survival range), larval settlement depth, settlement habitat, and larval diurnal vertical migration behavior. Different model configurations were performed with the three hydrodynamic scenarios: passive larvae, diurnal vertical migration behavior, and temperature-dependent mortality. Connectivity matrices were primarily used to interpret the model results.

RESULTS: Wind reductions depend on wind speed and are largest, due to the turbine thrust coefficient curve, for wind speeds between the cut-in speed of about 3 m/s and about 11 m/s, the speed at which the rated power is reached. For complete buildout, climatological wind reductions at 10 m height can reach or exceed 20% in limited areas within turbine arrays, and 10% downwind. They weaken exponentially within tens of km away from the arrays but can extend as far as 100–200 km downwind. Reduced winds decrease locally driven wind waves, particularly near turbine arrays but also inshore, especially for arrays aligned with principal wind directions. Weaker winds lead to strengthened southward along-shelf mean currents. Wind reductions increase temperatures over much of the domain and cause the thermocline to shoal and strengthen, both characteristics consistent with suppressed wind-driven vertical turbulence in the surface mixed layer. Seasonal cold pool formation and evolution is not fundamentally altered. Effects on bed shear stress and sediment mobility are generally reductions near the coast, and in areas near the installations, that are more pronounced for the 95th and 99th percentiles than median values, and due to reduced waves not reduced currents. Results from the biophysical larval dispersal model with baseline for passive larvae (no behavior) showed that, for all three species, larvae were generally transported from the northern to the southern region of the study area, and larval connectivity was higher in the northern region. Key differences between complete buildout and baseline were decreased retention in the north and longer larval dispersal distances. Adding diurnal vertical migration behavior in the model increased mean larval connectivity, to about 3.0–3.5% from 0.5–1.5%. Adding temperature-dependent mortality decreased larval connectivity due to high mortality of larvae.

CONCLUSIONS: Development of wind energy areas will cause reduced wind speeds locally within and downwind of turbine areas. Reduced winds affect waves, currents, oceanographic processes, sediment mobility, and larval dispersal. Highest impacts are found generally for the full build-out scenario, with some exceptions due to variations in local conditions. The simulated minor reductions on wave conditions, bed shear stress, and sediment mobility are likely unimportant relative to natural variability. The main effects of hydrodynamic changes on larval dynamics include decreased retention in northern areas and longer dispersal distances. Impacts on regional oceanographic processes, for example seasonal stratification and cold pool evolution, are generally minor because effects of buildout are more pronounced within wind energy arrays and weaker outside them. However, increases to water temperature and stratification strength may be of sufficient magnitude to potentially affect ecological processes.

STUDY PRODUCT(S):

1. **BOEM study report:** Georgas N, Garavelli L, Codiga D, Day E, Engel L, Hemery L, Misa W, Monim M, Moghadam H, Morandi A, Ilia A, Speers J, Tajallibakhsh T (RPS Ocean Science, South Kingston, RI, and Pacific Northwest National Laboratory, Seattle, WA). 2025. Offshore wind impact on oceanographic processes: North Carolina to New York, volume 1. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management.360 p. Obligation No.: 140M0123C0001. Report No.: BOEM 2025-016.
2.
3. **Model and related files**: Observation dataset files used for model calibration/validation. Hydrodynamic and larval model output files for all scenario runs. Visualization software.

4. **Study presentation slides**
5. **Draft manuscript**: Navigating Larval Dynamics amid Offshore Wind Development, Garavelli, L., Engel, L., Hemery, L., Monim, M., Day, E., Codiga, D., and N. Georgas. --- Submitted, Fisheries Oceanography.
6. **Poster.** 104th American Meteorological Society Annual Meeting, Baltimore, MD, 1/28-2/1, 2024.
7. **Presentation.** 154th American Fisheries Society Annual Meeting, Honolulu, HI, 9/15-19, 2024.

MAP OF STUDY AREA: Cover Figure of report OCS Study BOEM 2025-016.