New York Bight Offshore Wind Farms:

Collaborative Development of Strategies and Tools to Address Commercial Fishing Access

Final Report | Report Number 22-24 | September 2022

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Collaborative Development of Strategies and Tools to Address Commercial Fishing Access

Final Report

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Abstract

The New York Bight and New England marine spaces host a diverse fishing industry that includes a variety of gear types and fishing vessels from around the region. Offshore wind (OSW) energy development has the potential to affect commercial fishing activity at each phase of development, including restricting access to some fishery participants during construction and through the placement of fixed structures. For the two industries to coexist in an economically meaningful way, reducing risk for fishermen working within or transiting through an OSW development is critical. The overall goal of this study was to develop technical strategies and tools to minimize the disruption to commercial fishing, while also ensuring economical energy generation and safe operations for the developers and for mariners transiting in and around the OSW arrays. The study primarily focused on the Atlantic scallop and surfclam/ocean quahog fishing industries in the New York Bight, with study tasks including information gathering (e.g., literature review, interviews, and data availability assessment), techno-economic scenarios analysis, and a pilot project assessment with considerations for fixed bottom turbines and inter-array cables.

Keywords

Commercial fishing, offshore wind energy, scallop, surfclam, ocean quahog, turbines, cables

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Acronyms and Abbreviations

ACL	annual catch limit
AEP	annual energy production
AIS	Automatic Identification System
ALARP	as low and reasonably practicable
ASM	at-sea monitoring
AWOIS	Automated Wreck and Obstruction Information System
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
BOS	balance of system
CapEx	capital expenditures
CBRA	cable burial risk assessment
CONMAP	Continental Margin Map
COP	construction and operations plan
CPS	cable protection system
CVOW	Coastal Virginia Offshore Wind
DAS	days-at-sea
DMIS	data matching imputation system
DOE	U.S. Department of Energy
DOD	U.S. Department of Defense
DOF-COM	Declared Out of Fishery (VMS code)
EMF	electromagnetic field
FAA	Federal Aviation Administration
FAD	fish aggregating device
FCR	fixed charge rate
FLDRS	fisheries logbook data recording software
FLORIS	flow redirection and induction in steady state
FMP	fishery management plan
ft	feet
FVCOM	finite volume coastal ocean model
GARFO	Greater Atlantic Regional Fisheries Office
GDP	Global Drifter Program
GIS	Geographic Information System
GMG	Global Marine Group, LLC
GOFISH	graphical offshore fishing information system homepage
GTCR	Georgia Tech Research Corporation
GWh	gigawatt-hours
HRG	high resolution geophysical

HYCOM	hybrid coordinate ocean model
IAC	inter-array cable
ICPC	International Cable Protection Committee
IEA	International Energy Agency
IFM	industry funded monitoring
IFS	industry funded scallop
I/UCRC	Industry/University Cooperative Research Center
km	kilometer(s)
kV	kilovolt(s)
kW	kilowatt(s)
kWh	kilowatt hours
LCOE	levelized cost of energy
MMIS	Marine Minerals Information System
m	meter(s)
MAFMC	Mid-Atlantic Fishery Management Council
MARCO	Mid-Atlantic Regional Council on the Ocean
MARIPARS	Massachusetts and Rhode Island Port Access Route Study
MCA	Maritime and Coast Guard Agency (UK)
MREI	marine renewable energy infrastructure
m/s	meters per second
MW	megawatt(s)
MWh	megawatt hour(s)
NCCOS	National Centers for Coastal Ocean Science
NCOM	Navy Coastal Ocean Model
NEAMAP	Northeast Area Monitoring and Assessment Program
NEFMC	New England Fishery Management Council
NEFOP	Northeast Fisheries Observer Program
NEFSC	Northeast Fisheries Science Center
NEUS-LME	Northeast United States-Large Marine Ecosystem
nm	nautical mile(s)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NROC	Northeast Regional Ocean Council
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
OCS	outer continental shelf
OQ	ocean quahog

OpEx	operational expenditures
ORBIT	offshore renewables balance of system and installation tool
OSS	offshore substation
OWF	offshore wind farm
OSW	offshore wind
PAC	project advisory committee
RCS	radar cross section
RNC	Raster navigation charts
RODA	Responsible Offshore Development Alliance
ROMS	Regional Ocean Modeling System
ROSA	Responsible Offshore Science Alliance
RPB	regional planning body
RSA	research set aside
SAR	search and rescue
SC	surfclam
SCEMFIS	Science Center for Marine Fisheries
SEIS	Supplemental Environmental Impact Statement
SOV	service operation vessel
TSS	traffic separation scheme
USCG	United States Coast Guard
USGS	U.S. Geological Survey
UXO	unexploded ordnance
VHF	very high frequency
VMS	vessel monitoring system
VTR	vessel trip report
W	watts
WAR	windmill artificial reef
WEA	wind energy area
WTG	wind turbine generator
WTRIM	Wind Turbine Radar Interference Working Group

Summary

The New York Bight and New England marine spaces host a diverse fishing industry that includes a variety of gear types and fishing vessels from around the region. Offshore wind (OSW) energy development will potentially affect commercial fishing activity at each phase of development, including restricting access to some fishery participants during construction and through the placement of fixed structures. For the two industries to coexist in an economically meaningful way, reducing risk for fishermen working within or transiting through an OSW development is critical. The overall goal of this project was to develop technical strategies and tools to minimize the disruption to commercial fishing while also ensuring economical energy generation and safe operations for the developers operating within OSW arrays. The project was performed collaboratively with Project Advisory Committee (PAC) membership from the commercial fishing industry, OSW developers, and State and federal agencies.

For the first project task, the objective was to gather information from a literature review and interviews with members of the commercial fishing industry to identify key considerations related to potential risks to fishing practices during development of OSW projects as well as associated minimization measures. The literature review assessed approximately 150 literature resources associated with European wind farms and initial OSW development in U.S. waters. The literature review did not look at project-specific permitting requirements but provided a more general survey of what is known and not known from a generalized scientific standpoint. Some of these items may or may not have already been addressed in individual projects. Consideration was given to risks to the commercial fishing industry across a broad range of categories, including operational risks to fishing due to structures and hazards, as well as regulatory, socioeconomic, insurance, and species redistribution impacts. Operational risks to fishing due to structures and hazards were within the main scope of this project, and the primary takeaways, including impact minimization measures, are summarized as follows:

- **Overall Size, Shape, and Location of Project Area**—One of the main concerns for the fishing industry in the United States and Europe is the total footprint that OSW project areas will have and their proximity to and spatial overlap with historic fishing grounds. To conduct their business operations, fishermen need access to their target species in areas where they can safely operate mobile or fixed gear in the weather conditions in which they operate. Because new hazards are being introduced, the potential for collisions, allisions, or gear hanging on turbine base structures, cables, or scour protection has been expressed as a concern for fishing vessels. Individual OSW projects in the United States are required to complete project-specific navigational safety risk assessments (NSRAs), based on the individual specifications of a project, with the United States Coast Guard (USCG), the entity responsible for providing recommendations concerning mitigation measures. In general, impact minimization measures include, but are not limited to:
    - Siting away from areas of high fish concentration; however, where this is not possible, to consider colocation needs.
    - Considering limits to geographic size of individual and total projects.
    - Utilizing state-of-the-art methods for windfarm layout design.
- **Turbine Array Layout Impact on Harvesting and Transit of Fishing Vessels**—Factors of project layouts that have been identified as influencing fishing operations include the directionality, grid uniformity, and spacing of turbine arrays. In addition, the ways in which a project layout impacts fishing can depend on vessel size, gear type, and whether a vessel is harvesting or in transit through the area. Impact minimization measures include, but are not limited to:
    - Utilizing fishermen's expertise to develop specific project designs.
    - Testing out navigation and gear use within windfarm arrays (e.g., including modifications to gear and training required to meet ability to fish within project area).
    - Incorporating fishing vessel transit requirements.
    - Executing long-term monitoring programs in combination with targeted research, paired with adaptive management strategies to address observed/detected impacts.
- **Cabling**—Inter-array and export power cables pose considerations for the operability of fishing vessels within an array and along cable routes. Interactions between cables and fishing gear create risk to the vessel, crew, and cables. The physical presence of wind turbines and the buried cables running between them has posed concerns for fishermen regarding the risks of snagging nets and collisions and allisions. Impact minimization measures for cabling include, but are not limited to:
    - Designing cable routes to maximize the potential for responsible cable burial.
    - Optimizing export and inter-array cable layouts that account for existing fishing activity, including minimizing the amount of cable laid.
    - Laying power cables using the method that causes the least damage to the seabed.
    - Laying high voltage direct current (HVDC) cable with opposing electrical currents alongside each other and with sufficient burial.
    - Planning cable location and directionality with delineation of cable locations on charts.

- Considering decommissioning plans, including removal after use, and bringing the cable to shore.

- **Protective Materials**—Offshore wind projects require the introduction of materials to the seafloor to protect the turbine and cable infrastructure against changing benthic conditions and accidental damage from marine industries and their offshore activities. Otter trawls, beam trawls, scallop dredges, gill nets, and demersal longlines all involve weighted nets, chain bags, or lines that may snag on additional cable protection materials and scour protection. Impact minimization measures for protective materials include, but are not limited to:
  - Performing additional research and development on material design to understand fishing and environmental impacts, including reef effect.
  - Requiring removal of debris from the seabed resulting from OSW construction and operation.

In the northeast United States, there is limited research on fishing operational needs and risks for fishermen operating within and around OSW arrays. Thus, semi-structured interviews were conducted to gather data on scallop and surfclam/ocean quahog (SC/OQ) as well as fishermen's operational characteristics to aid in filling these gaps. The federal limited access to Atlantic sea scallop and SC/OQ fisheries were identified as being most appropriate for this study for several reasons, including their importance in the NY Bight and representation by a relatively easily defined group of participants. These interviews gathered qualitative data from sea scallop fishermen (seven respondents) and SC/OQ fishermen (collective industry response) on fishing operations (e.g., tow characteristics, operating with other vessels/gear, sea-state conditions) and fishermen's concerns with operating within or around a wind array. Based on these interviews, respondents generally preferred larger spacing between turbines, were concerned about towing over cables and cables becoming unburied, and had concerns about hanging up on scour protection, but differences were also observed in the level of concern depending on the respondent and type of risk.

Based on the risks identified by the fishing community, an assessment was performed to identify the relevant existing data sets in each fishery and fishing practices utilized in the area of interest to help inform development of mitigation strategies. Fishery-dependent and independent data sets were reviewed for the areas of interest to better understand how existing data may be best utilized. For fishery dependent data, the following sources were assessed: vessel trip reports, vessel monitoring system, dealer data, observer data, study fleet data, automatic identification system, and information derived through documentation of fishermen's (or others') ecological knowledge. Fishery independent data are those that do not require the participation or monitoring of fishery operators in their collection of data.

Sources assessed included federal surveys, Northeast Area Monitoring and Assessment Program, and other State-based surveys. Consideration was also given to cooperative research, select data products and aggregations, and confidential fishery data and related projects. Gaps in priority data sets were also identified to inform future data collection and modeling efforts.

For the second project task, several possible strategies were analyzed that OSW developers could potentially use to help increase Atlantic sea scallop and SC/OQ fishing access within OSW arrays in the New York Bight. The access scenarios were developed based on input from fishing participants and the PAC. The cost and performance impacts of the different access scenarios were quantified relative to a baseline scenario in terms of annual energy production (AEP), capital expenditures (CapEx), and levelized cost of energy (LCOE). The baseline scenario and five additional scenarios were defined based on varying the turbine row spacing and no-build area location for scallop and SC/OQ fishing access. The turbine layout of the baseline scenario was optimized for Scenario 1 and retained the same turbine positions as the baseline scenario but relocated the offshore substation (OSS) to alter the array cable layouts. Scenario 2 increased spacing between turbine rows. Scenario 3 provided more open area for fishing vessel operations—a 2 nautical mile (nm) no-build area. Scenario 4 provided an expanded open area for fishing vessel operations—a 5 nm no-build area, with Scenario 5 incorporating a repositioning of the no-build area. Finally, Scenario 6 provided more open space for fishing by using fewer, larger turbines spaced further apart (turbine upsizing).

The scenarios examined showed that, except for Scenario 6, Turbine Upsizing, increasing turbine or no-build area spacing decreases AEP relative to a baseline scenario optimized for AEP. This is due to increased wake losses and leads to higher LCOE in all but Scenario 6 relative to the baseline scenario. Across all scenarios, the changes in AEP relative to the baseline scenario ranged from -6.4% to +2.0%. Changes in array cable system costs ranged from -22.6% to +34.4%, and changes in cable installation CapEx ranged from -21.1% to +7.2% of the baseline scenario costs. LCOE varied +/-5% across the scenarios relative to the baseline. Since the array cable costs only represented 2–4% of the Total CapEx, changes in AEP drove differences in LCOE. Additionally, turbine upsizing from 12 MW to 15 MW turbines (Scenario 6) appears to present multiple advantages for fishermen’s access and developers’ project costs if turbine positions can be more favorably arranged to help reduce cable crossings and increase the area available to fishing. These trends would likely be amplified if turbine rated power continues to increase beyond 15 MW in the future.

For the third project task, the pilot project built upon the previous OSW information gathering and scenarios tasks which identified risks to scallop and SC/OQ fishermen and analyzed how different turbine layouts and cable configurations could be employed to minimize effects on the fishing industry. The pilot project investigated the seabed characteristics within the Hudson North and Hudson South Bureau of Ocean Energy Management (BOEM) call areas in the New York Bight. The investigation focused on the seabed conditions which could affect the wind turbine foundation, OSS foundation(s), and cable installation and burial as these are the components of OSW infrastructure most likely to affect mobile bottom tending fishing gear. Rather than using historical fishing data, the fishing potential of the sites was assumed to be uniform across all the sites. This prevented any bias where the route engineering practices would be best employed to maximize fishing access and allows for future variation of fishing effort distribution.

The seabed characteristics investigation used numerous publicly available data sets and Geographic Information System (GIS) software to map the seabed sediments and geomorphological features, the presence of natural seabed scouring, marine currents and obstructions such as boulders, wrecks, unexploded ordnance (UXO) and existing cables. Abundant information on the characteristics was found within the pilot areas. A set of engineering practices are presented which may improve the security of the OSW infrastructure given the specific seabed challenges the areas pose. These engineering practices in turn reduce the chance of interaction between fishing gear and the OSW infrastructure, in particular power cables. The result is a "toolbox" of scallop and SC/OQ "fishing friendly" engineering approaches which can be adopted by future OSW projects as needed, building on prior task outputs.

The large number of existing fiber optic telecommunication cables installed across the pilot project area over the last 37 years provided an insight into historical cable burial depths achieved and how frequently those cables have faulted since installation. The historical data suggests an average burial depth of 0.944 m (3.098 ft) has been sufficient to protect the 22 fiber optic cables installed across the pilot project area over the last 37 years, as no cable faults have been recorded by OceanIQ's cable fault database within the pilot project areas. Additionally, BOEM has recommended a burial depth of at least 6 feet (ft) for both inter-array and export cables when technically feasible. The existing cables across the pilot project sites are distributed widely and are likely to be crossed by future OSW developments. Careful consideration on how best to engineer these crossing points will be required. This may involve clearing out of service cables or crossing in service cables; a particular emphasis is given on how to do this while minimizing the effect on fishing activities.

Two summary tables present the risks found to cables and to fishing across the pilot project sites. Examples of these risks include bottom mobile tending gear snagging on exposed cables, unsuccessful cable burial for various reasons, and damage to fishing gear from post lay scour protection. Having assessed the risks and regional characteristics, a series of engineering practices were presented which could be used to ensure future developments are successful in producing reliable electricity over their design life, while trying to limit the impact on scallop and SC/OQ fishing. These are also likely to be the engineering practices used for other bottom tending gear fisheries; however, further evaluation would be necessary to ensure these findings hold true for those additional fisheries.

1 Introduction

Increased global energy needs coupled with rising climate change concerns have furthered the need for additional clean energy sources. The United States has introduced several renewable energy options in the past decades, but recently, there has been a renewed push toward developing ways to harness energy offshore. While offshore wind (OSW) energy projects have been in operation for decades across Europe, the first project in the United States was the Block Island Wind Farm (BIWF), which is comprised of five 6-MW turbines and began operation in 2016. In summer 2020, two additional 6-MW turbines were installed in federal waters off Virginia as part of the Coastal Virginia Offshore Wind (CVOW) pilot project. Despite the limited development to date, there are established and planned leases to be sited in wind energy areas (WEAs) off several Mid-Atlantic and southern New England states, which are the focus of this report; leasing is also occurring in other regions of the United States.[1] On March 29th, 2021, the White House held an Offshore Wind Roundtable which outlined a series of actions, grants and initiatives to achieve its stated goal to deploy 30 GW of offshore wind by 2030, and a longer-term goal of 110 GW by 2050.[2] On May 11th, 2021, the Record of Decision (ROD) was granted for Vineyard Wind's final federal approval to install an 800-MW wind farm off southern New England, with anticipated installation starting in 2022.[3]

Given the anticipated acceleration of OSW development in U.S. Atlantic waters, it's important that the fishing community is involved in the conversation from the beginning as new wind farms are considered. At the time of this publication, the New York Bight has seen $1.437 billion in winning BOEM lease block auctions, with more lease sales planned for the Central Atlantic before moving to the Pacific.[4] These factors, along with the earlier White House Roundtable held on the topic, it is especially timely that the practices of the fishing community in the region are conveyed and considered, and fishing participants play a key role in the planning process. The overall goal of this project is to develop technical strategies and tools to minimize the disruption of commercial fishing associated with OSW arrays, while also ensuring economical energy generation and safe operations for the developers and for mariners transiting in and around these arrays. The intent is to perform this project collaboratively with Project Advisory Committee (PAC) membership from the commercial fishing industry, OSW developers, and State and federal agencies. Currently, more information is needed on how the anticipated buildout of OSW projects in the U.S. Atlantic will impact commercial fisheries in coastal and offshore areas, including how effects of single projects may interact cumulatively when there are multiple projects that affect certain fisheries. Fisheries are a significant socioeconomic contributor to the Northeast and Mid-Atlantic coastal communities, and various fishing sectors operate in areas now designated as WEAs. At the same time, wind energy is expected to offset reliance on fossil fuels and therefore help mitigate the effects of climate change on the natural environment, as well as build a new industry that will create national and local jobs in the renewable energy sector. As the government advances new leasing and projects move closer to construction, fisheries leaders, OSW developers, government agencies, and scientists are continuing to collaborate to identify and assess common concerns and how to mitigate impacts.

2 Literature Review of Risks and Impact Minimization Strategies

A thorough literature review was performed to collate published literature and reports which would directly inform this project on considerations for commercial fishing operations in and around offshore wind (OSW) projects, including operational access, health, navigational safety, and any associated best practices for fishing/offshore wind impact minimization measures. Underlying the literature review were priority topics related to considerations and potential risk to fishery operations associated with OSW identified by the project team and Project Advisory Committee (PAC) members. These topics included: operational restrictions due to structures or hazards (i.e., turbines, cables, etc.), changes to insurance policies, operationality of vessel radar, icing and ice throw risk, potential redistribution of species and fishing effort, implications for search and rescue, and socioeconomic impacts to fishing communities and businesses.

To inform this review, the project team developed an annotated bibliography and matrix of relevant literature, including initial contributions from the Coonamessett Farm Foundation. The findings of the literature review are summarized in this section of the report. The literature matrix contains approximately 150 references from Europe and the United States, ranging in date from 1994 to 2021.

There is a large amount of gray literature and news articles describing various topics relating to OSW and fisheries, but less that is peer-reviewed or utilizes standard scientific methods. However, this gray literature is often important as it can include convening reports to address particular topics, e.g., transit corridors or science synthesis products. To determine the relevance of various sources of information, the literature review included sources that addressed the basic preconditions for a fishing trip to occur in a given area:

1. Does the vessel have regulatory authorization to fish in locale?
2. Can the vessel's gear be deployed from a logistical perspective?
3. What is the availability of fish?
4. Is it safe enough to fish in the area?
5. Are there market, cost, or other socioeconomic considerations that would make a fishing trip viable?

If all these conditions are met, a vessel operator may choose to fish in an area but could still experience operational or economic impacts if conditions differ from historical experience. Understanding these fishing requirements in partnership with an understanding of OSW project requirements is important in evaluating methods and impact minimization measures to improve coexistence of OSW and fisheries. None of the requirements can be considered in isolation. Although closely related, questions that go beyond operational access and risk, such as evaluation of economic or biological impacts, are largely outside the scope of this report and are briefly mentioned for contextual purposes only.

2.1 Regulatory Considerations

U.S. commercial fishermen to operate offshore must have legal authorization, and can generally do so by obtaining a permit to fish from the federal government. For wind farms, the United States Coast Guard (USCG) has not indicated that fishing activities would be restricted in and around the farm, unless it is necessary to ensure safety of navigation, protect life and property at sea, or protect the environment (Kearns and West, 2018). However, concern has been expressed by fishermen, such as at Block Island Wind Farm (BIWF), that their access could be restricted in the future, due to existing U.S. federal and State laws which authorize ocean areas to be restricted for navigational safety, fisheries management, or conservation purposes (Webster and Porter, 2020). At this time, after 4.5 years of operation at BIWF, there have been no closures nor restrictions on fishing implemented (Smythe et al., 2020) after construction.

USCG maintains broad authority to restrict maritime activities for safety and navigational purposes. USCG can establish a safety zone (an area to which access is limited "for safety or environmental purposes") or Regulated Navigation Area (an area subject to "hazardous conditions") but lacks the authority to do so further than 12 miles from shore.[5] For BIWF, the USCG implemented a 500-yard safety zone around the wind turbine location during construction activities.

During the surveying phase of the wind farm (one to two years), setbacks can also exist around High Resolution Geophysical (HRG) survey operations, for which developers command "wide berth" requests (e.g., Ørsted, 2021), with the caveat that developers are also requested to mitigate potential gear interaction. Certain restrictions of varying duration will likely be implemented in lease areas for safety purposes. BOEM has indicated that fishermen may lose regulatory access to portions of lease areas during construction phases and accessibility may be impacted from an operational fishing perspective once the turbine installation is complete (BOEM, 2020).

In addition to safety restrictions, regulations pertaining to fishery management or protected resource conservation may limit the ability to fish within or around arrays in the future (Methratta et al., 2020). Regional fishery management council's goals, as established by the Magnuson Stevens Act, are to create a stabilizing, goal-seeking (maximum sustainable yield), regulating/balancing feedback loop for the fishery. The Mid-Atlantic and New England Fishery Management Councils, which manage fisheries in the northeast, have developed area-specific management measures (e.g., Habitat Closed Areas, Gear Restricted Areas, Special Management Areas), and changes to the management of these areas or the implementation of new site-specific regulations could be a consideration in wind energy development areas. One source of uncertainty is whether National Oceanic and Atmospheric Administration's (NOAA) Fisheries will need to modify scientific survey methods to accommodate OSW installations. BOEM has funded National Marine Fisheries Service (NMFS) to design a modeling framework (an Observation System Simulation Experiment, OSSE) to enable evaluation of new fishery resource survey methodologies and integrated survey designs compatible with offshore wind development in order to meet scientific and management mission objectives.[6]

In terms of impact minimization strategies, the USCG will be the primary party responsible for implementing any safety zones or buffers around offshore wind farms. The agency has said that it would evaluate on a case-by-case basis, and that it only intends to implement access restrictions during construction.[7] Further consideration of regulatory exclusion in offshore wind farms (OWF) is not considered actionable within the scope of this study.

2.2 Operational Restrictions to Fishing Due to Structures or Hazards

Fishermen have expressed concern over the feasibility of operating various gear types in or around the footprint of an OSW project and near cable routes (Methratta et al., 2020). For example, any obstruction to operations could affect the success of a fishing trip and such impacts could be strong enough to have impacts associated with other fishing areas and shoreside operations.

Gear loss is one important consideration within the spectrum of operational limitations not explicitly addressed elsewhere in this report. For some gear types, if gear is damaged during a trip, the trip must either be aborted, or gear must be fixed at sea. This results in less time fishing during that and possibly future trips. These scenarios would directly result in decreased catch and economic losses. The only commercial-scale U.S. offshore wind farm approved to date (Vineyard Wind 1), and many other developers in advanced stages of project permitting, have established compensation protocols to address gear losses that may mitigate these particular economic impacts to some extent (BOEM, 2020).

The degree of operational constraint will depend on several factors relating to OSW project location and design. In addition to fishing considerations, the OSW industry also seeks to minimize any damage to cables or infrastructure as it may impact OSW energy production, cause economic loss, and upset energy supply.

2.2.1 Overall Size, Shape, and Location of Project Areas

2.2.1.1 Risk Description

One of the main concerns for the fishing industry in the United States and Europe is the total footprint that OSW project areas will have and their proximity to and spatial overlap with historic fishing grounds (Mackinson et al., 2006; Methratta et al., 2020). To conduct business operations, fishermen need access to target species in areas they can safely operate mobile or fixed gear in appropriate weather conditions.

In the UK, OSW developments have been described as spatially demanding (Mackinson et al., 2006), with the potential to reduce the total area of fishing grounds. For example, fishing vessels can no longer fish where a turbine has been installed and for some area around them, even if the total area of displacement is uncertain.

In the North Sea region, a spatial analysis was performed to identify the potential opportunities and challenges for offshore wind farm locations with respect to fisheries and other ocean uses (Gusatu et al, 2020). The availability of offshore space for wind farm deployment was analyzed by four different scenarios for the management of the maritime area using numerous Geographic Information System (GIS) data sets. Results indicated a low availability of suitable locations for offshore wind near shore and in shallow waters, even when considering multi-use with fisheries and protected areas. However, the areas within 100 km from shore and with a water depth deeper than 120 m present greater opportunities for both single use (only offshore wind farms) and multi-use (mainly with fisheries), from an integrated planning perspective.

The Draft Supplemental Environmental Impact Statement (SEIS) for the Vineyard Wind project suggested it is reasonably foreseeable that there will be approximately 2,000 turbines on the Outer Continental Shelf (OCS) along the east coast of the United States given current lease areas and project plans (BOEM, 2020). This potential cumulative buildout of turbines crosses several U.S. Atlantic OCS regions and, thus, has the potential to impact multiple fisheries.

While not currently anticipated in the NY Bight, the implementation of floating OSW with its additional floating components of cables and anchoring infrastructure could pose unique challenges to safe vessel operations and to fishing methods in general, depending on water depth, type of mooring system, and other considerations (National Environment Research Council, 2016; Methratta et al., 2020).

Various gear types encounter specific operational challenges that must be assessed independently. Mobile gears, such as dredges and trawls, are towed behind a moving fishing vessel. Dredges and benthic trawl gear must have contact with or near the bottom to catch fish, and are connected to the vessel via warps, cables, chains, and trawl winches (FAO 2001). Because gear is attached to the vessel, these vessels are at risk of "hanging" (entangling) on obstructions on the seafloor. The risk can vary from damaged or lost gear to vessel damage and safety concerns for fishermen. Because new hazards are being introduced, the potential to hang on turbine base structures, cables, or scour protection has been expressed as a major concern for fishing vessels in the UK (Gray et al., 2016). The author's findings suggested that fishing activity within the UK offshore wind farm boundaries has changed, primarily because fishermen are fearful of fishing gear becoming entrapped by seabed obstacles such as cables, cable crossing points, and rock armoring, and are wary of vessel break down with the consequent risk of colliding with a turbine. However, Gray et al. (2016) also reported that fishing was found to coexist with offshore wind farms in some cases based on fishermen feedback and the role of suggested best practices (see section 4.2). In a separate study of lobster fishing in the UK (Roach et al., 2018), re-opening of an offshore wind site after construction lead to fishing levels that were similar to control sites outside of the wind farm, suggesting that lobster fishermen were able to operate within the wind farm. Note that turbine spacing in UK wind farms to date is on the order of 0.4–0.5 nautical miles (nm), versus newer wind farms in the U.S. with larger turbines that are envisioned with wider spacing; also note that turbine spacing is only one factor to consider in terms of applicability to the U.S.

Regarding specific gear types, NYSERDA gathered some direct input from fishermen in its Offshore Wind Master Plan: Fish and Fisheries study (NYSERDA, 2017). In order to address the feasibility of fishing within an OSW farm, the State developed scale drawings of common fishing vessels and gear types showing vessels with gear deployed within the relative spacing of wind turbines, including for scallops and surfclam/ocean quahogs. Surfclam and ocean quahog operators were interviewed and indicated that the fishery will "work an area hard until the catch drops and then move on. They may return 6 months later when catch rates return to high." They also stated that clams do not migrate horizontally (unlike scallops and finfish), so the placement of a lease area is of utmost importance in determining the degree of conflicts. Fishing vessels regularly towing trawls in the New York Bight avoid “hangs” (rocks, shipwrecks, etc.) in the region that may damage their nets, and wind farms were identified as presenting additional obstacles that fishing vessels would need to actively avoid. In some cases, particularly in rough weather, fishermen with gear extending more than 0.25 miles from their vessels could find it difficult to operate within a wind farm, according to the report. Depending on the type of gear used by individual fishing vessels, other fishing methods that use clam or scallop dredges might similarly be more likely to avoid areas with wind turbines.

In general, there are a number of factors that influence where a vessel will focus fishing effort, including historic catch, fisheries management restrictions, individual business needs, distance from port, expected weather during the duration of the trip, density of non-targeted species, and density of target species. The New England Fishery Management Council (NEFMC) Groundfish Plan Development Team analyzed fishing patterns in relation to Atlantic cod and concluded that fishing patterns mirror fish distribution patterns (NEFMC, 2014a), as would be expected.

Fish distribution often varies with time (see NOAA Fisheries fishing footprints website for an animated time series of catch for species in the Greater Atlantic Region). These changing distributions are why access is so important to the fishing industry; in any one year the fish population can shift locations and the fleet’s success is dependent on the ability to find and follow targeted species. However, this isn’t as relevant to shellfish harvests as to other fisheries, such as finfish. For shellfish, population shift or fleet movement doesn’t happen from migration of adults but rather from larval settlement occuring in a location where larvae then grow to target size.

Increases in, or constriction of, vessel traffic supporting OSW developments may have an impact on fisheries access. In the UK, Rawson and Rogers (2015) found that the impact of this vessel traffic is specific to the location of each development and driven by traffic management measures and other local constraints. OSW projects introduce new vessel activity at sea and in ports. BOEM (2020) estimates that construction of each individual offshore wind project proposed in the Atlantic would generate an average of 25—and a maximum of 46—vessels in the area at any given time over a period of two years per project; note that cumulative numbers are higher. Rawson and Rogers (2015) indicate that efforts to model navigational risks to vessel traffic around OSW projects to date has generally been predictive and there is limited information as to whether the models accurately reflect realized navigation risk post construction. Increased vessel activity could cause direct impacts in terms of collision avoidance and could induce changes in locations of recreational fishing vessels, mobile gear, and other obstacles. The turbines themselves may be at risk from collisions with vessels. Bela et al. (2017) performed simulation analysis of ship strikes on turbines and concluded that under certain conditions (when wind force and ship strike [velocity of 3 m/s] have opposite directions) the turbine structure can be compromised.

Another aspect in which the size and location of OSW projects could impact fishing behavior is the ability to safely and directly transit as vessels are heading to or from their home port, other ports, or between fishing grounds. Captains and crews will have to remain vigilant if transiting a WEA, especially in strong tides that may require constant steering (USCG, 2020). The implementation of vessel transit lanes for New England OSW farms has received considerable discussion given implications for safe transit by the fishing industry (Equinor, et al., 2019; BOEM, 2020; RODA, 2020). To learn from the experience in New England and potentially seek an accepted approach to transit through the New York Bight prior to individual lease sales, NYSERDA and New York State Department of Environmental Conservation (NYSDEC) worked with Responsible Offshore Development Alliance (RODA) to jointly develop, convene, and complete a process for engaging fishermen and agencies to work together to identify transit routes in proposed WEAs (NYSERDA, NYSDEC, and RODA, 2020). While not preferred, vessels may be required to transit through a WEA due to the onset of poor weather, incentives for captains to maximize fishing time, and maintaining product quality by reducing time to market rather than increase transit times routing around WEAs.

BOEM has conducted navigational risk assessments for broader offshore wind planning (Salerno et al., 2019). Individual OSW projects also complete project-specific navigational safety risk assessments (NSRA) based on the individual specifications of a project. An NSRA is required from the developer of the OSW farm, using studies, standard industry practices, or guidelines from recognized sources applicable to their wind farm or waterway to assess the navigational safety risks and potential impacts to navigation safety (BOEM, 2018). The USCG is responsible for reviewing the NSRA on behalf of BOEM and provides recommendations concerning mitigation measures.

2.2.1.2 Impact Minimization Strategies

Impact minimization measures for overall size, shape, and location of project areas include, but are not limited to:

- Siting away from areas of high fish concentration, and where not possible, consider colocation needs (lease planning and project planning stage).
- Consider limiting geographic size of individual and total projects (lease planning stage).
- Utilize state-of-the-art methods for windfarm layout design (project planning stage).

When selecting the location, size and shape of a windfarm, there are many considerations, including, but not limited to, the importance of the site commercially, whether it is in a protected area (Mackinson et al., 2006), spatial considerations for other ocean and environmental uses, viewshed, and whether there is a viable wind resource. For example, BOEM announced in February 2012 the Rhode Island and Massachusetts WEA, which comprises approximately 164,750 acres within the "area of mutual interest" identified by Rhode Island and Massachusetts. This MA-RI WEA was significantly reduced in size from the larger original “call” area. Portions of the call area that were not designated a WEA would have likely caused substantial conflict with existing fishing uses, and BOEM has stated the “high value” of these fishing grounds was one of the factors that led it to remove them from further consideration for leasing (BOEM, 2012).

The Danish environmental monitoring program and its follow-up program have led to the important conclusion that, with proper spatial planning, it is possible to construct offshore windfarms in an environmentally sustainable manner that do not lead to significant damage to nature (Danish Energy Agency, 2013). It is recognized, however, that others may not agree with this assessment.

Site Away from Areas of High-Fish Concentration
(Where not possible, consider colocation needs)

Note that this siting consideration addresses present-day fishing grounds. However, there is also clear indication of certain species’ distribution altering with changing climate, natural variability, ocean acidification, and other factors, which could affect where future fishing grounds are located.

Efficient Marine Spatial Planning would allow the following:

- Identify and avoid major fishing grounds.
- Coordinate with NOAA Fisheries and Regional Fishery Management Councils and avoid essential habitats for specific fish stocks, such as spawning and nursery areas.
- Reduce overall impacts on ecosystems on which fisheries depend (Dupont et al., 2020).

The establishment of successful colocation would be supported by early engagement and community management, and clear protocols for permissions, insurance, liability, and gear retrieval are essential (Hooper et al., 2015). In light of the potential for fishermen to lose access to significant areas within offshore windfarms, Blyth-Skyrme (2010) produced a menu of possible mitigation options which would be of use to fishermen, developers, regulatory and statutory bodies, and marine resource managers in discussions related to current and future windfarm developments, as well as in other offshore industry development. The report included ways to keep fishermen fishing by reducing or eliminating negative impacts of windfarms on commercial fishing activities through (1) early and constructive consultation; (2) promoting existing fishing activities within and around windfarm sites; (3) increasing access to fisheries, enhancing performance, reducing costs, increased product price or enhancing marketability; and (4) identifying opportunities to switch to new or alternative fisheries and other activities. Current OSW projects overlap with essential fish habitats and Habitat Areas of Particular Concern (HAPC) as identified by NEFMC, Mid-Atlantic Fishery Management Council (MAFMC), and NOAA Fisheries (BOEM 2021). Note that virtually the entire continental shelf of the Greater Atlantic Region is covered by Essential Fish Habitat for various fish stocks as determined by Regional Fishery Management Councils and NOAA Fisheries, although HAPCs are less extensive.[8]

The remainder of this section includes some additional considerations and regional decisions that were made to help establish the bookends of opportunities when siting an offshore windfarm.

Consider Limiting Geographic Size of Individual and Total Projects

For the Massachusetts/Rhode Island WEA's turbine layout, the following was proposed by lease holding developers and favorably evaluated by USCG:

- Developing along a standard and uniform grid pattern with at least three lines of orientation and standard spacing to accommodate vessel transits would eliminate the need for the United States Coast Guard (USCG) to pursue formal or informal routing measures within the area.
- Allowance of traditional fishing operations, and search and rescue operations, throughout the area should be favored.
- Lanes for vessel transit oriented in a northwest to southeast direction, 0.6 nm to 0.8 nm wide would allow vessels the ability to transit effectively.
- Lanes for commercial fishing vessels actively engaged in fishing oriented in an east to west direction, 1 nm wide (USCG, 2020) would preserve some access along traditional tow routes.

The Rhode Island Department of Environmental Management concurred that a selection of a uniform grid pattern that is contiguous among abutting lease areas (as committed to by the developers Equinor, Mayflower Wind, Ørsted/Eversource, and Vineyard Wind on a letter to the USCG dated November 1, 2019) will improve fishing access within the turbine array and may reduce risk of allision or collision due to more logical navigation patterns. It was acknowledged that comprehensive mitigation plans are needed for all individual projects moving forward and multiple data sources should be considered (RI Dept. of Environmental Management (RIDEM)—Janet Coit, Director, 2020).

RODA submitted a rebuttal to this document asking for the addition of transit lanes to the layout proposed by the developers, which would adhered to the following design principles: (1) Turbines spaced in an east–west, north–south grid; (2) Turbines spaced for continuity of rows among lease areas; (3) Turbines spaced further apart to reduce operational and navigational risk; (4) Designation of six transit lanes at least 4 nm wide; (5) Transit lanes located to accommodate traditional transit routes; (6) Development and approval of project layout and transit lanes must be consistent with rigorous analysis of the best available data, including vessel monitoring system (VMS), vessel trip reporting (VTR), automatic identification system (AIS), and other data sets using appropriate time series to capture fishing activity, accounting for all vessels sizes, gear types, home ports, and interannual variability within fisheries (RODA, 2020–Proposal for New England Wind Energy Project Layout).

Another data point with respect to windfarm siting was shared by the British Maritime and Coastguard Agency (MCA) who proposed a minimum safe separation distance of 1.5 nm between shipping routes and the wind towers which they felt still does not remove the dangers for ships traveling inside the proposed windfarm field (Brookner, 2008).

One scenario could involve utilizing fewer but larger turbines (i.e., turbine generation capacity in megawatts (MW) to increase spacing between turbines and reduce the number of structures that need to be navigated by fishing boats and gear. Development of the International Energy Agency (IEA) 15-MW offshore reference turbine is a good example of the trend toward larger next-generation offshore turbines (Gaertner et al., 2020).

Mackinson et al. (2006) recommended spacing turbines as close together as is safely possible to reduce total windfarm size. The authors suggest consideration for alternative spacing options for turbines as well as increasing distance between turbines without expanding overall windfarm size. Fewer—and more spread out—turbines would make it safer to navigate the windfarm area and would allow long liners to set and retrieve lines up to 1,500 m.

Utilize State-of-the-Art Methods to Windfarm Layout Design

Previous recommendations are to have turbines in a prescribed uniform layout (RODA, 2020b; BOEM, 2021). Use of state-of-the-art methods for windfarm layout design will likely diverge from the uniform spacing. Thus, it's important to acknowledge that (1) these strategies may not be complementary, (2) different approaches may be required according to project- or region-specific conditions, and (3) there could be trade-offs.

A case study using the Horns Rev 1 windfarm demonstrates the crucial importance of the shape and orientation and the effectiveness of the study's proposed co-optimization method. The findings shown in this study call out the benefits of considering layout optimization in the planning phase of offshore windfarms. Future studies will consider objective functions beyond annual energy production (AEP), including investigating windfarm boundary shapes other than parallelograms and investigating the co-optimization problem in a more realistic setting with considerations of water depths, exclusive zones, and other limiting factors (Feng and Shen, 2020).

It will be important for turbine layout decisions for there to be focus on (1) investigating potential improvements and best practices for Wake Expansion Continuation[9] (WEC), (2) applying WEC to other wake models, (3) providing a more complete comparison to gradient-free windfarm layout optimization including discrete parameterization, and (4) validating the results obtained through WEC using a higher-order modeling approach such as Large Eddy Simulation (LES) (Thomas and Ning, 2018). The WEC focuses on reducing the multi-modality of a wind farm layout solution space that will produce the most energy by iteratively optimizing the farm and varying the wind turbine wakes within each iteration.

Another configuration, called the boundary grid (BG) layout, places a portion of the wind turbines around the boundary, spaced equally traversing the windfarm perimeter. The rest of the turbines are placed in a grid inside the farm boundaries. The windfarm layouts created have a regular pattern, the ability to include shipping lanes in the design, and have an easily defined cabling pattern. The author of this publication feels that BG parameterizations solve many of the problems that typically accompany windfarm layout optimization. “It is a simple, easily implemented technique that can immediately be applied by researchers and windfarm developers, playing an important role in the continued growth of wind energy” (Stanley and Ning, 2019).

More generally, it is important to develop a holistic view of offshore windfarm impacts on ecosystem functioning (Raoux, 2017). This holistic view ensures that developers: (1) avoid placing offshore wind energy structures in critical habitat areas and along migration routes; (2) constrain the footprint size and construction schedules to minimize disturbance to key species and processes; and (3) reduce potential noise and vibration impacts (Petruny-Parker et al., 2015).

2.2.2 Turbine Array Layout Impact on Harvesting and Transit of Fishing Vessels

2.2.2.1 Risk Description

In both the United Kingdom and United States, factors of project layouts that have been identified as influencing fishing operations include the directionality and spacing of turbine arrays (Mackinson et al., 2006; NYSERDA Offshore Wind Master Plan, 2017; BOEM, 2020). In addition, the ways in which a project layout impacts fishing can depend on whether a vessel is harvesting or transiting.

In the U.S., there has been a series of communications between fishing representatives, developers, and state and federal regulators related to the layout, spacing, and directionality of New England offshore wind projects (RODA, 2020; Equinor et al., 2019; BOEM, 2018). The Massachusetts and Rhode Island Port Access Route Study (MARIPARS) 2020 study was undertaken by the USCG to evaluate the proposed layout of OSW projects off the coast of RI and MA for a variety of users (e.g., shipping, recreation, and commercial fishing, among others). Regarding spacing, the study concluded that turbine layouts should be developed along uniform grid patterns, preferably with a minimum of three differently oriented transit lanes. This study was sharply contested by the fishing industry. While the recommendation for uniform grid patterns was not contested by the fishing industry, several other findings of this study remain a concern (e.g., RODA, 2020b).[10] Specific considerations for layout of the Vineyard Wind 1 project are summarized in the Final Environmental Impact Statement (FEIS) BOEM (2021).

In the UK, Hooper et al. (2015) interviewed fixed gear pot fishermen about colocation with offshore wind farms and identified the following primary concerns: safety, collision risks, gear damage/loss, insurance and legal changes, and access to grounds. Offshore wind developers and fishermen identified concern regarding the deployment of fixed gear (pots) for crab and lobster fishing within OSW farms. The range of minimum safe distance from a turbine to deploy fixed gear identified by both groups overlapped to some extent with estimates of 25 m to 500 m from developers and 100 m median distance (1– 2,000m range) from the fishing industry. Depending on turbine spacing, safety zones around turbine bases, species distribution, and other factors, this could leave nominal spacing available for the deployment of fixed gear. However, a study of the lobster fishery (using fixed gear) at the Westermost Rough offshore wind farm (minimum 950 m spacing) reported that fishing levels within the wind farms after construction were similar to control sites outside of the wind farm, indicating that lobster fishermen were able to operate (Roach et al., 2018).

Data from vessel tracking systems could theoretically prove useful in better understanding how spacing between turbines may impact the ability for fishing vessels to access their fishing grounds, although studies to date have focused primarily on using it to evaluate changes in fleet behavior after OSW construction.[11] For example, Coates et al (2016) examined data from the satellite-based VMS to estimate fishing effort over time in the Belgian part of the North Sea to determine the impact that area closures to fishing induced by OSW farms had on open areas. Given the No Fishery Area, they found that trawlers' effort increased in areas surrounding the closed areas.

In European seas, the European Parliament (2020) analyzed the impact of OSW development on fisheries using not only VMS data, but other data products as well based on geographic ship position information, including AIS data. A key finding was the need for harmonization of fishing effort data to enable cumulative ecological and socio-economic environmental impact assessment of the expansion of marine energy. They also identified best practices examples for colocation of offshore wind farms and fisheries, including in Belgium, the Netherlands, and Germany.

Offshore wind farm layouts can be designed with either evenly spaced or irregularly spaced turbines, depending on regional considerations. A variety of evolving engineering and modeling tools exist for optimizing wind farm layouts (e.g., Acero et al., 2014; Dou et al., 2020; Feng and Shen, 2020). The Middelgrunden OSW project, Pillai et al. (2017) demonstrated that the wind farm layout optimization process could successfully account for both realistic constraints discussed between wind farm developers and stakeholders and an economic (i.e., LCOE) evaluation tool. For future projects, quantification of windfarm layout constraints in a similar way could aid in discussions between developers, regulators, and fishermen to ensure that the wind farm is designed as efficiently as possible given the real constraints faced for a particular site. In both Europe and the U.S., there are many considerations that go into the determination of wind farms layouts to account for inputs from a variety of ocean users, including the fishing industry (Mackinson et al., 2006; NYSERDA Offshore Wind Master Plan, 2017; BOEM, 2020).

2.2.2.2 Impact Minimization Strategies

Impact minimization measures for turbine array layout impact on harvesting and transit include, but are not limited to:

- Utilize fishermen's expertise to develop specific project designs.
- Test out navigation and gear use within windfarm arrays (e.g., including modifications to gear and training required to meet ability to fish within project area).
- Consider transit requirements.
- Execute long-term monitoring programs in combination with targeted research.

Utilize Fishermen's Expertise to Develop Specific Project Designs

Recent innovations in the UK and U.S. include earlier and more meaningful inclusion of fisheries representatives and fishing communities in planning and decision-making, involving fisheries liaisons in the process, conducting more cumulative studies, and taking collaborative approaches to considering the effects of offshore wind on fishing (Haggett et al., 2020).

This inclusion alongside robust tools will inform a more open and transparent navigational risk assessment (NRA) to identify risk-control options (RCOs)—measures which can reduce the probability and/or consequences of an accident. It is important to ensure that direct results of the NRA process be more open and accessible to seafarers. Seafarers should be provided with decision support tools when operating near offshore windfarms (Mehdi et al., 2018).

Test Out Navigation and Gear Use within Windfarm Arrays

(This includes modifications to gear and training required to meet ability to fish within project area.) Mackinson et al. (2006) underscored the importance of field testing the maneuverability and operation of various gear types in and around windfarms and ensuring adequate information on long-term trends in the levels of different types of fishing activity to help interpret possible impacts from turbine arrays.

The New England Fishery Management Council Groundfish Plan Development Team (2014) advised that management regulations have different effects on vessel classes. Vessel classes have differing abilities to respond to these effects (i.e., a large vessel has many more areas accessible and is not as restricted by safety concerns of traveling farther offshore or to other locations to fish, while a smaller vessel is much more constrained spatially).

For the Atlantic Shores and Ocean Winds lease areas, Last Tow LLC (2020a, b) worked with Oceanside Marine/LaMonica Fine Foods and the developers with the goal of helping to plan for wind turbine developments that would be minimally disruptive to local fishing operations. Azavea was contracted by Last Tow to perform analytics on past fishing trips by Oceanside Marine vessels within the lease areas. The objective was to help give Oceanside Marine/LaMonica Fine Foods a better understanding of the spatio-temporal characteristics of these fishing trips which will help inform developers' placement of wind turbines and inter-array cables (IAC). Their primary informational measure included calculating the proportion of fishing within the lease areas and other metrics using VMS data.

Some of these risks include navigational challenges related to offshore renewable energy installations, and, as such, the United States Coast Guard (USCG) urges seafarers to consider the following factors: (1) the operator's experience and condition regarding fitness and rest, (2) the vessels characteristics, which should include the size, maneuverability, and sea keeping ability as well as the overall reliability and operational material condition of propulsion, steering, and navigational equipment, (3) weather conditions—both current and predicted including sea state and visibility, (4) voyage planning to include up-to-date information regarding the positions of completed wind towers or wind towers under construction and their associated construction vessels (USCG, 2020—Port Access Route Study). Following the building of the first large-scale OSW development, full assessments of impacts should be conducted, and lessons should be applied to more efficiently mitigate impacts of later projects.

Responsible Offshore Development Alliance (RODA) recommends consistent and uniform navigational aids and marking across all offshore wind projects to minimize navigational risk for mariners. Recommendations include identification and marking of turbines to be sufficiently large, distinct, and visible in all conditions to ensure mariners can easily identify turbines and their location within a wind energy area. Additionally, the use of other technologies used for navigational aids, such as AIS on turbines, cell coverage in wind energy areas and smartly spaced fog signals should be used judiciously (RODA, 2020—Recommendations for Aids to Navigation for the Joint Industry Task Force).

Consider Transit Requirements

Rawson et al. (2015) states that it will be important to improve the predictive modelling of vessel traffic around offshore windfarms and other offshore installations through input from experienced navigators, regulators, and other knowledgeable stakeholders. This will lead to a reduction in the uncertainty of vessel traffic modelling in the future.

The UK NOREL working group estimates that 2 nm should be given between a shipping lane and a wind farm boundary. Where a shipping lane is located in between two windfarms, the minimum distance should be a buffer of 2 nm to port, six boat lengths for vessel navigation and a buffer of 2 nm to starboard. Guidance from the Netherlands, however, provides a template for developers suggesting a turning circle of six boat lengths and a safety buffer of 500 meters from the edge of a shipping lane. The use of traffic management measures associated with the development, such as a traffic separation scheme (TSS) or buoyage, has a significant impact on vessel routes which must be included in any traffic modelling. In the absence of traffic management, the model should consider not only the development itself but also the presence and interaction with other navigational constraints. According to the authors, the guidance and input into traffic modelling of experienced navigators, local harbor masters, and other knowledgeable stakeholders is essential in properly incorporating these factors (Rawson and Rogers, 2015).

NYSERDA, NYSDEC, and RODA gathered feedback from commercial fishermen regarding fishing transit through proposed possible New York Bight WEAs from January 2019 through January 2020. The responses underscored the importance of establishing transit lanes to allow for safe, regular, and coherent travel across the region; ensuring commercial fishing economic opportunities for all ports; and allowing for transit to and from various ports and fishing grounds in the straightest and most direct route possible to minimize transit time, associated costs, and economic impacts on the commercial fishing industry. Feedback also included the importance of ensuring transit lanes (1) provide safe passage of vessels in a range of sea conditions, (2) are between lease areas, (3) are reasonably limited in number, (4) have designations that are data-informed to the greatest extent possible, (5) utilize a shared and widely accepted methodology, (6) include risk analysis for both calm seas and storm conditions, and (7) follow a process for determining lanes that is broadly inclusive of the commercial fishing industry (NYSERDA, NYSDEC, and RODA, 2020). It should be noted that no-build zones between leases were included as part of the Final Sales Notice (FSN) for the NY Bight auction to aid in navigation. The FSN also included setbacks for adjoining leases and select scallop fishing grounds. This was a direct result of input from the fishing industry and activities performed under this study.

Execute Long-Term Monitoring Programs in Combination with Targeted Research

Targeted research and long-term monitoring are significantly important to understand the effectiveness of mitigation measures for minimizing turbine array risks. In order to utilize information learned from monitoring activities in effective mitigation measures, there has to be some mechanism for adaptive management or modifying outcomes based on research results. With respect to monitoring, the following could be considered:

- Establish regional research and monitoring frameworks to assess the cumulative impacts of multiple projects and to inform the appropriate size and scale of future development using data over multiple years/seasons (Dameron, 2018).
- For individual windfarms, conduct adequate baseline replicable survey work prior to construction for at least two to three years to identify critical habitat areas and seasonal species distributions to develop effective and efficient baseline and monitoring protocols (Petruny-Parker et al., 2015).
- Standardized monitoring programs and harmonization of fishing effort data are required to enable cumulative ecological and socio-economic, as well as environmental impact assessment of the expansion of offshore renewable energy and compatibility and comparability of data must be improved (European Parliament Committee on Fisheries, 2020).
- According to the European Parliament Committee on Fisheries (2020), maritime spatial planning must play a key role and must put greater emphasis on the assessment of achieving co-location options, which is of the utmost importance in achieving a win-win situation for both sustainable fisheries and the offshore energy sector. Hooper et al. (2014) state that the socio-economic issues surrounding co-location should be addressed, including, as a first step, determining the perceptions and experiences of fishermen and offshore windfarm developers.
- It should be noted that NYSERDA is encouraging the implementation of this long-term monitoring by requiring $10,000 per megawatt for regional monitoring. The State of New Jersey also followed suit.

2.2.3 Cables

2.2.3.1 Risk Description

Inter-array and export power cables pose considerations for the operability of fishing vessels within an array and along cable routes. Interactions between cables and fishing gear create risk to the vessel, crew, and cables. Anchors and fishing gear have been estimated to cause one-third of accidental damage to all subsea cables in Europe (European MSP Platform, 2019). Note that in Europe some cables are buried at a depth of a meter, but others just lie on the seafloor. In the telecommunications industry, the estimate for fishing faults globally is between ~35% and ~52% of all faults (2016-2018; Kordahi et al., 2019). In the power cable industry, Scottish and Southern Energy list fishing as causing 40% of third-party damage faults (Dinmohammadi et al., 2001).

For the European Union, an early review was performed of cabling techniques and environmental effects applicable to the offshore wind industry (Vize et al., 2008). For mobile fishing gear that contacts the benthic substrate, the greatest risk was found to occur when gear snags a cable, posing significant danger to the vessel and crew, if not properly managed. Concrete mattresses (used as a primary cable protection and also for crossing over other existing subsea cables and pipelines) were identified as "usually being approved by other stakeholders, particularly fishermen who consider concrete mattresses to be potentially less damaging to their fishing gear than rock dumping." Vize et al. (2008) reported that monitoring at the earliest-established offshore wind farms, Horns Rev and Nysted, had not found significant impact of either the export cable or the IACs on fish stock displacement.

In the UK, Mackinson et al. (2006) presented mitigation options suggested directly by fishermen. These included: laying power cables using the method that causes the least damage to the seabed, laying high voltage direct current (HVDC) cables with opposing electrical currents alongside each other, and burying cables into the seabed. To date OSW farms have used HVAC cables which can be operated as single cables although there is now some discussion on using HVDC for some longer export cable applications. HVDC cables need a pair of cables (poles) to operate.

The temporary suspension of activity associated with cable installation, repair, or removal, which can result in reduced catch or increased costs (Vize et al., 2008) may impact both mobile and static gear vessels. Guidance in Drew and Hopper (2009), cautions fishermen to keep at least one nautical mile away from a cable laying vessel. If the cable is being buried by a cable plough, fishing gear should never be operated astern of such a vessel for risk of engaging with a plough which will typically be operating three times the water depth away from the stern of the main cable installation vessel. Cables can also be buried by a Remotely Operated Vehicle (ROV) which are more likely to be operating directly below the vessel they are deployed from. Fishing vessels that cannot fish within the immediate area will thus possibly be "displaced" to adjacent fishing grounds to continue fishing. This could lead to additional risk of gear conflict and even reductions in catches in instances when fishermen must work in unfamiliar or less productive grounds (Vize et al. 2008).

Cable burial is one of the primary methods for protection of cables, though there are times when sufficient depth of cable burial cannot be achieved and other methods must be used (NYSERDA/TetraTech, 2021). In the U.S. there are no regulatory requirements for burial depth outside of federally defined shipping channels. However, based on BOEM COP guidance (2020), lessees and grantees should avoid or minimize impacts to the commercial fishing industry by burying cables, where practicable, to avoid conflict with fishing vessels and gear. The Carbon Trust[12] (2015) developed guidance for a comprehensive Cable Burial Risk Assessment (CBRA) which assesses the various risks to the security of cables present in the project area. In addition, BOEM is now recommending at least 6 feet (ft) for burial cable (BOEM Draft Fisheries Mitigation Guidance[13]). These risks are assessed using objective data sets such as AIS vessel traffic data, the shallow geological conditions, erosion/accretion due to currents and seabed mobility as found by geophysical and geotechnical marine surveys, and any region-specific risk factors. The result is a recommendation on the burial depth required to prevent damage to the cables from all the risk factors including from fishing activities and anchors (NYSERDA/ TetraTech, 2021). If these target burial depths are then achieved a direct outcome should be the prevention of damage to fishing gear through the avoidance of any fishing gear "hanging" on cables.

In places where cable burial using common burial tools is unfeasible or cost prohibitive, such as over bedrock, alternative methods for cable protection may be used including rock placement or concrete mattressing. To date, COPs for Atlantic OSW projects submitted to BOEM have varied target burial depths, including 4 to 6 ft (Deepwater Wind South Fork LLC, 2020), and 5 to 8 ft (Vineyard Wind LLC, 2020).

In the U.S., the physical presence of wind turbines and the buried cables running between them has posed concerns regarding the risks of snagging nets and collision of nets and vessels; however, this risk is expected to be mitigated through minimum burial depth requirements (NYSERDA Fish and Fisheries Study, 2017). A group called the International Cable Protection Committee provides charts to fishermen to plot the routes of submarine cables, intended to help them avoid snagging (Drew and Hopper, 2009). In the New York Bight, there are at least five international telecom cables running through the Hudson Canyon scallop special access area, and scallopers are known to tow over them. The North American Submarine Cable Association of cable owners has reported near zero cases of cable damage in this region since 2000.[14] In the 1990's a triangular piece of steel known as a "cable jumper" was incorporated into scallop dredge design to help the dredge ride over cables; it has been incorporated into subsequent designs and continues in common use.

In addition to sufficient burial depths, potential conflict between fishing gear and cables can be reduced through intentional planning of location of laid cables (NYSERDA/TetraTech, 2021). In the U.S., there are two primary considerations for cable route planning with respect to fishing interests:

(1) identification of heavily fished grounds during upfront planning—avoiding these areas whenever possible and (2) developing appropriate mitigation that is focused on types of fishing gear and seabed composition.

Floating offshore wind turbines are not within the scope of this report. However, floating deployments are anticipated to grow and will have unique challenges that will need to be considered and addressed. For example, a potential challenge to navigation and operations involves the long and extensive cable networks that will anchor floating turbines to the seafloor (Methratta et al., 2020). An identified research need for floating turbines is the prediction of the impact on fish and shellfish stocks from array footprints (National Environment Research Council, 2016).

2.2.3.2 Impact Minimization Strategies

Impact minimization measures for cabling include, but are not limited to:

- Designing cable routes to maximize the potential for good cable burial.
- Optimizing export and IAC layouts that account for existing fishing activity, including minimizing the amount of cable laid.
- Laying power cables using the method that causes the least damage to the seabed.
- Laying HVDC cables with opposing electrical currents alongside each other and sufficient burial.
- Planning cable location and directionality with delineation of cable locations on charts.
- Considering decommissioning plans.

Design Cable Routes to Maximize the Potential for Good Cable Burial

In order to ensure cables are able to be buried to the required depth below the seabed, the composition of the seabed must be well understood. The composition and physical properties of the shallow seabed sediments and the geophysical features across the site are an important factor when considering the optimization of cable route engineering design. Seabed features likely to hinder cable burial are actively avoided, such as steep slopes and sand waves. Equally important is the avoidance of extremely hard or soft seabeds which can prevent cable burial to the required depths (NYSERDA/TetraTech, 2020).

The Carbon Trust (2015) offers the Cable Burial Risk Assessment (CBRA), which is a probabilistic assessment of the risk of cable burial, which, they claim, optimizes the burial process, and provides greater assurance to developers, insurers, cable installer, and the industry, as well as potentially reducing the overall cost of cable installation. They anticipate that where stakeholders and consenting bodies have requested significant burial depths on existing windfarms due to a perceived threat, this probabilistic method can be used to support the safe reduction of specified depths based on actual site conditions (Carbon Trust, 2015). Another potentially useful tool has been provided by the Commonwealth of Massachusetts Ocean Management Plan (2015), which employs a compatibility assessment, screening analysis, and optimization tool to identify potential transmission corridor routes for further characterization, investigation, and assessment work, with the goal of synchronizing transmission planning and siting with the next stages in the BOEM process, including leasing, site assessment, and National Environmental Policy Act analysis (Commonwealth of Massachusetts, 2015).

The European Marine Spatial Planning (MSP) Platform (2020) offers six cable-related solutions as follows:

- Develop corridors for cables and pipelines as part of an offshore grid plan.
- Use MSP to co-design suitable cable routes.
- Develop no-anchor zones in well-specified areas. Develop no trawl zones alongside cables and pipelines.
- Require cables and pipelines to cross shipping lanes by the shortest route possible.
- Require cable and pipeline companies to use appropriate burial methods.

Optimize Export and IAC Layouts that Account for Existing Fishing Activity, Including Minimizing the Amount of Cable Laid

The impact of inter-array and export cables on fishing activity can be minimized through consultation with the fishing industry and through an understanding of current fishing activity in the WEA such as trawl orientations and transit routes. Cable layouts can be designed so that they have a reduced impact on fishing activity and vessel transits within a WEA if these considerations are taken into account.

Laying Power Cables Using the Method that Causes the Least Damage to the Seabed

Vize's 2008 report covers types of cables and small diameter pipelines currently installed in the European Union (EU) shelf marine environment; installation and maintenance techniques for cable and pipeline installation; specific physical impacts to seabed during installation, covering a wide-range of sediment types; and impacts related to intertidal habitats, subtidal ecology, natural fish resources, commercial fisheries, marine mammals, ornithology, shipping and navigation, safety (collisions), seascape and visual character, and marine and coastal archaeology. Where cable installation activities are proposed within sensitive locations and the significance of the impact is high it may be possible to mitigate the effect by altering the cable route or micro-siting of the cables to avoid localized areas. Baseline information on the distribution of sensitive habitats and species within the construction area can be effectively used to plan the positioning of anchor arrays while disturbance due to anchors can be further reduced by using tenders to lift the anchors rather than dragging them across the seabed.

Access to a site requires careful planning to avoid any sensitive features. Vize et al (2008) advises that it may be necessary to remove vegetation prior to installation and replant/enhance following installation. Stabilization techniques may also be necessary in certain conditions. The choice of cable route and cable laying techniques should be determined following an assessment of existing commercial fishing activities in the area and the sensitivities of the resources upon which they depend. The use of best engineering practices would be employed, such as ensuring that 100% of the cable route has adequate protection with no exposed sections of cable, wherever possible. Using suitable local fishing vessels as guard vessels for cable laying operations provides useful alternative income to the fishing industry. Monitoring of the cable route post installation (e.g., multibeam or side scan sonar) and regular communication with fishermen should help minimize impacts and risk from construction operations. Communication with fishermen will be greatly facilitated using a suitable fisheries liaison officer (Vize et al., 2008).

Laying Cable with Opposing Electrical Currents Alongside Each Other (HVDC) and Sufficient Burial Depth to Prevent Fishing Gear Interactions

At the Beatrice Offshore Windfarm Ltd (*BOWL*), various forms of embedded mitigation were considered such as requiring that IACs and export cables be protected from third parties, primarily by seabed burial to the required depth to achieve the desired level of protection against assessed local threats/seabed activities. Where sufficient cable burial depth was not achieved or cable burial was not possible, BOWL required the installation of suitable cable protection, with consideration to fisheries interests when selecting cable protection methods (Prepared by Brown and May Marine Limited, 2015). Petruny-Parker et al (2015) states the importance of burying and regularly monitoring the burial depth of power cables to minimize exposure to electromagnetic fields. It is also important to lay cables with opposing currents alongside each other and dig them into the seabed (Mackinson et al., 2006).

Planned Cable Location and Directionality with Delineation of Cable Locations on Charts

Fishermen have requested the reporting of seabed hazards with spatial precision and regular communication before they would consider returning to the windfarm areas (Gray et al., 2016). Fishermen recommended a greater use of concrete mattresses rather than rock armoring to protect cables. Another fisherman said that “More accurate seabed maps of cables, cable crossing points, rock armoring, seabed debris etc. may encourage fishing closer to the turbines and within the windfarm." Gray et al. (2016) continues to state that the potential risks to fishing inside offshore windfarms could be reduced by involving the industry in the development of cable plans, the provision of comprehensive, up-to-date and readily available maps of potential seabed hazards to fishing; use of fishing-friendly cable armoring structures; more effective cable burial techniques, particularly where the nature of the seabed can significantly change; durable cable armoring; removal of waste material; post-installation surveys to verify that fishing activities can safely resume and communication of findings to the fishing industry, and regular monitoring for cable exposure and other unmapped seabed hazards and communication (Gray et al., 2016). The best way for fishermen to avoid catching cables is to know where they are and stay away from them when using anchors, grapnels, and any other gear that penetrates the seabed or snags cables (Drew and Hopper, 2009).

Consideration of Decommissioning Plans

It is also important to consider a decommissioning plan that weighs the pros and cons of abandonment versus recovery of the cabling after the operational life is complete (NYSERDA, Tetra Tech, 2020). The decommissioning plan should detail the standards and timeline developers must meet for restoring the lease area to its original state, which is of major priority for the fishing industry.

2.2.4 Protective Materials

2.2.4.1 Risk Description

Offshore wind projects require the introduction of materials to the seafloor to protect the turbine and cable infrastructure against changing benthic conditions and accidental damage from marine industries and their offshore activities (NYSERDA/TetraTech, 2020). Such material can take a variety of forms, including natural boulders, gravel, concrete, polyurethane, or synthetic fronds to replicate a natural range of habitats (Glarou et al., 2020). Otter trawls, beam trawls, scallop dredges, gill nets, and demersal longlines all involve weighted nets, chain bags, or lines that may snag on cable armor (NYSERDA/TetraTech, 2020). However, the risk of damage has been considered low, given modifications (or the potential for modifications) to bottom gear used in areas where structure is common (e.g., rollers, cookies, rockhoppers, etc.), designed specifically to pass over natural and artificial seabed obstacles to reduce the probability of gear damage or loss. Vineyard Wind (2021) stated that it may engage with the fishing industry to determine what form of additional cable protection measures (rock placement, rock bags, concrete mattresses, and/or half shell) would be the least likely to create new "hangs" (or snags) for mobile gear.

Export cables from an offshore wind array may need to cross other subsea assets or other pre-existing assets (e.g., fiberoptics or other cables) between the offshore wind farm and the shore landing, resulting in the need for protection at these crossings (NYSERDA/TetraTech, 2020). A layer of protection is applied after the new cable is laid on top of the crossed cable. Top and bottom protection materials at cable crossings can be concrete mattresses or rock berms, for example. Many mats have tapered edges to minimize the risk of fishing gear snagging; the installation contractor should also ensure the mats are laid flat to minimize the risk.

Scour protection can be used to prevent the erosion of sediment on the seafloor around individual foundations of offshore wind turbines. The functionality of scour protection has been analyzed for different European offshore wind farms, and it was suggested that further research may be needed to optimize the dimensioning of scour protection systems and to study the use of new materials (Matutano et al., 2014). Material used to protect from sediment erosion around the turbine base (i.e., scour) is often made of rock and may include a filter layer of gravel that is further shielded by a rock armor layer and placed around the foundation of the turbine (Glarou et al., 2020). The footprint of the scour varies with turbine size, environmental conditions, and other factors, with a radius typically reaching up to 20 m or sometimes more around a monopile. The size and design of the scour protection, and whether scour protection is needed at all, is determined by wave and current activity, water depth, and sediment characteristics, along with structural aspects of the turbine. For example, Vineyard Wind's COP indicates it would place scour protection around all foundations to stabilize the seabed near the foundations as well as the foundations themselves; the scour protection would be ~3 to 6 ft (1 to 2 meters) in height, would extend away from the foundation as far as 92.5 ft (28.2 meters), and would consist of rock and stone ranging from 4 to 12 inches (10 to 30 centimeters) (Vineyard Wind, 2021).

Based on a systematic literature review, Glarou et al. (2020) concluded that scour protections meet the definition of an artificial reef and may increase populations of species that live in, spawn at, or feed around hard strata. The authors suggested conducting further empirical research into tailoring future scour protection designs to enhance abundance and diversity of desired species. In the Dutch North Sea, eco-friendly designs of scour protection have been explored, with the aim to enhance ecological functioning in offshore wind farms (Lengkeek et al., 2017). Guidelines associated with these designs include specifications on types of substrate materials, configurations, and how efficacy of these scour protection structures can be monitored and evaluated (e.g., Carey et al., 2020).

2.2.4.2 Impact Minimization Strategies

Impact minimization measures for protective materials include, but are not limited to:

- Additional research/R&D on materials design to understand fishing and environmental impacts, including reef effect.
- Requiring removal of debris from the seabed resulting from OSW construction and operation.

Additional Research/R&D on Materials Design to Understand Fishing and Environmental Impacts Including Reef Effect

Petersen and Malm (2006) underscored the importance of conducting more research on how to design a wind turbine footing for specific biological purposes. They attest that research is needed into the habitat requirements of key species, species interactions, energy flows within a windfarm system, and an understanding of scale. The authors claim that if the management decision is that of avoiding or minimizing potential impacts of offshore windfarms, the focus should be on surfaces and arrangements that result in the least settlement of organisms, and cleaning of the construction materials should be considered as a mitigating action.

Minimization measures could include ensuring that scour protection (e.g., geotextile bags or concrete blocks or similar) does not further endanger fishing equipment such as trawlers (Matutano et al., 2014). Based on European analysis, integration of an effective scour risk assessment during the site development environmental impact assessment (EIA) forms an essential, and increasingly important, factor in protection. A holistic approach to scour risk assessment involves collecting field knowledge on the natural sediment transport across the entire site throughout the seasons, together with information on the sub-surface sediment stability (Black, 2008).

Fazeres-Ferradosa et al (2019) proposes an optimization of scour protections by combining reliability-based techniques with the novel concepts of dynamic and wide-graded armor layers. The goal is to develop a decision support system (DSS) for scour protection design and risk and reliability analysis to be used by professionals and researchers dealing with fixed foundations applied to marine renewable energy projects (e.g., wind, wave, and tidal).

Current evidence suggests that fish species of both high- and low-commercial value utilize the hard substrata that scour protection adds to the marine environment, although species that rely on other substrata will be displaced or diminished. Glarou's (2020) review has identified several scour protection manipulations that could influence abundance and diversity of marine species. The authors claim that modifying future scour protection designs, fish abundance and diversity may be enhanced. (Glarou et al., 2020) While Krone et al. (2017) states that scour protections made of synthetic materials could offer less spatial niches and might have chemical characteristics which reduce the inhabitability for individual megafauna species. Further research on the ecological effects of offshore wind structures is needed as renewable wind energy becomes more widely adopted (Andersson and Ohman, 2010).

Requiring Removal of Debris from the Seabed Resulting from OSW Construction and Operation
Minimization measures around construction debris removal during the construction and O&M phases of the project have been found throughout many articles collected as part of the literature review.

2.3 Icing and Ice Throw Risks

2.3.1 Risk Description

Depending on the region, one of the crucial hazards encountered by commercial fishing vessel operators is the phenomenon known as icing (Chatterton and Cook, 2008; Mustafa et al. 2019). Two types of ice are of concern for fisheries operations in and around OSW arrays located in cold climates: (1) atmospheric icing, which may lead to ice formation on turbines' structures—including on rotor blades, which can result in "ice throws" and (2) sea ice or ice pack, which could impact vessel navigation in addition to causing additional static and dynamic forces on the turbine structure.

Regarding sea ice, thick ice in cold seas (such as ice-bound waters of northern Europe) may induce the pile-up phenomenon which can cause increased loads on the foundations of the turbines (Battisti et al. 2006). Some amount of this "pack ice" occurs every winter in certain ice-bound areas, typically in springtime when sea ice starts to move. However, a NYSERDA study found this type of pack ice is not an issue in the New York Bight given its more temperate climate conditions, compared to northern Europe (NYSERDA, 2010).

The accumulation of ice on a vessel's superstructure can, in rare circumstances, lead to tragic incidents such as capsizing caused by instability. Microclimate or micrometeorological impacts are observed around OSW farms (Siedersleben et al., 2018). Wind farms represent an additional source of turbulence and may influence the stratification of the marine boundary layer. The few studies thus far that have investigated the potential effect of wind farms on the marine boundary layer were motivated by visible cloud effects observed at offshore wind farms, including off the coast of Denmark. Fishing vessels can "ice up" while working offshore, and increased variability in icing conditions may be introduced by the microclimates generated within OSW farms.

Atmospheric icing can lead to ice shedding (ice throws) during fishing and other vessel operations. In Europe, Battisti et al. (2006) developed a procedure for analyzing the risk of ice pieces shedding from turbines, based on the work of Seifert et al. (2003) with onshore turbines in Germany and Austria. The diameter of an ice risk zone was calculated and could be considered for informing vessel operations during periods of potential ice shedding. Numerical simulations were performed to predict the ice fragments' distribution on the sea surface around a typical megawatt-size three-bladed offshore wind turbine, with relevance to areas in Northern latitudes where sea ice occurs annually. The simulations showed ice piece distributions with a major strike probability in the area within 200 m around the turbine, with a maximum distance covered by an ice piece of about 250 m. The "strike probability per year and per square meter" can be computed from the distribution of the ice fragments on the sea surface. The strike probability was considered for risk to a maintenance vessel but could also be relevant to a fishing or other vessel within an operational area. In the Canadian context, Biswas et al. (2012) developed a model of ice throw trajectories from wind turbines and concluded that "although [it] may be a relatively rare event… a 1 kg [ce] plate-like fragment could travel up to 350 m from the base of [a] turbine." According to Battisti et al. (2006), safety issues for operating personnel during maintenance due to ice strikes risk is still considered an open and unsolved problem.

Specific to the New York Bight, NYSERDA (2010) assessed the potential risk from ice accumulation on wind turbine blades and the generation performance of a wind plant. Two primary types of icing exist within the New York State offshore region: "(1) atmospheric icing, which includes glaze (caused by liquid rain or drizzle that freezes on contact with a surface) and rime (white or milky deposit of ice formed by the rapid freezing of super-cooled water drops (i.e., fog) as they impinge upon an exposed object), and (2) icing from sea spray. For the New York Bight area, the atmospheric icing frequency is predicted to be minimal, occurring less than 0.1% (below nine hours per year). Icing from sea spray is expected to be limited to elevations below 16 m (52 ft), which is below the lowest approach of the wind turbine blades." As turbines become increasingly larger in size (e.g., Haliade-X, GE, 2020), the distance from the ocean surface will also increase and icing from sea spray will become even less of a risk.

For the Vineyard Wind project, the risk of icing was assessed in its Navigational Risk Assessment (NRA) report (Vineyard Wind, 2018). The NRA utilized a method established by the Department of Wind Energy, Technical University of Denmark that studied "conditions favorable for the formation of atmospheric icing" in the context of wind energy and operation of wind turbines. Ice accumulation was observed to occur when air temperature was less than 0 °C (32 °F), relative humidity was greater than 95% (i.e., high fog or cloud conditions), and during relatively low-wind speeds. A 10-year query of NOAA meteorological data for the Nantucket Shoals monitoring buoy showed that conditions for the formation of atmospheric icing never occurred for the historical record analyzed, indicating that ice formation is a very low risk in this area. Even so, as further precaution for mariner safety, Vineyard Wind will advise of weather conditions of potential ice formation as described in the Mariner Communication Plan.

Possible mitigations associated with icing and ice throw risk at OSW farms are provided below.

2.3.2 Impact Minimization Strategies

Impact minimization measures for icing and ice-throw risk include, but are not limited to:

- Preconstruction assessment.
- Wind turbine design adjustments and maintenance modifications (including cold weather packages, deicing and anti-icing devices, and systems that reduce the actions of sea ice).
- Further research around passive and active ice protection techniques.

Preconstruction Assessment

As a general recommendation it can be stated that windfarm developers should be very careful at ice endangered sites in the planning phase and take ice throw into account as a safety issue (Seifert et al., 2003).

Parent and Llinca (2011) assert that icing events should be evaluated during the assessment phase by taking measurements during at least one year using an ice detector, heated/unheated anemometers with heated boom, dewpoint, and visibility detectors (the simultaneous indication of icing from at least two different sources improves prediction reliability). Icing assessment should be performed with multiple anemometry and relative humidity (double anemometry helps estimate onsite icing) and icing detection should be performed using ice sensors and power curve check during operation. In summary, the authors recommend utilizing a better control strategy that properly uses deicing instead of anti-icing.

Wind Turbine Design Adjustments and Maintenance Modifications (including cold weather packages, anti- and deicing devices, and reducing the actions of sea ice).

Mustafa et al. (2019) offers additional minimization measures as follows:

- Wind turbine components and foundation should be designed to be resistant to the damages and vibrations caused by ice accretion and sea ice.
    - Ice mitigation systems should comprise cold weather packages, anti-icing/deicing devices and systems reducing the actions of sea ice. The design of such systems should be integrated in the design of the turbine to assess the economic benefit of their operation in cold climates and to set limits for continuous operation during icing periods (Battisti et al., 2006).
- Adopt cold weather packages and offshore corrosion protection systems.
- Design inspection and maintenance planning to accommodate limited access to wind turbines due to seawater freezing.
- Provide required training for maintenance crews and work only when their health and psychological conditions are appropriate.
- Ensure use of proper equipment and clothing and follow regulations like using safety ropes and cranes and working in pairs, etc.
- Consider utilization of drones (or similar techniques) to spray deicing liquid to the blades to clean blades off accreted ice.
- Investigate effects of the use of chemical Anti/Deicing systems (ADIS) on the environment.

Further Research Concerning Passive and Active Ice Protection Techniques

Fakorede et al (2016) offers passive and active ice protection techniques that require additional research:

- Improving ice protection methods by combining techniques; improving control strategies for anti-icing and deicing systems.
- Determining the long-term effects of heating on wind turbines blades.
- Overcoming the limitations of active pitch-control techniques (impact of ice loads on wind turbine life, and effectiveness of the strategy itself).
- Controlling and optimizing active pitch-control techniques.
- Optimizing ice detection methods; optimizing icing-event forecasting.

2.4 Operationality of Fishing Vessel Radar

2.4.1 Risk Description

Another potential safety concern for fishermen is the functionality of their radar within OSW farms because wind turbines may cause interference. Fishing vessels heavily rely on radar to track other vessels and gear (vessels equipped with AIS can also track other structures that have been equipped with AIS transponders), especially in bad weather conditions. In the U.S., several federal agencies (U.S. Department of Defense [DOD], U.S. Department of Energy [DOE], Federal Aviation Administration [FAA], and NOAA) established the Wind Turbine Radar Interference Mitigation

(WTRIM) Working Group to address wind turbine radar interference as an impact to critical radar missions, ensure the long-term resilience of radar operations in the presence of wind turbines, and remove radar interference as an impediment to future wind energy development. A webinar held in July 2020, introduced marine navigation radar, and included presentations on marine navigation issues, existing studies, wind developer and mariner perspectives on the issues (WTRIM, 2020).

Turbines may create irregularities on vessel radar, preventing captains from being able to distinguish individual targets from each other. Vega et al. (2013) outline the impacts of wind turbines on radar, including marine radar, and identify echoes from the turbines (which can hide the presence of small vessels) as the main issue. Some practical trials have concluded it is possible for trained mariners to safely navigate in and around wind farms and identify other vessels (MARICO Marine, 2007). However, in the U.S., operators of commercial fishing vessels less than 200 gross tons, which make up the vast majority of fishing vessels operating in Southern New England and the Mid-Atlantic regions, are not required to have any formal training on the use of marine radar. More recently, USCG has stated that the potential for interference with marine radar is site specific and depends on many factors including, but not limited to, turbine size, array layouts, number of turbines, construction material(s), and the vessel types (USCG, 2020).

Offshore wind developers funded a study investigating the effects to marine radar of the Kentish Flats wind project in the United Kingdom (MARICO Marine, 2007). That study documented that "effects were generated on marine radar systems in the vicinity of wind farms," which included interference to the ability of radar operators outside of a wind energy array to identify small vessels within the array. The study also noted some valuable potential mitigation strategies. However, it was limited in that observations occurred only from about 1 nm outside of a wind energy facility and expressly warned it should only be used to draw conclusions from its specific context of "collision avoidance in pilotage waters from about 1 nm outside a single small wind farm, not to general navigation close to or within other anticipated wind farm developments." These reports were based on smaller turbine sizes than are currently proposed for use in U.S. waters; no studies were discovered for this literature review that evaluate radar interference associated with larger current generation turbines.

Previous reports associated with the Cape Wind project did indicate a significant potential for turbines to interfere with marine radar. The USCG commissioned a report titled "Report of the Effect on Radar Interference of the Proposed Cape Wind Project" which found that the project's implementation would significantly adversely impact the ability of a vessel inside or outside of the wind energy facility to detect a vessel within that facility by radar (USCG, 2009). In a separate study, a baseline evaluation was conducted using modeling (but not studies of operational offshore wind facilities) to simulate potential electromagnetic and acoustical challenges to sea surface, subsurface and airborne electronic systems presented by offshore wind energy facilities (Hao Ling et al., 2013). This study indicated a potential for radar interference from offshore wind turbines.

Some of the available literature contains measurements that may be useful in considering turbine spacing impacts to radar interference or safe vessel distance guidelines. The Cape Wind FEIS indicates that secondary reflections (aka "false targets") cannot occur closer than the second circle of turbines due to physics (Perry, 2008). Overall, the number of secondary reflections close to the radar is small but increases as the distance into the wind farm increases. The Vineyard Wind FEIS (2021) stated that offshore wind projects have the potential to interfere with marine vessel radars. The FEIS stated that "Marine radars have varied capabilities and the ability of radar equipment to properly detect objects is dependent on radar type, equipment placement, and operator proficiency." General mitigation measures were identified to minimize the impacts of loss of radar detection, such as properly trained radar operators, properly installed and adjusted vessel equipment, marked wind turbines, and the use of AIS.

Turbine spacing may impact the radar range that a fishing vessel can utilize when navigating within an array. In an assessment of the Cape Wind proposed wind farm, Brookner (2008) indicated that at a radar range of 0.75 nm, multiple turbines within that range can create enough clutter as to make a small (10 square meter) craft difficult to detect or to notice. USCG Closest Point of Approach guidelines suggest a minimum distance of 0.5–1.0 nm between vessels and fixed or moving hazards, and evidence supports that small craft cannot be distinguished from turbine radar signatures until they are at least 385 m (0.21 nm) away from a turbine (UK Maritime and Coastguard Agency, 2004).

Radar concerns are not limited to vessels; all traditional radar systems operate using fundamentally the same technology. Literature describing interference from OSW turbines to other radar systems may be informative to those utilized by fishing vessels. The Department of Defense has repeatedly raised concerns that "radar clutter (i.e., "false targets") from the wind turbine blades would seriously impair the agency's ability to detect, monitor, and safely conduct air operations" (U.S. DOE, 2016). In response to early concerns over land- and sea-based turbines, the National Security Council requested the White House Office of Science and Technology Policy conduct an internal study in 2011 that found wind turbines interfered with radar used for national defense, security, aviation, and weather forecasting "by creating clutter, reducing detection sensitivity, obscuring potential targets, and scattering target returns. These effects on radar systems tend to inhibit target detection, generate false targets, interfere with target tracking, and impede critical weather forecasts" (Sandia National Laboratories, 2014).

Radar interference could have implications for search and rescue operations (SAR). Effects to airborne radar could affect SAR operations because the gain reduction necessary to remove clutter will obscure small targets, i.e., small craft, which tend to produce a weaker return signal. Small craft are more difficult to identify by airborne radar; for example, in a study using British lifeboats, vessels of about 35–40 ft in length were found to be difficult to identify (UK Maritime and Coastguard Agency, 2004). Several countries including the United Kingdom, Germany, Netherlands, Austria, and Norway require developers to obtain special permission for wind facilities to ensure that radar conflicts are minimized. Each has also established "protection zones" requiring setbacks from 5–50 nm around military radar systems (U.S. DOD, 2006).

See below for a more detailed discussion of possible mitigations associated with operationality of vessel radar and offshore wind farms.

2.4.2 Impact Minimization Strategies

Impact minimization measures for operationality of vessel radar include, but are not limited to:

- Upgrade radar systems.
- Modifications to turbine designs and/or design layout including use of reference buoys.
- Additional studies, training, and continued dialogue.

2.4.2.1 Upgrade Radar Systems

The USCG has identified several mitigation techniques to reduce the effect of the turbines on radar including reducing the radar cross section (RCS) of the turbines and increasing the RCS of the vessels within or near the windfarm (Perry, 2008). Increasing the RCS of vessels within the windfarm would increase the signal strength of the radar return from the vessel and result in a more visible vessel. However, since the main problem with the windfarm is not radar visibility, but noticeability, USCG claims that increasing the RCS of vessels would have only minor effect on navigational safety while decreasing the RCS of the wind turbines would tend to reduce the number of false targets present. Reductions of approximately 10–15dB in turbine RCS could be possible using a variety of techniques. However, false targets will still occur since the turbines would remain significant reflecting objects (USCG, 2009; Perry, 2008).

These effects from shipborne or shore-based radar can be mitigated by vessels keeping well clear of windfarms in open water or, where navigation is restricted, keeping the windfarm boundaries at suitable distances from established traffic routes, port approaches, routing schemes, etc. (UK Maritime and Coastguard Agency, 2004).

The mitigations that exist at present to completely preclude any adverse impacts on air defense radars are limited to those methods that avoid locating the wind turbines in radar line of sight of such radars. These mitigations may be achieved by distance, terrain masking, or terrain relief and requires case-by-case analysis (U.S. Department of Defense, 2006).

2.4.2.2 Modifications to Turbine Designs and/or Design Layout Including Use of Reference Buoys

Sandia National Laboratories in its 2014 ITF&E Industry Report proposed concepts to modify the size, shape, or materials of the wind turbines themselves, especially focusing on the blades, to reduce the radar reflectivity of the wind turbine so that it is no longer a meaningful source of clutter to the primary radar. Other possible impact minimization measures include changes to the windfarm design to mitigate the impact on surveillance operations, radar replacement (replacing existing radars with more advanced radars), using infill radars to augment the coverage of the existing radars, radar upgrades, or C2/automation upgrades to improve tracking performance.

MARICO Marine (2007) states that it is highly beneficial for maritime operations to improve the performance of marine radar generally. Knowing that interfering spurious echoes can be produced by ships' structures and fittings within the radar scanner aperture, MARICO says that scanners should be sited in the most advantageous position to these, after taking all other considerations into account. This will be particularly important where vessels' trades take them close to offshore windfarms known to return very strong echoes. These considerations should include problems related to the siting of scanners off the fore and aft line. Vessel Traffic Service (VTS) radar scanners, particularly those mounted on or near wind turbines should be carefully sited to avoid coincidence of reflections from both large slab-sided vessels and the windfarm turbine towers within the reflected beam width.

There are several applicable mitigation options, all of which are based on modifications to be applied at the windfarm or in the radar system. The options on windfarms rely on modifying windfarm layout and the use of stealth technologies in the turbine design; the techniques in the radar services consist of incorporating advanced filters and signal processing, adaptive scanning, or installing new radars that obtain unaffected data in the area around the windfarm (Vega et al. 2013).

MARICO Marine endorses the concept of using designated reference buoys or other appropriate targets, to aid adjustment of radar settings, could provide a valuable aid to the operation of marine radar near and within windfarms (MARICO Marine., 2007).

Case-by-case radar impact studies should be collected before a windfarm is installed (Angulo et al. 2014).

2.4.2.3 Additional Studies, Training, and Continued Dialogue

The Federal Interagency Wind Turbine-Radar Interference Mitigation (WTRIM) Strategy specifies mutual goals and objectives established under a memorandum of understanding (MOU) between the Department of Defense (DOD), the Department of Energy (DOE), the Federal Aviation Administration (FAA), and the National Oceanic and Atmospheric Administration (NOAA) for ongoing collaboration to mitigate technical and operational impacts of wind turbine projects on critical radar missions that operate in proximity. The authors state that realizing the benefits of continued wind energy development while ensuring national safety and security can only be accomplished through continued dialogue and proactive mitigation actions between renewable energy developers and those charged with executing critical radar missions and coordinated investment across the federal government in mitigation measures (Gilman et al., 2016).

Ling et al. (2013) recommends that research and development into approaches to mitigate the impact of offshore windfarms on electronic systems be initiated through new research funding. The systems to be addressed, in order of their sensitivity to windfarm interference, are: (1) airborne radars operating in high-resolution sensing modes, (2) coastal high frequency (HF) radars, (3) marine radars, and (4) acoustical sensors operating below 1 kHz. For radar systems, Ling et al. states that particular focus should be placed on low-cost solutions such as those based on signal filtering algorithms or modified navigation practices. In the case of underwater noise, one might investigate possibilities for expanding techniques currently focused on pile driving operations (such as bubble screens, pile sleeves, and hydrodynamic sound dampers) to entire windfarm installations (Ling et al, 2013).

Finally, it is recommended that enhanced radar training should be included in future training courses, in particular, simulator training (MARICO Marine, 2007).

2.5 Search and Rescue

2.5.1 Risk Description

Navigational safety is a consideration for mariners affiliated with both the fishing and OSW industries. Incident data reports provide an overview of health and safety performance at offshore wind farms in the UK, including industry benchmarking metrics (G+ Global Offshore Wind, 2016). In 2016, there were nine emergency response or medical evacuation (ERME) incidents reported from UK sites, eight on operational sites and one on a construction site. For these ERMEs, 56% were from a vessel, and 44% from a wind turbine generator.

The Maritime and Coastguard Agency (MCA) provides SAR response in the United Kingdom Search and Rescue Region. MCA requires the development of Emergency Response Cooperation Plans, including details relevant to SAR operations, for the construction, operation, and decommissioning phases of a WEA (OREI, 2020). As proposed for WEAs in U.S. waters, UK fishing vessels are not excluded from offshore energy areas but guidance from the MCA on Search and Rescue operations maintains that there may be factors which limit the "options normally available to the SAR Mission Coordinator, and so SAR response to offshore renewable energy may, unless well supported by the developer/operator resources, be consequently limited or prevented" (OREI, 2020). In instances where SAR may be particularly difficult, MCA may require additional mitigation measures from the OSW developer to ensure that SAR is possible. Experience from offshore development in the UK highlights the benefits of coordination between agencies and consistency (in protocols, numbering, array layout, etc.) of wind energy areas to improve the likelihood of a successful SAR mission.

As with all navigation and vessel operations, a captain is responsible for his or her crew and vessel, and thus aims to minimize risk to the maximum extent possible. In 2019, BOEM announced a Notice of Availability of Guidelines for Lighting and Marking of Structures Supporting Renewable Energy Projects for public comment, and OSW developers and fishermen worked together through RODA's Joint Industry Task Force to provide BOEM and USCG further recommendations for aids to navigation. Because vessels are not anticipated to be legally excluded from offshore wind farms in the U.S., mariners will largely need to rely on appropriate marking of structures and their own discretion to determine if it is practicable to enter an area. In addition to environmental conditions such as weather, visibility, and currents, insurance coverage, company policy, or presence of aids to navigation may influence this decision. The feasibility of search and rescue (SAR) will also affect a captain's decision to enter an OSW array; if fishermen knew the USCG was unable to conduct SAR operations within a wind array (or unable to operate during certain weather) the risk of entering an area may become too high.

A series of Port Access Route Studies by USCG have analyzed SAR operations in and around WEAs. In the final MARIPARS (USCG, 2020) USCG data from 2005 to 2018 showed an annual average of 9.5 incidents requiring SAR in Southern New England area now leased for wind energy development. This analysis demonstrates the need for robust SAR procedures within a WEA.

The MARIPARS highlights the necessity of predictable patterns and adequately spaced wind turbines for USCG surface and aviation assets to conduct SAR missions. For aviation support during SAR missions, USCG has outlined several recommendations to ensure helicopter maneuverability in the MA-RI WEAs (USCG, 2020). Among others, recommendations to aid in SAR include:

- Minimum 1 nm between turbines along a search path.[15]
- Standard and uniform grid.
- Continued evaluation of SAR operations and mitigation measures as wind farms are built out.

Specific to the MA/RI leases, turning within an array is critical and circumstances such as turbine spacing of less than 1 nm or poor environmental conditions, requiring a SAR helicopter to fly the entire length of an array before turning, may cost vital time during a rescue mission. USCG (2020) states that spacing turbines with a minimum of 1 nm along a search path (parallel lanes) supports SAR aviation missions as this spacing creates a 0.5 buffer on each side of the helicopter and allows for turning into the adjacent lane using normal search speeds and flight procedures.

Predictable patterns of turbine layout will also assist USCG during its SAR operations. The MARIPARS (USCG, 2020) recommends a standard and uniform gridded layout for the Southern New England OSW lease areas and notes that spacing between turbines in multiple orientations will provide more flexibility for SAR missions. This may prove to be vital during conditions with poor visibility. Lastly, the MARIPARS emphasizes the “learn as we go” approach. USCG plans to evaluate SAR operations and various mitigation strategies as WEAs are built out in U.S. waters.

USCG will also have to make decisions for the safety of its assets and crew during SAR missions. Environmental conditions such as icing, thunderstorms, or turbulence, will greatly affect helicopter SAR operations. “In some cases, weather and wind may be so severe as to not allow for USCG assets to enter the WEA” (USCG, 2020). This may become particularly concerning in inclement weather that could force vessels to return from offshore immediately, requiring mariners to assess the risks between taking the most direct route to port through a wind array versus a longer route circumnavigating a project.

As previously stated, individual OSW projects in the United States are required to complete project-specific navigational safety risk assessments (NSRAs) based on the individual specifications of a project (BOEM, 2020). These NSRAs are reviewed by the U.S. Coast Guard to evaluate the following: (1) the impact the offshore energy installation will have on other marine users and (2) the potential for it to interfere with vessels, aircraft, or other authorized users of the air space and the sea surface, water column, or sea bottom (for example, fisheries).

See below for a more detailed discussion of possible mitigations associated with search and rescue impacts.

2.5.2 Impact Minimization Strategies

Impact minimization measures for search and rescue include, but are not limited to:

- Protective arrangements, emergency response plans, and marine areas/safety zones around windfarms.
- Developer-provided support vessel, surveillance, turbine lighting, use of navigational aids (e.g., AIS, waypoints) and layout numbering.
- Design of collision-friendly foundations and clustering of maintenance activities.
- Collision risk assessments early in project stages and a collision reporting system.

2.5.2.1 Protective Arrangements, Emergency Response Plans, and Marine Areas/Safety Zones around Windfarms

In the MA-RI Wind Energy Area, for the purposes of safety zones, the USCG recommends lanes for search and rescue operations to be oriented in a north to south, east to west direction, and 1 nm wide to ensure two lines of orientation for USCG helicopters to conduct operations (USCG, 2020). The safety zones around an offshore windfarm are typically up to 500 m around the project area during construction and decommissioning. A safety zone of 50 m around offshore wind foundations can also be established within which the speed of maintenance ships is restricted (depending on weather conditions) and/or maintenance activities are regulated (Presencia and Shafiee, 2018).

An offshore windfarm developer/operator may need to provide mitigation measures to ensure effective search and rescues can be performed. The Maritime and Coastguard Academy (MCA) in the UK provides offshore emergency management courses for the industry to enable marine coordinators, installation managers, senior management, crew transfer vessels (CTV) and operations support boat crew and any other company staff who may be involved in the management of and response to emergencies, to be trained and made aware of the correct procedures and processes to be followed in SAR situations and other emergencies. The MCA requires earliest possible discussions with developers on proposed layout options for any offshore windfarm before decisions are made on the final layout design (Maritime and Coastguard Agency, 2020).

2.5.2.2 Developer-Provided Support Vessel, Surveillance, Turbine Lighting, Layout Numbering, and Use of Navigational Aids (e.g., AIS, Waypoints)

According to the Maritime and Coastguard Agency in the UK (2020) principal OSW mitigation measures include:

- Linear layouts.
- Clear and unique identification markings visible to surface craft and aircraft.
- Hover reference marking of wind turbine blades.
- Aviation hazard and aviation search and rescue (SAR) lighting of wind turbines.
- Lighting and marking in accordance with the UK General Lighthouse Authorities requirements.
- Rapid control and shutdown of individual and groups of devices (wind turbines in particular).
- Provision of in-field AIS available for use by HM Coastguard.
- Provision of in-field marine-band VHF DSC radio systems available for use by HM Coastguard (Lowson, P., 2016).

Also, for safety, vessels involved in the construction, operation, and maintenance of Hornsea Three (including guard vessels and survey vessels) were provided with the relevant lines of communication to minimize interaction with fishing vessels when undertaking their normal activities (Hornsea, 2019).

2.5.2.3 Design of Collision-Friendly Foundations and Clustering of Maintenance Activities

Moulas et al. (2017) encourages designing turbine foundations in a "collision-friendly" way but, first and foremost, to invest in more sophisticated collision models (hazard analysis tools) using finite element analysis to accurately assess the consequences of ship-wind turbine collisions. The lack of adequately detailed damage assessment model may lead to under- or over-designed control measures for protection of wind foundations and ships against collision impacts, and thereby incurring extra cost to windfarm operators or ship owners. The model could include:

- Inclusion of soil parameters into the ship-wind turbine collision damage assessment model.
- Determination of the residual strength of the structure after the collision impact.
- Investigation of the effects of wind and wave loads during the collision.
- Determination of the effect of the collision on the fatigue life of the joints.

Ding et al (2014) recommends use of a 3D model using ABAQUS/Explicit which includes the model of bucket foundation, tower and nacelle of the offshore wind turbine, and ship bow.

Presencia et al. (2018) also recommends improvement of a ship-wind turbine collision reporting system. To monitor the risk of ship-wind turbine collisions, a data collection and reporting system should be established in the offshore windfarm to record and follow up with ship collision incidents, allowing the identification of trends and implementation of further controls.

Dai et al. (2013) concludes that collisions between turbines and service vessels even at low speed may cause structural damage to the turbines and suggests a need for improved consideration of this kind of collision risk when designing offshore wind turbines and windfarms.

Christensen et al. (2001) states that collision-friendly foundation design (CFFD) should relate to the characteristics of the soil, properties of the material, wind conditions, etc. It will be important to design crashworthy devices for offshore wind foundations to absorb some portion of the collision kinetic energy from ships through plastic deformation and protect the wind turbine structures from damage. Maintenance vessels too must be designed and manufactured in a way that they can better withstand collision forces and stresses. It is important to select appropriate ship vessels for maintenance purposes, e.g., a boat with a landing structure such as an Ampelmann system keeps appropriate distances away from turbines, resulting in reduced probability of direct contact and wear between ship and turbine structure. It is also important that maintenance ships be equipped with reliable navigation, propulsion, and control systems. Since the sizes of ships needed to carry out the maintenance tasks for deep-sea installations are usually larger than those used for shallow-water assets, the magnitude of consequences of a collision will be higher. New regimes of proactive maintenance for deep-water offshore windfarms must be developed to avoid unexpected failure in structures. Clustering of maintenance and repair works for wind turbines can help in this regard. Maintaining the turbines individually can result in high frequency of ship traffic, and hence, increased risk of ship collisions with turbine structures.

2.5.2.4 Collision Risk Assessments Early in Project Stages and a Collision Reporting System

Biehl et al (2006) states that the risk of collision can be reduced, but it cannot be totally avoided. In addition to the "safe" structures and the evaluation of collision risks, the risk management for each windfarm should include two goals:

- Minimizing the collision risk by observing and controlling ship traffic: radar, optimizing ships for collision safety, and training of the crews of ships.
- Developing countermeasures: scenarios that might lead to collisions should be compiled and strategies developed to avoid them.

Christensen et al (2001) states that it is of great importance to initiate risk analysis activities at an early stage of a project to ensure that proper action can been taken in the detailed design phase if any needs are identified. The results of the updated risk analysis may lead to proposals for introduction of risk reducing measures, such as different types and markings, protective arrangements and/or safety monitoring, or guard vessels.

A simplified and more rapid calculation method is needed for collision risk analyses (Bela et al., 2017). A proper risk mitigation plan, if needed, is established to reduce "as low as reasonably practicable (ALARP)" the total risk of ship-wind turbine collisions.

Mitigation measures recommended by studies on ship collisions with offshore wind turbines include: the use of waypoints, protective arrangements, design of "collision-friendly" foundations, marine areas/safety zones around wind arrays, collision risk assessments early in project stages, use of navigational aids such as AIS, and preparing emergency response plans (Presencia and Shafiee, 2017). As large WEAs are built out in the U.S., developers should consider implementing mitigation measures that have already been identified. Mitigation measures recommended by RODA and the commercial fishing industry include dedicated 4 nm wide traffic lanes through large or adjacent WEAs (RODA, 2020b).

Additionally, mitigation measures to increase safety and SAR effectiveness can be supplemented by the offshore energy developer. As outlined by the MCA, the offshore energy industry can provide support through direct rescue response with support vessels, increase maritime surveillance through the deployment of AIS transceivers and radar, turbine lighting and layout numbering for quick and efficient reference, and extended offshore radio communication (OREI, 2020).

Search and rescue considerations are integral to evaluating the riskiness for a vessel to enter a WEA. Outlined above are several mitigation measures that may improve the success of a SAR mission and should be considered during the planning phase of an OSW project. International practice for SAR includes hailing and notifying all vessels near to an accident. This report focuses on fishing vessel operations within a WEA, but it is worth noting that as users share the space, rescue assistance for all operators offshore could come from SOVs, fishing vessels, and leisure crafts alike. It is paramount that the final backstop to ensure mariners safely return home, search, and rescue, is provided with as many tools as possible to succeed.

2.6 Additional Considerations

The topics considered in this section are outside the scope of what can be fully considered in this project, but they are important for consideration of the overall topic. These topics include changes to insurance policies; potential redistribution of species and fishing effort; and socioeconomic impacts to fishing communities and businesses. Impact minimization strategies are not included for these topics, which although very important, are not under the purview of this project to propose solutions.

2.6.1 Changes to Insurance Policies

Beyond physical operational constraints, a potential barrier to fishing vessel operations in OSW projects is the unknown future rates for vessel insurance and potential restrictions imposed by insurers. Fishing is generally prohibited within European OSW projects, except in the UK (Dupont et al., 2020). This has been determined on national levels, or at times by a developer and their insurers, due to safety concerns associated with accidental damage and collisions. In the UK, some fishermen have expressed concern that insurance costs would increase if they were to fish inside wind farms, and that this would constitute at least part of the reason not to fish inside any developments (Blyth-Skyrme, 2010). BOEM and USCG indicate there is currently no authority for either agency to restrict fishing vessels from transiting or operating in a WEA. But private insurers may elect to restrict coverage, or the price of coverage could increase, creating additional costs for a fishing business (European Parliament, 2020).

The Netherlands Enterprise Agency (RVO) conducted a workshop to understand the potential consequences of future offshore wind development for Dutch fisheries and included insurance companies as stakeholders at the workshop (Primo Marine, 2019). Presently many claims for OWFs are related to cable failures, and allowing fishing activities introduces new additional risks, which has implications for insurance companies that are by nature risk averse. The fishing vessel is essentially a lower cost asset, which can inflict a major (unintended) damage to higher cost assets (i.e., subsea cables), without proper mitigations in place. In Europe, insurance costs per year during the operational phase are already considered a significant percentage of the overall operational expenditure. An increase in risk of claims being made as well as an increase in frequency and value of claims, would likely result in a higher insurance cost (premium and/or deductible) for the wind farm developer/operator. To allow for safe fishing operations would require creating wider corridors, resulting in larger OSW farms or fewer turbines, and a probable increase in the cost of insurance policies for both wind developers and fishing industries.

In the UK, where fishing is not excluded from OSW farms, insurance companies predicted no increase in insurance premiums, based on responses from two companies (Blyth-Skyrme, 2010). However, fishermen have indicated a concern for increased insurance costs if they were to fish within an array. Opportunities were also identified related to insurance for fishing vessels inside wind farms, including that group rates for fishermen's cooperatives or regional groupings may be negotiable. However, European Parliament (2020) stresses that insurance for fishing vessels operating in UK wind farms is very problematic owing to the insufficient indemnity levels offered by fishing vessels' insurance policies.

As an emerging industry, the future impacts to fishing vessel insurance premiums and coverage extent from OSW development in the U.S. are largely unknown. Similarly, it is unknown how, or to what extent, restrictions to vessel access in an area may or may not change insurance and coverage for OSW developers. To protect their assets in the water, wind companies and their insurers will also be cognizant of how the continuation of vessel operations in an OSW farm will affect their risk and insurance coverage. In the U.S., the Vineyard Wind FEIS states that "At this time it is not possible to assess the potential number of insurance claims or future decisions by private insurance companies that could result in increased premiums or loss of coverage." (BOEM, 2020). As stated in the FEIS, Vineyard Wind has established a trust fund to support Rhode Island fishermen's navigational and safety equipment, which could be used to deflect any increases wholly or partially in those fishermen's insurance costs.

2.6.2 Potential Redistribution of Species and Fishing Effort

Multiple factors associated with OSW development can influence marine species and their distribution, including but not limited to installation and operational noise, electromagnetic fields (EMFs) generated by turbine cables, and the addition of large amounts of hard substrate to the environment.[16] While detailed consideration of the environmental interactions between OSW development and fish stocks is largely outside the scope of this report, it is not possible to entirely separate environmental conditions from an evaluation of fishing operations.

For certain foundation types, noise impacts from pile-driving during the installation phase are likely to be high (Hammar et al., 2014), and have thus resulted in a variety of noise mitigation measures. Beyond the installation, ongoing operational sound is at lower noise levels, but over extended periods, and should be monitored for any potential effects on fish and other species of commercial interest. Any negative impacts to fish, shellfish, squid, and other species could result not only in hard to quantify impacts to marine ecology but may also lead to less total allowable catch for fishermen across a stock range, resulting in reduced profit and potentially long-term operational success. EMF generated by cables can also influence marine life (Andersson and Ohman 2010), but the shielding on cables and target burial depths reduce these impacts (CSA, 2019). These potential impacts on fisheries are not discussed further here but could be assessed on site and regional scales.

Following the installation phase, redistribution (displacement and establishment) of fish and invertebrates is likely to occur, as are changes to ecological communities. With the development of OSW projects off the U.S. Northeastern coast, some amount of hard substrate will be added to the marine environment. Introduced hard surfaces in the water column will have varying influences on local ecology (Glarou et al., 2020). There have been studies on individual impacts to species at wind energy areas in the North Sea, Baltic Sea, and other European waters, along with a few reviews of what is known, and a meta-analysis of finfish abundance at OSW areas (Methratta and Dardick, 2019). Recent review papers have presented results from studies on the ecological effects of OSW projects in both the Northeast U.S. Shelf Large Marine Ecosystem (NEUS-LME) and European waters (Methratta et al., 2020; Perry and Heyman, 2020).

Methratta et al. (2020) discuss commercial and recreational fisheries implications, as well as management impacts based on predicted ecological effects of OSW development on several marine species. An example is the predicted effect on demersal flatfish, e.g., summer flounder. The amount of the stocks' preferred soft bottom habitat would likely be reduced locally, which could lead to local declines in abundance (which could have population level effects depending on the scale of habitat conversion). Modified hydrodynamic patterns could also change larval dispersal, potentially leading to population effects that could lower income, revenue, and hindering the economic viability of the fishery. Changes to any species' abundance or distribution will likely lead to fisheries management implications.

Though ecological impacts vary by species, it has been observed that commercially important target species locations and movements are potentially altered around monopile structures within European OSW projects (Raoux et al. 2018). Changes in species behavior and location would likely put an additional burden on fishermen, who would need to develop a new understanding of where to fish (if operationally feasible and allowable under fishery management regulations), and also need to adjust their harvesting plans and techniques accordingly. As seen in the recent Block Island Wind Farm Study, thus far, there are not major changes in population level being observed at the pilot scale level. Even though no major impacts are observed, this is not conclusive evidence that OSW development will have a positive impact, have negative impact, or have no impact. Future studies are needed as more turbines are installed offshore (Wilber et al, 2022).

The phrase "artificial reef effect" is used frequently in both scientific literature and by OSW developers. An artificial reef effect implies that the substrates or surfaces that make up the turbines and their bases are somewhat analogous to that of natural reefs and other substrates that support epifaunal life and characterizing those effects as purely beneficial assumes that species associated with hard strata are prioritized over those with affinity to mud, sand, or gravel habitats. OSW foundations cannot generally be considered natural rock equivalents as the materials used are typically much smoother than reef structures, and often selectively increase certain natural hard bottom species (Krone et al. 2013). As several studies mention, including Andersson and Ohman (2010) and Degraer et al. (2019), "artificial hard substrata differ significantly from naturally occurring hard substrata and should therefore not be considered a substitute."

A review by SCEMFIS (2020) also discusses the potential for the wind energy areas to serve as artificial reefs, which would be expected to have a positive impact on the density of fish that utilize structure for habitat. It is not known whether the lease areas will result in a larger reef complex with cascading or interaction effects. There may be cascading effects on fish communities as a result of the type of epifaunal organisms—i.e., food resources for larger fish, that settle on and colonize turbine surfaces. For instance, a study including stomach content analysis by Reubens et al. (2014) showed a demonstrated preference by Atlantic cod and pouting for prey species found on turbines in the Belgian part of the North Sea. Structures can also support commercially important European lobster and crab species (Hooper et al., 2015), including potential increased production rates of crab (*Cancer pagarus*) as determined by one study in the German Bight of the North Sea (Krone et al., 2017). Each OSW project will be subject to varying environmental conditions, and as such, resultant impacts to local species and ecology will need to be studied on an individual as well as cumulative basis.

Vaissiere et al. (2014) summarize some concerns over the "artificial reef" effect, mainly that species composition may be altered, with potential increases of new invasive species caused by changing the substrate composition. They note that turbines are not designed to serve this function. Krone et al. (2013) studied the increased habitat turbines would give the blue mussel *Mytilus edulis* and the *Anthozoa* and the *Amphipoda Jassa* spp. by increasing hard structure. However, they conclude that more research is needed to learn the long-term stability of this shift and the impacts of the full buildout of turbines in Europe.

Though aggregation of certain commercially important stocks in a wind array, such as lobster, may be considered attractive, it is important to ascertain whether it will be possible for fishermen to take advantage of any increase in (or aggregation of) stocks, or whether practical constraints and/or increased risk will prevent this from happening. In surveys conducted in the UK in 2015 (Hooper et al., 2015), factors influencing fishermen's opinions of fishing within an array included geographical range and level of risk perception. The lack of reported experience of (crab and lobster) potting within a wind farm was not related to stock concerns, but to uncertainty around safety, gear retrieval, insurance, and liability. This perception was common in surveys conducted by Mackinson et al. (2006), in which "increased hazards" and "changes in fishing activities" were two of the many major concerns expressed by around 80 fishermen surveyed.

While much of the discussion around the redistribution of species is on the attraction to OSW structures, some species, including flatfish and whiting, have exhibited avoidance behavior to hard substrate surrounding the monopile structures. Additionally, temporary use of structures by fish suggest that season and weather conditions may have more of an impact than the presence of structure for some species (Van Hal et al., 2017). In this study from the North Sea, high abundances of fish near the structure were observed during some days, while equal distribution of fish in the area was observed on other days. The authors concluded that the area around the structures was thus only used temporarily for shelter or feeding. Seasonally, the aggregation level differed most likely due to different species occurring in the area.

As stated in previous sections, depending on policy and management decisions in a particular country, OSW areas could serve as full or partial fishery exclusion zones. If such exclusion areas increase ecosystem productivity and abundance of commercially targeted fish stocks, fishermen could conceivably benefit if they could fish on the outskirts or "spillover zone," as occurs in some MPAs (Ashley et al., 2014; Roach et al., 2018). However, it is important to highlight the necessity for fishery management policies that support this idea, and to consider additional problems or challenges for fishermen that might occur as a result. Furthermore, studies in Southern New England have shown that longstanding fisheries closures did not increase scallop or ecosystem community productivity (Hart and Rago, 2006; Stokesbury and Harris, 2006), so it is important to evaluate whether a "spillover effect" would in fact occur. Fishermen and fisheries scientists are likely to be the experts in predicting conflicts or opportunities associated with exclusion areas, and some considerations might include increased competition amongst vessels (Mackinson et al., 2006) or decreased total available catch if more fishermen, both commercial and recreational, began fishing these so-called spillover zones.

Overall, localized impacts on the ecosystem are currently unknown and will be difficult to analyze. Baseline and long-term monitoring are necessary to understand any changes; however, the presence of the turbines and the natural variations in composition of fish species makes monitoring difficult (Petruny-Parker et al., 2015). Though many studies have demonstrated that OSW infrastructure has shown an aggregation effect on fish populations, the findings are not yet conclusive enough to inform fishery management plans for the following reasons:

- The detail and scale of ecological effects are not known in this geographic region and will likely include both positive and negative changes depending on the particular stock and site.
- The OSW turbine structures themselves may not be contributing to perceived aggregations of fish any more than seasonal or temporal controls.

- The OSW areas may disrupt fish migration routes, including that fish may not migrate past the OSW areas to their inshore grounds where certain fishermen harvest.

Predator/prey relations need to be considered. For example, an increased aggregation of sea stars would be detrimental to shellfish larval settlement.

2.6.3 Socioeconomic Impacts to Fishing Communities and Businesses

Commercial fishing is an economically important and historic use of the ocean. Coastal communities along the Atlantic seaboard have a rich maritime tradition that has continued into present times. NOAA Fisheries economic impact trends report (NOAA 2017) estimated the annual sales impact from the fishing and seafood industry in the United States to total over $244.1 billion, up 11.1% from 2016, with 70% of that coming from the commercial sector. An additional $110.7 billion was the estimated value-added, and there were approximately 1.74 million jobs in the industry. Numerous Atlantic coastal communities have unique traditions and cultures based around the maritime history of the region. A recent report commissioned by the European Parliament concluded there was “a clear gap of economic and socio-cultural impact assessments” regarding fisheries and OSW, including direct and indirect costs of lost fishing opportunities (Steltzenmüller et al., 2020).

The socioeconomic impacts of OSW to fisheries are complex and difficult to assess, but data from spatially explicit databases have proven useful, including VMS, VTR, Southeast Regional Headboat Survey, and Marine Recreational Information Program. Using these types of data, Kirkpatrick et al. (2017) presented analyses of socio-economic impact of OCS wind energy development on fisheries in the U.S. Atlantic. This analysis was conducted by NOAA NMFS for BOEM and included all WEAs at the time from Massachusetts to North Carolina. Exposure assessment identified the individuals, groups, ports, and gear types likely to be affected by WEA development, and the magnitude of impact was estimate for those potentially affected. For commercial fisheries, the most exposed gear and vessel classes included clam and scallop dredge vessels >50 ft in length from ports in New York State and New Jersey, and pot and gillnet vessels <50 ft in length from ports in Rhode Island and the south coast of Massachusetts. Sea scallops were found to represent the single most exposed species to WEA development on the Atlantic coast. Specifically, the NYS WEA at the time of this report (which included Hudson North) was identified as containing valuable sea scallop grounds (especially in the eastern portion), but not as productive as other areas in the mid-Atlantic or Georges Bank. Recently, NOAA Fisheries developed a website with reports summarizing fishing activity within each offshore wind lease or project area during 2008–2018.[17]

Forthcoming efforts by NMFS, BOEM, RODA, the International Council for the Exploration of the Sea, and others will explore these issues in greater detail. Each of the topics in this report may create socioeconomic impacts individually or in the aggregate. Section 4.5.2 below summarizes some of the existing analyses on fisheries revenue exposure in Atlantic OSW areas.

Fishing companies establish their business plans frequently and often on an annual basis, based on annual catch limits (ACL) and historic activities. The Regional Fishery Management Councils set ACLs for all species in federal waters. Based on catch limits and fishery-specific effort controls, vessel owners estimate their potential revenues for the year. Unexpected or increased expenditures can significantly affect net income, profits, or margins. All the potential impacts to fishing operations will also have an effect. WEAs can affect the ability to harvest the full ACL, if fishing grounds are lost. Costs to harvest resources inside the WEA may be higher than outside the WEA (e.g., increased insurance). Additional fuel may be necessary to transit around a WEA if a vessel cannot safely travel through it; this may also decrease time available for fishing further reducing revenues.

In one study, fishermen showed strong views about expected negative financial impacts, were reluctant to provide economic information directly for fear it would be used against them or otherwise harm them and expressed that they would consider taking legal action if needed (Mackinson et al., 2006).

Fishermen who determine that they will need to modify their harvesting practices to maintain their livelihoods may be limited in their ability to do so. “Switching to other fishing methods is restricted by availability of capital, licenses, and quota, and does not appear to be an attractive option because of higher costs and uncertain risks” (Mackinson et al. 2006). Disruption to fish stocks and fishing effort has led to some monetary compensation schemes for commercial fishermen. For example, Vineyard Wind established compensation funds through state (Coastal Zone Management Act) processes in Massachusetts and Rhode Island to address fishing losses, a trust fund to support navigational and safety equipment and to deflect any increases in insurance costs, and an innovation fund with program and research project grants (BOEM, 2020). However, discussions surrounding compensatory mitigation are highly contentious. As several independent surveys and numerous conversations with fishermen have shown (anonymous, pers. comm, 2021), many fishermen do not feel monetary compensation is an adequate replacement for their businesses and heritage.

In addition to compensatory measures, numerous opportunities have been realized or proposed for fishermen to diversify or supplement their income, including direct or indirect employment with the offshore wind industry (e.g., piloting boats to conduct surveys during construction, captaining eco-tours to the wind turbines, or selling fuel to a developer) (Hagget et al., 2020). However, focusing solely on economic opportunities and costs limits diminishes the understanding of fishermen as individuals who ascribe meaning to their time at sea (Russell et al., 2020) as well as to the greater societal value of seafood production. Many fishermen strongly identify with their livelihood, “as members of occupational and place-based communities on land and at sea” (Hagget et al., 2020), and therefore act outside of simple economic interests when deciding how to earn income.

3 Interviews to Identify Regional Needs and Risks

A critical component of the project was the incorporation of the fishing industry's expertise in the development of impact minimization strategies. To achieve that, a series of interviews with the fishing industry were conducted with the goal of identifying the needs and risks for their fishing operations inside and outside of WEAs. Discussion topics focused on fishing characteristics, fishing operations, state of the sea, wind array interactions, cables, and mitigations. The two fisheries chosen as a focus for this study under the project Statement of Work were the federal limited access Atlantic Sea scallop and surfclam/ocean quahog fisheries. These fisheries were identified as being most appropriate for this study due to: (1) their importance in the NY Bight, (2) an easily defined group of participants, (3) a high degree of concern regarding cable interactions, (4) the ability to concentrate interviews and/or workshops in a relatively small group of ports, and (5) a relative abundance of data. Thus, interview participants were former or current captains in these fisheries and were selected based on their willingness to participate and diverse geographic representation.

The survey first established a baseline of fishing operations in the open ocean, with varying weather conditions, to improve our understanding of the conditions faced and better identify important issues and conflicts that would impact fishing within or around a wind energy area. RODA developed these questions with input from NOAA's Northeast Fisheries Science Center (NEFSC), the National Renewable Energy Laboratory (NREL), and Global Marine Group, LLC (GMG). Once a set of draft questions was developed, the fisheries representatives on the PAC reviewed and provided feedback, allowing RODA to further refine the survey. Once the final set of questions was approved (Appendix II), interviews were scheduled. Several fishing industry members were contacted from Maine to New Jersey.

These were semi-structured interviews, which allowed for some follow-up or clarifying questions. No follow-up questions deviated from the goal of the survey; any follow-up questions were asked to ensure the interviewer had a full understanding of the response and that all questions were fully answered. The interviews were not recorded; thorough notes were taken from which the summary was drafted. Interviewees were supplied with the full notes that were taken during the interview for their review to ensure the interviewer fully understood and accurately documented their responses. Because of the COVID-19 pandemic, all interviews with the sea scallop fishery members were conducted remotely via Zoom. The surfclam fishery interviews were self-conducted as we were unable to meet in person.

Based on availability, a total of seven interviews were conducted with sea scallop fishery participants between January and April, 2021 (Table 1). The average duration of these interviews was 94 minutes (range 50 minutes–2.5 hours). There is limited research on fishing operational needs and risks for Northeast U.S. fishermen operating within and around wind arrays. Semi-structured interviews were conducted to gather data on scallop and surfclam/ocean quahog fishermen’s operational characteristics to aid in filling these gaps. These surveys gathered qualitative data on fishing operations (e.g., tow characteristics, operating with other vessels/gear, sea state conditions) and fishermen's concerns with operating within or around a wind array. These interviews helped identify major risks and impact minimization strategies. A fisherman from the mackerel fishery was also interviewed, but those results were not included herein.

Table 1. Summary of Number of Interviews Conducted by Home Port in the Sea Scallop Fishery

Home Port (City, State)	Number of Interviewees
New Bedford, MA	2
Stonington, CT	1
Barnegat Light, NJ	2
Point Pleasant, NJ	1
Cape May, NJ	1

3.1 Summary of Interviews

Several common themes emerged in the interviews. Overall, the fishing industry interviewees expressed concern about operating within WEAs. There was one industry member who thought he could operate in a WEA; however, this individual also stated that he did not want the WEAs anywhere near his fishing grounds.

3.2 Scallop Captain Responses

During the interviews, scallop captains were asked questions on fishing characteristics, fishing operations, state of the sea, wind array interactions, cables, and mitigations. The following sections summarize input received from the seven interviews that were conducted during December 2020 to February 2021.

3.2.1 Fishing Characteristics

Interviewees were first asked about their gear types, vessels, and primary fishing grounds within the Atlantic Sea scallop fishery (Table 2). All interviewees were owners, owner/operators, and/or captains who operate within the NY Bight, with decades of overall experience (average 30 years). All fishermen interviewed primarily fished for scallops, except for one who additionally fished for squid. In terms of gear, all interviewees use scallop dredges, with one respondent preferring the term "rakes" and another respondent specifying use of a dredge with four-inch rings. All interviewees used two (paired) dredges, except for one fisherman who used one or two dredges, depending on the boat (i.e., permits dictate number of gear and footprint of gear). Dredge sizes (in width) ranged from a small dredge (10.5 ft) to a larger dredge (15 ft), with most using 15 ft paired dredges (four of seven respondents) and the others using 13 ft or 14 ft paired dredges; one respondent additionally used the smaller 10.5 ft dredge. Vessel sizes ranged from 72 ft to 109 ft, with an average of ~90 ft.

Table 2. Summary of Gear and Vessel Types Identified in Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Gear Type	Dredges/Rakes	7
# of Dredges	2	6
	1 or 2	1
Dredge Size	15 ft	3
	10.5, 13, or 14 ft	4
Vessel Size (Responses here add up to more than 7 because of multiple vessels owned per captain)	72 ft–89 ft	8
	90 ft–109 ft	5

3.2.2 Fishing Operations

3.2.2.1 Tow Characteristics

Most of the interviewees towed for between 15- and 50-minutes, with 50 minutes being the most common length (Table 3). One respondent conducted 60-minute tows. Duration of tow depended on bottom and scallop density (high densities can result in tows less than 10 minutes). Dredge could fill in as little as 10 minutes with scallops or bottom; if catch of scallops decreased for any reason then tow could be lengthened. Average speed of a tow was generally 4.5 knots. Speed could vary depending on tide and weather conditions or bottom type (one participant reduced speed to 3.7–3.8 knots on rocks but up to 5 knots in clean bottom). Locations for a tow seemed to largely be dependent on management restrictions, historic catch, recent fishing reports from other captains, weather, and in one instance recent scallop resource survey results. Tows can be limited by bottom type; vessels with greater horsepower can tow on rockier bottom. One respondent mentioned the use of rock chains when towing on rocky bottom. One participant usually followed a depth contour on a tow or if there was a stronger wind that he had set into it (excess of 25 knots).

Direction of a tow was influenced by the oceanic conditions such as tide and sea state (if rough conditions then participants indicated they might tow into the waves). Depth of a tow varied for one participant between 20 and 40 fathoms in the Mid-Atlantic; waters off Massachusetts are deeper and tows varied between 25 and 55 fathoms there. Those depths are where they generally find scallops. One participant said they never see scallops at 12 fathoms anymore and the maximum water temperature they would find scallops in was 55°F. Depending on the vessel's capabilities, particulary hard sea bottom might be avoided so that gear would not get hung up.

One participant stated that success in catching scallops is the biggest factor and catching them might be better on a NE/SW tow or on a NW/SE tow. Depth was usually held constant for this participant, and he would try to follow the contour lines.

3.2.2.2 Fixed Gear Avoidance

One interviewee avoided fixed gear and stayed away at least 1 mile. Other respondents were more comfortable operating within quarter mile of fixed gear, especially if it was well marked. Another would get within 50–75 ft of known fixed gear or wrecks but not if it was unknown then the distance would increase. However, if weather were rough or the tide was strong a greater distance to fixed gear would be preferred. This is because of how the fixed gear operates. Gillnets can shift in the tide and may shift to one side of the highfliers making it difficult to tow closely to fixed gear. Buoy lines can shift for lobster gear. Captains operating near fixed gear need to accommodate these scenarios in rougher weather, resulting in tows/haul backs further away from the fixed gear. No participants wanted to get too close to fixed gear or risk any potential hang ups or wrecks. Knowing who owned the fixed gear influenced the behavior of one participant; unknown gear was given a wider berth. Fixed gear could affect the direction of a tow for one participant, but vessels usually worked together.

3.2.2.3 Turnaround Tows

Turnaround tows were frequently used by interviewees. These are tows where a vessel will complete half its tow in one direction, then turn the vessel, and complete the tow going in the opposite direction. This allows vessels to target dense scallop beds. Vessels typically turn into the tide or into the wind; turning with the tide is harder and takes longer to turn. Strong seas can push a vessel off its planned track and make the turn wider than expected. A provided example was a turn that took 35 minutes because the vessel turned the wrong way, and the tide pushed the boat. One participant indicated they would tow for 2–2.5 miles one way and then turn around and do the same on the way back, depending on time or length of tow. Their boat would need less than a half mile to turn but this varies with size of vessel and tide. Another vessel typically takes about a half mile to turn.

Table 3. Summary of Fishing Operation Considerations from Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Tow Length	Average of 50 min	5
Tow Speed	Average of 4.5 knots	7
Fixed Gear Avoidance	Yes	1
Turnaround Tows	Yes	7

3.2.3 State of the Sea

The next set of questions were intended to understand how fishing operations differ under less favorable conditions. Sea state descriptions were provided for reference (Table 4).

Table 4. Sea State Classification and Descriptions

Beaufort Number	Description	Wind Speed (Knots)	Description & Wave Height (ft)
0	Calm	<1	Calm, gassy 0 ft
1	Light Air	1-3	
2	Light Breeze	4-6	Calm, rippled 0 - 0.3 ft
3	Gentle Breeze	7-12	Smooth, wavelets 0.3 – 1 ft
4	Moderate Breeze	11-16	Slight 1 – 4 ft
5	Fresh Breeze	17-21	Moderate 4 – 8 ft
6	Strong Breeze	22-27	Rough 8 – 13 ft
7	Near Gale	28-33	Very Rough 13 – 20 ft
8	Gale	34-40	
9	Strong Gale	41-47	
10	Storm	48-55	High 20 – 30 ft
11	Violent Storm	56-63	Very High 30 – 45 ft
12	Hurricane	>64	Phenomenal 45 ft and over

3.2.3.1 Rough Weather

Gear frequently operates better in rough waters, approximately 8–13 ft (Table 4). This is because the conditions help shake out bottom material because the gear is bouncing a little on the bottom, resulting in less picking through the catch on deck. One respondent suggested fishing in "dirtier" bottom in rough weather. Most captains would stop fishing when seas hit 20 ft. The frequency of the waves can also influence operations—if they are too close and breaking then they might stop fishing (even in lower wave heights) because of the risk to crew on deck. Vessel size was also important to the ability to operate in rough conditions; small vessels cannot operate in strong gale conditions. One participant with a larger vessel (100 ft) had fished in 50 knot winds but positioned the boat so that he was not towing broadside to the wind. A smaller vessel was thought to only be able to fish in 35– 40 knot winds. Smaller vessels were said to have a lower maximum sea state available to them.

Tow time is occasionally modified in rough conditions if the dredge/rake is catching more. Vessels may choose to tow for longer in rough weather and reduce the total number of haul backs (sometimes by as many as 5 or 6 tows per day) completed in a 24-hour period, up to 1 hour and 15 minutes for one participant. This is to reduce time on deck, which puts crew at risk of injury. Towing speed can change in rougher weather; it might not be economical to tow too hard and burn more fuel. In a provided example, in a turnaround tow the speed in one direction may be 3–3.5 knots but 5 knots on the way back. Another participant agreed that the speed might be slower in strong winds and the vessel would tow into the wind and haul back fair wind.

Direction of the tow in rough weather was dependent on the wind direction; vessels will set gear into the wind and haul back fair wind. Vessels may take longer to turn in rougher conditions and may drift faster during haul back.

3.2.3.2 Day/Night Considerations

Day/night did not matter to the interviewees, as vessels will operate in rough conditions regardless of time of day. It was frequently mentioned that it was sometimes easier to operate in rough conditions at night because it was easier to see the running lights of other vessels in the area (and not see how big the waves were).

3.2.3.3 Fog Considerations

Interviewees were asked to refer to the visibility scale provided for answering questions (Table 5). Fog conditions did not matter to the interviewees, though some expressed that they would be more careful with less visibility. Because of the reliance on vessel radar, interviewees stated that fog does not generally affect operations. One captain told of trips where they operated in the fog for the entire trip, with trouble seeing the deck from the wheelhouse. Again, fog at night was perceived as sometimes easier to operate in because captains could see the running lights on other vessels. There were numerous stories of vessels fishing for 10–12 days without being able to see their bow.

Table 5. Visibility Scale Based on Weather Conditions

Code No.	Weather	Yards
0	Dense fog	Less than 50
1	Thick fog	50-200
2	Moderate fog	200-500
3	Light fog	500-1000
		Nautical Miles
4	Thin fog	1/2-1
5	Haze	1-2
6	Light Haze	2-5 1/2
7	Clear	5 1/2-11
8	Very Clear	11.0-27.0.
9	Exceptionally Clear	Over 27.0

3.2.3.4 Distance from Other Vessels

Distance from other vessels was important to the interviewees. Everyone follows the Rules of the Road as set by the USCG.[18] Some captains give other vessels more space in rough conditions. There can be a lot of vessels around especially when access areas open; there have been 100 or more vessels operating within a small area (e.g., 10 vessels operating within 1 mile of each other). Captains will usually be watching their radar and are in constant contact via radio with other vessels towing near them. Vessels may be more willing to fish closer to vessels they know. It was generally agreed that if there was any uncertainty, more space was given to other vessels.

Table 6. Summary of Sea State Considerations from Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Rough Weather	Gear frequently operates better in rough waters (~8-13 ft); 40-50 knots max winds for operations	7
Day/Night	Does not matter for operations	7
Fog	Still operational due to vessel radar	7

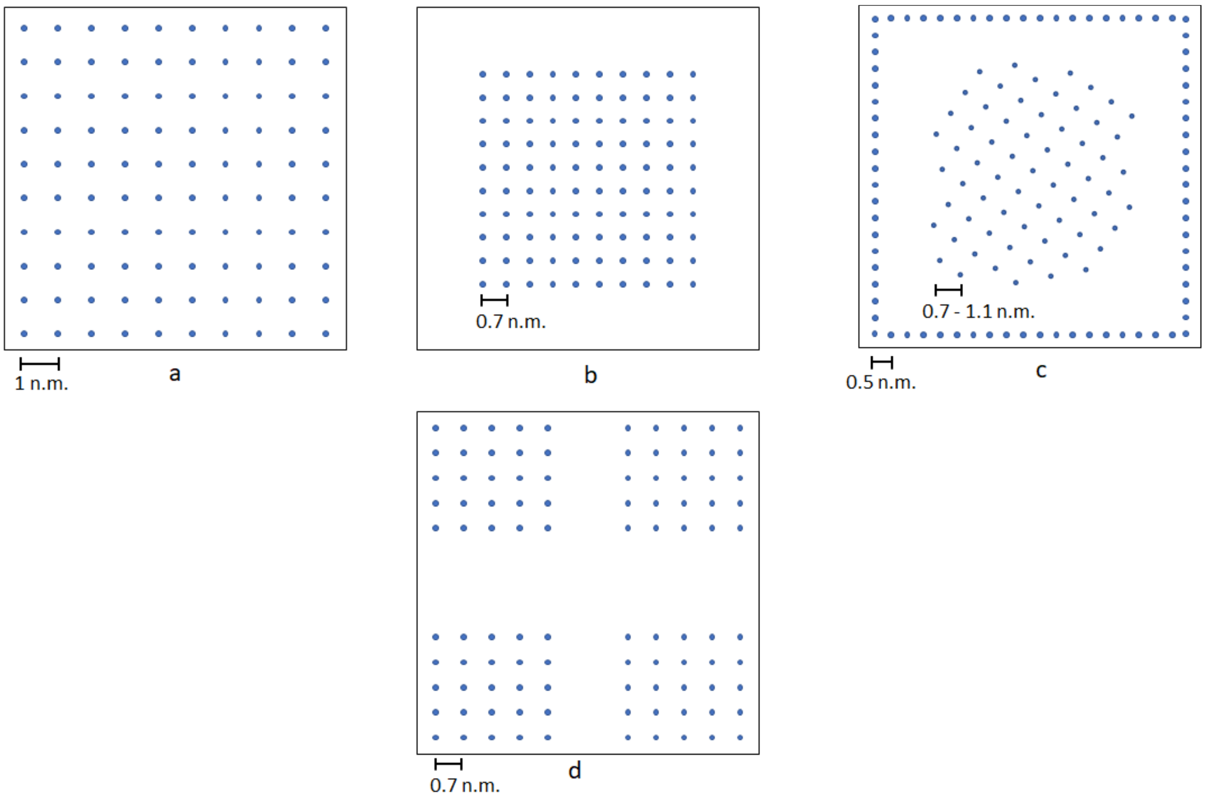
3.2.4 Wind Array Interactions

3.2.4.1 Layout Scenarios

A set of hypothetical wind array layout scenarios was presented to interviewees (Figure 1). Scenarios were developed based on the layout considerations identified in the literature review for current projects in U.S. Atlantic waters. These hypothetical scenarios were intended to serve as a starting point for gathering feedback from the fishermen. For this set of questions, they were asked to consider their operational needs in regard to turbine spacing and orientation, not cable placement. In Figure 1, the coastline was described as to the West (left) with the prevailing wind direction out of the southwest (bottom-left). The sea state would be navigable, and the respondent would be looking to fish in and around the wind array.

- Scenario A has a grid spacing of 1 nm between structures.
- Scenario B consists of compact spacing of turbines with a smaller total footprint of ocean space. The average spacing is 0.5 to 1.0 nm between the structures. Although fishing would not be prohibited within the array, the expectation is that fishing may not occur within the wind array, but the array takes up the least amount of ocean space.
- Scenario C has a dense perimeter of structures with spacing of 0.5 nautical miles, and an interior grouping of structures with spacing of approximately 0.8 nm. Although fishing would not be prohibited within the array, the expectation is that fishing may not occur within the interior section and spacing between turbines would not be equal, but more space is available between this and the outer perimeter for operation.
- Scenario D showcases condensed groups of wind turbines (with a horizontal and vertical spacing of 0.7 nm) with increased spacing in between the groups.

Figure 1. Hypothetical Wind Array Layout Scenarios Included in Interviews



There were no consistently preferred scenarios (Table 6). Most of the respondents struggled to pick a preferred scenario because of concerns with turbine spacing and layout in the context of actively towing mobile gear (Table 6). There was no clear consensus on a scenario as they said it is difficult to pick one without experiencing one firsthand. All respondents had issues with some aspects of each scenario, e.g., turbine spacing in Scenario A would be tight if other vessels were also fishing, Scenario C was called "complicated." One interviewee preferred a dense layout that would minimize the overall footprint (e.g., Scenario B) allowing vessels more space to fish around the array. Scenario D was the second choice for that participant because of the ability to get through the array. Another participant considered Scenario A to be a possibility in favorable conditions but would be hesitant to haul back within the array and tended to prefer B and C. To avoid hauling back within an array, if a captain is towing for an hour at 4.5 knots, they need 4.5 miles to be clear before hauling back. Scenario B and C allowed some fishing around the perimeter, but both could get crowded once vessels noticed activity (via AIS) and came to investigate. Another participant suggested Scenario A might be better because of the increased spacing between turbines but also thought the other scenarios with fishable space could potentially work.

3.2.4.2 Avoiding Wind Arrays

It is difficult to conclude that the interviewees would permanently avoid operating within wind arrays, because they may be forced to fish within a WEA to stay in business. The majority stated that they will avoid fishing within an array. However, several noted that if the resource shifted to within the array, they could be forced to fish within them. It often came down to the economics and day or night conditions would not affect this decision as much as the profitability.

3.2.4.3 Uniform Grid Pattern

Three interviewees preferred a uniform wind farm layout. Consistency was considered important for fishermen who might be tired. One captain did not want to be "caught out" by a turbine coming out of nowhere (variable spacing scenario) if operating within a WEA. Risk was thought to increase if a captain had to make a sudden decision as to whether they could get through two turbines (under the variable spacing scenarios). One interviewee was not concerned about a uniform grid pattern provided that the turbines were spaced far apart. It was thought that vessels would just stay away from turbines (like telephone poles on a highway).

3.2.4.4 Small Spacing between Turbines

No interviewee was comfortable operating gear in WEAs with small spacing between turbines. Small spacings would be considered preferable if it resulted in less fishing grounds to be lost to WEAs. One interviewee considered operating in an array with 0.5 nm spacing to be "tough." However, there was some support for minimizing the overall footprint of WEAs by condensing the turbines into small areas. This would result in small spacings between turbines, and likely resulting in no fishing occurring between turbines, but more space would be available outside of the WEAs. If fishing was expected to be conducted within an array, it made sense to avoid small spacings; if too small, vessels would have to stay out.

3.2.4.5 Large Spacing between Turbines

The interviewees generally preferred larger distances between turbines. One captain preferred 4 nm distance (based on center points of turbines) between turbines because of the scour protection. The scour protection extends around the base of the turbine and has the potential to cause hangs on the large rocks/boulders used. Other vessels operating in a WEA also increased the risk and the need for greater distances between turbines. The smaller the distance, the harder it would be for two actively towing vessels to safely pass each other. One participant suggested a uniform grid that had long lines of turbines with more space between the lanes to allow vessels to tow in. Installation along latitude and longitude lines or as close as possible to E/W and N/S was also suggested to help fishermen know what to expect and increase consistency. Another participant suggested the bigger spacings the better, like oil rigs which have large spaces between them that can be fished. The participant suggested 5 nm between turbines and having a standby vessel at each field to help any vessel experiencing difficulties in an array, e.g., needing to be towed out before collision occurs.

3.2.4.6 Modifications to Fishing Necessary

One participant considered all aspects of a haul to be affected; however, it might not all be detrimental. All aspects of a haul would be affected because the turbines take up space restricting fishing by taking away fishable ground and could be a potential hazard for hanging up. There was concern about operating within the WEAs by most of the interviewees. It was stated that it could increase risk and put the crews' lives at stake, as described below. One captain was very concerned about the cables and did not want to tow mobile gear over a cable. The consensus was to avoid operating within the WEA unless they were forced into them by high densities of scallops.

If conditions were good, one captain thought the only thing necessary was to avoid the turbines; the only difficulty might be when turning in strong tide. In strong tide conditions, you might need more room to turn (tide pushes the boat) but you should be able to turn within 1 nm.

There were concerns about all aspects of a tow being modified—turning might be more difficult, tow duration could be affected (i.e., increased or decreased depending on distance to turbines) to make sure haul back was done safely. One captain put the vessel into neutral during haul back, putting the vessel at risk of drifting into a turbine (this was also a concern for engine failure occurring in a WEA; if the vessel loses an engine its crew might not even be able to set out their anchor or haul back their gear). One participant stated that a general haul back for a good vessel is typically 10 minutes (hauling and setting gear out again). Vessels are in gear for hauling back and setting gear. All this increased vigilance would likely result in added stress on the captain and crew. Limited access vessels are limited to seven crew (including operator) when participating in the scallop Days-At-Sea (DAS) allocation program and eight crew (including operator) when participating in the Sea Scallop Area Access Program.[19] For some limited access permits, the captain frequently helps process catch but cannot do that if they are constantly monitoring their position from the wheelhouse. The autopilot feature could fail, and the boat could go into a hard or gradual turn. Search and rescue was also mentioned—rescue vessels likely cannot go top speed within a WEA. Insurance was also a concern, but little information is currently available on impacts to insurance availability or cost.

Captains thought they could tow within a quarter mile to 1 mile of a turbine, depending on the scour protection. A participant did not want to get within 0.5 nm of a turbine because of the drag on the gear; the wire/gear is not always directly in line behind the boat, which would need to be accounted for, so boats do not hang up on a turbine.

One participant considered the ocean to be a big place with room for everyone to conduct their business (e.g., there is room for turbines away from scallop operations). Even if other vessels are around, experimental tows can be conducted to find the scallops (vessels can pass each other within a half mile or less).

3.2.4.7 Fixed Gear in an Array

Four interviewees stated they would avoid fishing in the array if fixed gear were present because it would increase obstacles. One participant was concerned that anyone fishing within an array would attract other vessels, since that is typical behavior—to see what someone else is catching in an area. Another participant thought it would be possible to fish near other vessels in an array, outrigger to outrigger; however, communication would have to be very good between vessels.

3.2.4.8 Other Recommendations

It was suggested that developers could provide technical assistance with radar interference. If new radar technology exists that is not vulnerable to echoes from the turbines, as some developers told at least one captain, it was recommended that developers should provide it to all fishing vessels for the safety of the crew. AIS could be used on the turbines to help vessels orient themselves and know where the turbines are. One participant suggested having a set “rules of the road” that applied to operating within a WEA or limitations on the number of vessels that could be operating with the WEA at any one time. Vessels are under pressure to fish under their Days-at-Sea (DAS) because the clock is running. One captain suggested construction of a mock turbine field to study impacts of radar interference. Multiple participants suggested having a permitted officer or patrol vessel at each site to monitor and assist any vessels in trouble.

3.2.4.9 Radar Interference Concerns

Most of the interviewees were highly concerned with radar interference; only one captain was not concerned with radar interference because of existing technology on the vessel. Currently, false targets can occur on radars; radar systems vary in their ability to deal with interference. AIS on turbines was thought to be helpful. Others had seen images from echoes from turbines in WEAs in the UK and were highly concerned. These echoes can fill up the screen and cannot be tuned out, potentially risking a vessel missing smaller targets. One participant was not concerned as he had three radars on the boat and did not expect bounce back. That individual also was not concerned about mitigating safety concerns with regards to radar because he stated he could tell if something is not moving (e.g., a turbine) and only relied on radar at night. A couple of participants suggested the installation of AIS on turbines to help mitigate safety concerns. AIS is used in NYS harbor, which is very busy with a variety of activities (i.e., not just fishing industry), implying a lot of AIS signals were not a problem for their AIS systems (i.e., their systems can handle 100+ AIS signals if installed on each turbine). One participant also suggested that all vessels should be equipped with AIS and required to use it; currently not all vessels are required to have AIS onboard.

One participant considered radar interference to be a major concern and may affect their ability to operate within a wind array during fog.

3.2.4.10 Increased Risk with Bad Weather

Sea state would affect the decision to enter an array to fish or transit. The maximum sea state varied by vessel but generally ranged between 7–8 on the Beaufort scale. Spacing and number of other vessels operating within it would impact decision to fish within an array. The distance a vessel was willing to pass by a turbine may increase in bad weather from 0.5 nm to 1 nm, particularly if pushing the limit on sea state (i.e., ~20 ft waves). Sea state would not influence the decision to transit through a wind array for one participant, but he did state it would for fishing within an array.

One participant considered the risk was primarily for the crew especially when on deck in strong winds and high seas, as opposed to being at risk of hitting a turbine. Transiting through an array during bad weather would require more vigilance and less sleep for captain and the other crew member tasked with steering. The boat may need to be turned a little bit to avoid turbines in rough weather; they would also likely give the turbines a wider berth in these conditions too.

One participant considered a strong breeze to make fishing within a wind array risky; calmer seas were preferred at night. Big seas can carry the boat during a haul back. Transiting could be done in gale conditions; however, the participant would still prefer to avoid the array if possible.

For safety concerns, one participant would not fish within a wind array at night because if the vessel broke down, the reaction time is longer, and you can drift quickly.

The rougher the weather the less likely a crew would be able to fish. Another participant would not go into an array with other vessels around in any weather greater than 25 knot winds. Information regarding the turbine bases or anchoring system would also be needed for operating safely. The participant considered it possible to transit during storm force weather but if it was strong gale, they would not transit. Gale force might be the strongest weather one participant would be willing to fish in at night within an array. The same applied for transiting at night, depending on visibility, if there was rain and it was harder to see the lights of other vessels.

A vessel may want to plan to reduce time spent fishing around turbines in bad weather and fish more before the weather changes. Or the location of tows may change; in an example given, a vessel might take some tows where they would not in the past to take advantage of conditions making it easier to fish within an array.

3.2.4.11 Fog While in a Wind Array

One participant did not consider fog to be an issue when operating within a wind array as they would just use their radar. Again, this individual did not have concerns about radar interference and suggested making the radar more or less sensitive by adjusting the gain. Another considered moderate fog to be a deterrent for both day and night. One participant had seen radar interference firsthand while in a wind array and was highly concerned about this impact and considered that if you had to rely on radar, you should not be fishing in the array.

Table 7. Summary of Wind Array Interaction Considerations from Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Scenario Choice	No consistent preference	7
Grid Pattern	Uniform preferred	4
	No preference – other factors more important (like distance apart)	3
Turbine Spacing	Small spacing between turbines	1
	Large spacing between turbines	6
Modifications to fishing necessary	Yes	7
Radar interference concerns	Yes	6
Increased risk with bad weather	Yes	7

3.2.5 Cables

3.2.5.1 Will Not Tow Over Cables

The consensus was that cables should be avoided (Table 7).[20] Cables represent a major risk to mobile gear operators; it is very dangerous for a vessel to hang up on a cable, especially a power cable. Most of the interviewees stated they do not want to fish over cables; even if the scallop dredge does not go as deep as 6 ft, they see it as a hassle and unnecessary risk. Shifting tides can move the sand and expose cables. One participant avoids existing cables when he knows where they are based on charts. Deeper burial was generally thought to be better, but there was concern that the cables would not stay at the promised depth. One participant would stay at least 1 mile away from the cables as marked on an updated chart. It was pointed out that there was a big difference between being comfortable towing over telecommunication cables and an electrical cable. Another interviewee thought 6 ft deep was sufficient and that concrete mattresses might be okay if designed to avoid driving the dredge into it, resulting in hanging up (entanglement).

3.2.5.2 Mitigation Ideas

One participant suggested burying cables as deep as possible to help reduce the risk they would become uncovered in more dynamic areas. He also suggested providing insurance for vessels to operate within a WEA, if they are forced to operate in there because of scallop density, and to provide updated charts showing the cable layouts. Mitigating cable layouts is difficult as you can only use charts rather than a physical marker such as a buoy. It was suggested that it would be important to monitor the depth of the cables because it can change. One participant suggested a dedicated navigation corridor instead of consistent 1 nm spacings in which all lanes are called “navigation channels.” It was also suggested that there should be a way to update cable layouts if shifting occurs.

3.2.5.3 Existing Cable Interactions

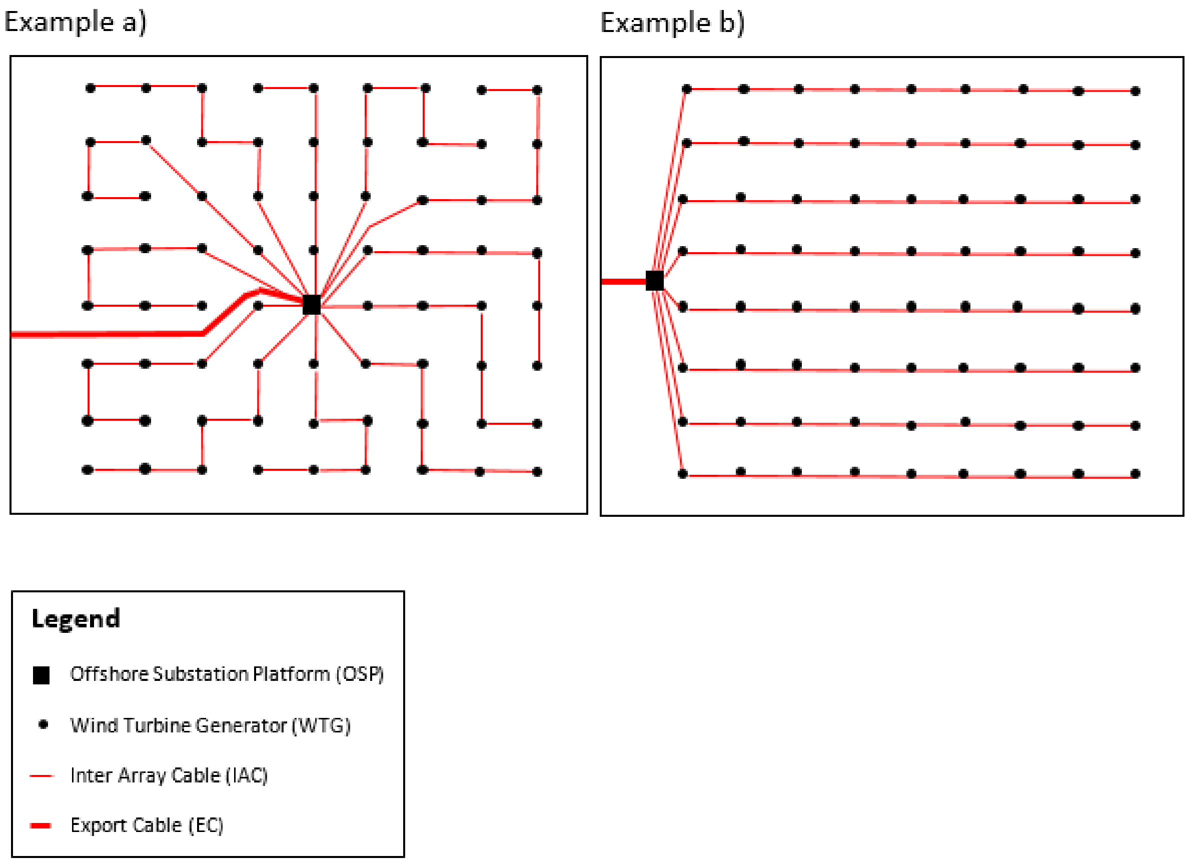
Most respondents had some level of interaction with existing cables. There were a lot of concerns about the ability to properly bury a cable in sandy areas with strong current—the bottom shifts and cables can be exposed. Also, in these areas, additional protection methods might be used that could increase risk of hang ups. One participant suggested developers should use an economical layout for themselves as he would just avoid fishing near the cables. One participant who had hung up on abandoned telecommunications cables, could see that they were marked on the charts, however, the cable had been moved over time because of shifting bottom and other vessels dragging them. The cables are heavy and dangerous to the vessel. One participant who had hung up on one said that if you haul back and the cable is still caught in the dredge, then you tie it off and try to free the dredge and drop the cable. However, you may not necessarily see the cable unless the dredge has been brought back. None of the participants who had cable interactions reported, or requested compensation for, getting hung up on abandoned cables.

There was concern over cable protection methods posing a risk for hanging up. Scour and cable protection methods should be well marked on charts to allow vessels to avoid them, if desired. Depending on the scallop distribution, vessels may try to tow as close to these as possible.

3.2.5.4 Layout Preference

The following hypothetical cable layout scenarios were presented during interviews to gather feedback (Figure 2). The square box represents the offshore substation platform, and the circles represent the wind turbine generators. The red lines represent the IACs, and the thicker red line represents the export cable. All wind generators should be linked to the substation platform (black square). Example A has a substation in the center of the wind array while example B has a substation on the perimeter of the array.

Figure 2. Hypothetical Wind Farm Cable Layout Scenarios Included in Interviews



Six out of seven respondents preferred layout B for cable scenarios. This would allow them to safely operate a tow without crossing a cable. Its consistency was highlighted as important by at least one interviewee. It may also allow fishing to occur if the cables could not be buried. One participant did straight tows so Layout B was preferred; however, it was still restrictive as the vessel could only tow east and west if avoiding the cables. Captains need to periodically check the engine room and conduct routine maintenance; if stuck at the wheel on watch, this routine work would not get done increasing risk of mechanical failure.

Table 8. Summary of Cable Interaction Considerations from Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Towing over cables	Avoid doing so	6
Mitigation ideas	Yes	6
Interactions with existing cables	Yes	5
Preferred Layout	Layout B	7

3.2.6 Mitigation

3.2.6.1 No Possible Gear Modifications

No respondents could think of a gear modification; a couple suggested it could be investigated by researchers; however, the rest did not think it was possible to modify the gear and still catch scallops (Table 8). The gear is designed and set up to catch scallops and not to unhook or roll over cables. One participant said that if smaller dredges were required within an array, and scallops were present, they would fish under those circumstances.

3.2.6.2 Shifts in Effort to Other Areas

There was concern that effort would increase in other areas as effort is displaced from WEAs because they were being avoided. Scallop vessels cannot really switch to other species; they are limited to 300 lbs. of bycatch.[21] There was also concern over the impact to the rotational management system in terms of the amount of fishing grounds these WEAs could take up. It was suggested that the WEAs could be put in less productive areas to mitigate conflict with the scallop fishery, especially keeping the access areas free of development.

3.2.6.3 Fisheries Management Limitations

Vessels associated with sea scallop permits cannot easily fish for other species because of fisheries management constraints. The sea scallop fishery management plan (FMP) limits the number of other species that can be landed on a scallop day-at-sea (only 300 lbs. for some permit categories). It also limits where these vessels can operate in any fishing year. Scallop permits are also extremely expensive (one estimate provided was $4 million).[22]

3.2.6.4 Compensation

Most of the participants did not know how to calculate compensation for lost fishing opportunities. One participant suggested fully removing all structures at the end of the lease to allow bottom to be clear again. Multiple participants noted that they do not want to be compensate—they want to fish and earn their own living. One participant did not think developers would compensate for anything. If the scallop fishery were stopped, it was doubted that each vessel would receive $1 million per year; and even if they did, it was unclear if that would trickle down to crew. Another participant suggested $8 million per vessel and/or $1 million per year per vessel. The scallop industry worked hard to make their fishery sustainable, and the participant considered this development to put that work at risk.

Table 9. Summary of Mitigations Identified during Sea Scallop Fishery Interviews

General Topic	Response	Number of Respondents (out of 7 total)
Possibility of gear modifications	No	7
Shift of effort to other areas	Yes	3
Fisheries management limitations	Yes	7

3.3 Surfclam and Ocean Quahog Captain Responses

As is standard practice, the surfclam and ocean quahog survey was a collective industry response that was self-conducted by both owners and operators, based on structural and cultural preferences of the fleet. At least one representative each from eight businesses either responded or reviewed and approved the interview question responses. The final responses were those agreed upon by each of the industry member representatives.

The primary ports of the survey participants included Gloucester, MA, New Bedford, MA, Fairhaven, MA, Point Pleasant, NJ, Atlantic City, NJ and Ocean City, MD. Vessels ranged in size from 55 ft to 160 ft The surfclam and ocean quahog fisheries are conducted using the hydraulic clam dredge. Because of the specific gear type used, details and nuance included in the answers, and the summarizing activity that already occurred in developing the response, the surfclam and ocean quahog participants asked that the response be included word-for-word in this report. Thus, all responses are included as direct quotes to make this clear.

3.3.1 Fishing Characteristics

Primary Port(s)—Response: "Gloucester, MA; New Bedford, MA; Fairhaven, MA; Point Pleasant, NJ; Atlantic City, NJ; Ocean City, MD"

Primary Fisheries (in terms of gross revenue)—Response: "Atlantic Surfclam and Ocean Quahog. Vessels are purpose built or conversions that do not participate in other fisheries."

Describe Primary Gear Type – Response: "The hydraulic clam dredge moves across the bottom on a pair of runners towed by the fishing vessel. It operates using high pressure water pumped from the vessel and forced through a series of nozzles to loosen and fluidize the sea bottom, the water is followed by a knife blade the width of the dredge (less the runner width) that cuts through the bottom and lifts the clams into the body of the dredge as the dredge is being towed along the bottom. The body of the dredge is made of evenly spaced bars that shed sand, shells, small rocks, and small clams while retaining market sized clams. The dredge is retrieved by the vessel, emptied and re-deployed during harvesting. A vessel may utilize either one or two dredges and either deploy and retrieve the dredges off the stern or the side of the vessel."

Dredge size(s)—Response: "48 inches to 200 inches measured across the knife blade."

Describe other Gear types**—**Response: "None"

Vessel size(s)—Response: "A vessel's size may be measured in several ways. Vessels in this fishery range from 55 ft to 160 ft registered length. Registered length is the measurement the United States Coast Guard and Vessel Documentation Management System utilize. The length overall of a vessel is longer than the documented length. Vessels are also of different widths, depths, tonnages and have different horsepower ratings. Depending on the use of the information "size" may take any one of these various forms."

Position - Response: "Owner, Owner/Operator, Captain—The responses to this survey have been submitted by both owners and operators of the Atlantic surfclam and ocean quahog industry.

How many years of experience do you have as a surfclam/ocean quahog captain? Response: "The surfclam and ocean quahog industry has seen an aging of vessel management with the average age of captains and mates rising over time. Most all captains in this fishery have 20 and 30 years of experience with many having even more. Although there are captains with less than 10 years of experience in the fishery they are in the minority."

3.3.2 Fishing Operations

The following questions were asked in regard to wide open ocean fishing operations under good conditions. These questions were designed to help understand any limitations of fishing within a wind array or changes needed to normal operations. For these questions, the sea state conditions are favorable with calm to light breeze, 0–1.5 ft waves, visibility is clear, and there are no other vessels around.

What is the average duration of a tow? Please also describe what factors determine the duration of a tow. Response: "A tow duration may average 35 minutes but range from just a few minutes to an hour or more. Many factors determine the duration of a tow but the main determining factors are the bottom sediment, the quality of the water being pumped down to loosen and fluidize the bottom sediments (water quality is dependent on the flow rate, stream size and shape, the pressure at which it is applied to the seafloor, and the absence of air that may be picked up through leaking seals or cavitation along the path of pump and discharge), the environmental conditions (wind speed, wind direction, wave height and tidal currents), and the physical properties and spatial variability of the clam bed being harvested."

Average speed of a tow? Response: "Tows are generally made between 2.8 knots and 3.8 knots. Different vessels will have different speeds that are efficient for them, these speeds will change with environmental conditions and sediment type."

What factors determine the spatial operational needs for fishing operations during a typical trip? Response: *"*Fishing operations consist of first locating what appears to be a spatially dense quantity of clams that can be harvested efficiently. The captain must determine the area and method the clams can be most efficiently harvested. This is done through a series of tows, each one different so that a mental map may be formed of the clam bed which is being harvested. This may be accomplished during a single trip or over multiple trips. These physical properties, spatial variance and the mental map determine the space the vessel will settle into to harvest with the goal of productive efficiency. The environmental conditions are also important factors in the spatial operational needs of the vessel. As environmental conditions change the efficiency of the harvesting methods in use also change and a vessel must change its harvesting course, speed, and positioning to retain productive efficiency."

"Because spatial operational needs have so many variables a data driven approach to looking at t hese needs is preferable. NOAA Office of Law Enforcement (OLE) Vessel Monitoring System (VMS) data was used in two analyses looking at spatial operational needs of the Atlantic surfclam fishery in the Atlantic Shores and Ocean Wind lease areas during the years data was available at the time of the report for the period 2007–2018. One analysis concluded that vessels of the LaMonica Fine Foods fleet used a median area of 10.0 square miles per trip and a mean of 19.03 square miles per trip in the Atlantic Shores wind energy areas. The other analysis concluded the vessels of the Atlantic surfclam fishery used a median area of 8.41 square miles and a mean of 16.39 square miles per trip in the Ocean Wind lease. (These analyses have been made available to study principal investigators.)"

What are the factors (e.g., bottom type, vessel limitations) that decide where you tow? Response: "The factors that go into the decision on where to tow are many and interdependent. The decision-making process usually starts at the dock by considering the clam processor schedule, distance from the dock of the various areas, anticipated speed of the vessel going out and back, the weather forecast, the anticipated working conditions for the expected duration of the trip, the condition and abilities of the crew, and other limiting factors. When considering these factors, the vessel operator weights the various combinations of risks and rewards in deciding on where to tow. In general, the vessel operators of the fishery, aim to keep the duration of each trip to a minimum; this allows the potential for the maximum number of trips. For example, the first and second boat back to the dock may be back-loaded right away and get back out for another trip while the third and subsequent boats back must wait for trucks, cages and or other vessels to offload costing valuable time that could be spent productively instead of waiting at the dock."

"One exception to this may be an environment where the clam processor schedule will only allow for limited number of trips and the vessel operator decides to risk time steaming (traveling to and from) or looking (making tows where it is unknown what will be caught) for the potential reward of discovering a productive area with a higher catch rates or adding to the detail of the operator's mind map or understanding of the area by steaming further from the dock or to areas where less is known. The risk of looking around in an area is reduced knowing there will only be a limited number of cages or trips caught because of the clam processor schedule.

A vessel may choose to work one area over another due to weather or environmental conditions. These conditions impact catch rates and crew safety and are carefully considered. An area that the bottom sediment wouldn't allow a vessel to work during calm sea conditions may be productive when there is a 5-foot sea due to the motion of the vessel in the rougher conditions enabling the dredge to filter the clams more efficiently from the unwanted sediment material. One crew may be able to effectively remove clams from an area where the vessel is catching a lot of shells but achieving a high rate of catch while another less experienced or more fatigued crew cannot. An area with a high catch rate may be avoided because the clams produce a low yield or an area with a low catch rate may be targeted taking into consideration the high yield and value to the clam processor thus producing high customer satisfaction and a more favorable schedule in the future."

“When working a specific area catch per unit of effort is the main factor in the decision on where to tow but crew safety and the quality of the catch are also considered. Until a vessel operator believes they are approaching productive efficiency for the area and conditions in which they are working they will continue to vary the area and method of fishing to achieve productive efficiency. Questions such as are there more clams to the east or to the north must be explored; can the crew effectively remove the amount of trash, shells or bycatch that is being caught; might we improve efficiency by making longer tows; shorter tows; circle tows? When it is felt that little is being gained from looking or varying the fishing method a vessel operator will settle in where fishing seems to be the most productive. The weighing of risk and reward continues throughout the trip, for example when an operator determines that he has ‘lost’ the race back to the dock and will have to wait for other vessels he may start to look or experiment again, adding to his knowledge and mind map of the area. Being able to achieve and maintain productive efficiency is critical to the success of the vessel as an ongoing business entity.

The number of factors and interdependent relationships are many and varied. Experience allows for more experimentation and additional factors to consider to achieve productive efficiency. Factors that limit the choices around direction or length of a tow that an operator can make such as subsea cables, rock, or mud concentrations, wreaks or structure reduce the possibility of achieving productive efficiency and will increase the risk of having an unproductive trip. Many unproductive trips will put the business entity in jeopardy.”

Do you have to change the direction of a tow during a trip? Response: “Yes, as conditions change the direction of tow must change to continue to harvest at productive efficient levels.”

Do you ever tow in circles? How big are the circles? What is the average duration of a circle tow? Response: “Yes, sometimes circle tows are necessary to achieve productive efficiency. Circle tows are generally 4/10 nm–7/10 nm in diameter. Circle tows are generally done for 25 to 40 minutes in duration, but they can be longer or shorter.”

Please describe any alterations made to your fishing operation with the presence of fixed gear, hard bottom (e.g., boulders or wrecks) or other vessels in the area. Response: “Fixed gear, hard bottom, or other vessels in the area are avoided.”

What is the closest distance to fixed gear that you will make a tow? Response: "This depends on environmental conditions, risks, and the catch rate (or potential reward). What is the relevance of this question to understanding and developing solutions for safe and efficient access to fishing grounds within WEAs?"

3.3.3 State of the Sea Scenarios

These next set of questions are intended to understand how surfclam and ocean quahog vessel operation differs under less favorable conditions. Sea state definitions were provided for reference (Table 4).

If you were fishing during the day with wide open seas and no other vessels around, what is the maximum Sea State (wind speed or wave height) you would fish? Response: "Clam vessels can usually fish up to Beaufort Number 5 conditions before catch rates and safety are impacted with some of the larger boats able to fish in Beaufort Number 6 conditions."

Is the duration of your tow modified under these conditions? Please describe. Response: "The duration of a tow is normally modified when sea state conditions change because conditions, especially wind speed and wave height, impact catch rates and sediment retention. As conditions increase from Beaufort Number 3 conditions to Beaufort Number 4 conditions a vessel typically catches cleaner allowing it to make longer tows. As conditions increase from Beaufort Number 4 conditions to Beaufort Number 5 conditions a vessel typically catches less, requiring it to make longer tows to fill the dredge. During worsening conditions, the time on the bottom will need to be increased. Hauling and setting will take on new risks and need to be decreased to the extent practical."

Is the speed of your tow modified under these conditions? Please describe. Response: "Not generally. Speed may have to be reduced one tenth or two tenths of a knot for the dredge to continue to tend bottom as sea state worsens during Beaufort Number 5 and 6 conditions, but other adjustments can be made instead of decreasing speed. During heavy weather, Beaufort Number 5 and 6 conditions, a vessel may only be able to tow in one direction, with the wind and seas, and have to modify operations by steaming back (transiting with the clam gear on the vessel) into the seas and turn around to make subsequent tows."

Do you make modifications to spatial operational needs? Please explain any changes or limitations to turning, direction, circle tows. Response: "Yes, as explained, changes in conditions often require changes in the fishing techniques being used (course or length of the tow)."

What is the maximum sea state you will fish in at night? Response: "This is generally the same as during the day."

Using the visibility scale provided (Table 5): In wide open seas during the day, what is the level of visibility you would not operate in? Response: "Visibility does not impact fishing in wide open seas."

The level of visibility you usually would not operate in at night. Response: "Visibility does not impact fishing at night in wide open seas."

How do other vessels fishing in the area affect your decision to fish under these conditions (sea state and visibility) or modify your operations? Response: "The addition of vessels, the increase of sea state and decreases in visibility all increase risk to vessel and crew and must be closely monitored when operating a vessel. All spatial risks are weighted against the expected reward of staying and fishing in proximity with moving locations, potentially reducing catch per unit of effort."

3.3.4 Wind Array Interactions—Offshore Wind Spacing Scenarios

A set of hypothetical wind arrays was provided (Figure 1). The following questions were used to determine perceived ability to fish within these wind array scenarios. For these questions, operational needs were considered in regard to turbine spacing and orientation, not cable placement.

Based on the descriptions of these 4 scenarios and your operational needs, do you feel there are benefits of one wind array over the other? Please explain. Response: "There are benefits to a wind array with the greatest amount of open spacing to harvest. Layout A has zero open space to harvest, Layouts B, C and D have varying sizes of open space with Layout D appearing to provide the most optionality to adjust to varying conditions which would provide the greatest benefit."

Based on your operational needs, would you prefer to operate within a 1x 1 nm grid pattern or turbines that are not uniformly spaced in a grid pattern, but a range of 0.5-1.0 nm apart? Response: "The surfclam and ocean quahog industry, with the current state of the fishery, cannot operate within either of these grid patterns described and achieve productive efficiency. [Current state of the fishery refers to the catch rates and degree of patchiness of the biomass.]"

Under good weather conditions, do you foresee yourself needing to modify your wide-open sea fishing practices (as you described in question 1) in order to operate within wind arrays due to the turbine spacing and orientation? Response: "Fishing practices must be modified to account for the addition of fixed structure in the water. Not operating within, or avoiding, the wind array due to turbine spacing is the likely result of all turbine spacing and orientation proposals we are aware of."

Is tow duration modified? Please explain. Response: "Yes, if fishing was to be attempted within a wind array, tow duration would be reduced in order to reduce the risk of "anchoring up" and losing control of the vessel. Anchoring up is the result of filling the dredge with bottom sediment and losing forward momentum. This risk increases as the dredge is filled and the dredge area for filtering is reduced. To reduce this higher risk at the end of the tow, tow duration would be reduced."

"Anchoring up is a risky condition even in open seas and the risk would rise exponentially if fishing within a wind array. The loss of forward momentum results in the loss of steering and increases the probability of getting gear in the wheel and losing all maneuverability and subject to being at the mercy of the wind and the current."

Is tow speed modified? Please explain. Response: "Yes, if fishing was to be attempted within a wind array, tow speed would be increased in order to reduce the risk of "anchoring up" and losing control of the vessel. Increasing tow speed reduces the risk of anchoring up but also reduces the towing efficiency, the dredge will catch less, sometimes much less at the increased speed. Anchoring up can be caused by several factors but vessel speed not remaining high enough to allow the dredge to efficiently filter bottom sediment from the catch is common. The most efficient vessel speed and that which the vessel will anchor up may be different by as little as 0.1 knot."

Modifications to spatial operational needs? Please explain any changes to turning, direction, circle tows that would be affected. Response: "The spatial operational needs of the vessels participating in the Atlantic surfclam and ocean quahog industry are imposed by the biology of the target species, sediment type in which they live and the environmental conditions that act on the vessel and fishing gear. Limitations in handling characteristics of the vessel would only come into play after a reasonable safe buffer between harvest area and the fixed structure are violated. Limitations in handling characteristics of the vessel should not be confused with the spatial needs to operate the vessel.
The handling characteristics of the vessel does not have a correlation to spatial operational needs unless operating within proximity to structure which is too risky to life and property in the open ocean.

It must be understood that fishing in the Atlantic surfclam and ocean quahog industry is much more complex than simply harvesting the clams. Locating an area that can be harvested depends upon many environmental variables. An area that may be harvestable one day may not be productive the next because of environmental changes. Spatial operational needs are dictated by locating a harvestable area and then determining if there is a course, speed and area that can be utilized to achieve productive efficiency and acceptable catch rates."

Any other operational modifications you foresee needing to make? No response.

What, if any, are your safety concerns with operating within wind arrays based on the orientation and spacing? Response: "Operating a clam vessel within a wind array that has been placed in the open ocean will increase risk to vessel and crew to unacceptable levels unless the orientation and spacing can be such that vessels can avoid being in proximity to the fixed structure of the array which won't happen until turbine spacing reaches 2 nm and IACs are run parallel to depth contours."

Do you have any other wind array orientation and/or spacing recommendations that are not presented within these 3 scenarios? Please describe. Response: "Space turbines 2 nautical miles apart in all directions and align rows and cables with the depth contours in the lease area."

How would other fixed gear and/or other vessels within the wind array affect your decision to operate within the wind array? Response: "Fixed gear and/or other vessels within the array would pose additional risks that would have to be weighted when making the decision to operate within an array."

Do you have any recommendations for mitigation strategies to operating within a wind array with other vessels? Response: "No."

What, if any, are your concerns about your safety due to radar interference from within wind array A? Response: "Radar interference from within any wind array will interfere with the ability of a vessel operator to make a full appraisal of the situation and will increase the risk of a collision. Radar interference will interfere with the ability to conduct long range scanning to obtain early warning of the risk of collision and the ability to properly plot vessel traffic. Additionally, structure and lights within the array will hinder other means of determining the risk of collision such as monitoring a vessel's compass bearing for changes."

Do you have recommendations on mitigating your safety concerns with the radar interference from within the wind arrays? Response: “Yes. Supply vessels with pulse compression radar units. Some of the risk of collision may be mitigated by installing AIS Aids to Navigation (AtoN) transceivers on each structure or using virtual AtoNs for marking each structure.”

3.3.5 Wind Array Interactions—Sea State Within Wind Arrays

The following set of questions were posed regarding anticipated fishing operations within wind arrays during certain sea state and visibility conditions.

If you are fishing during the day, at what sea state in the table above do you foresee there being too much risk fishing within a wind array? Response: “Fishing within a wind array in any sea state will increase the risk to life and property. Vessel operators will evaluate this risk differently, but the risk will not change, only it’s perception. Ultimately the fishing industry will bear the additional costs of the risks caused by the array with the loss of life, property, and increased insurance premiums.”

If you are transiting during the day, at what sea state in the table above do you foresee too much risk <u>transiting</u> within a wind array? Response: “Transiting within a wind array in any sea state will increase the risk to life and property. Vessel operators will evaluate this risk differently, but the risk will not change, only it’s perception. Ultimately the fishing industry will bear the additional costs of the risks caused by the array with the loss of life, property, and increased insurance premiums.”

Do you foresee yourself fishing within a wind array at night under good conditions and assuming lighting and marking requirements as set by USCG? Response: “The risks and rewards of fishing within a wind array under any conditions will be weighted by each vessel owner and vessel operator.”

If yes, at what sea state level do you foresee there being too much risk fishing within a wind array at night? Response: “The risks and rewards of fishing within a wind array under any conditions will be weighted by each vessel owner and vessel operator. The risk will increase with the sea state level and all of the risk will be borne by the fishing industry.”

If yes, at what sea state level do you foresee there being too much risk transiting within a wind array at night? Response: “The risks and rewards of transiting within a wind array under any conditions will be weighted by each vessel owner and vessel operator. The risk will increase with the sea state level and all of the risk will be borne by the fishing industry.”

Based on the visibility scale provided (Table 4), at what level of visibility would you consider there being too much risk operating within a wind array during the day? At night? Response: "The risks and rewards of fishing within a wind array under any conditions will be weighted by each vessel owner, vessel operator and eventually the vessel insurer."

3.3.6 Cables

The following questions were posed regarding cable layouts and any concerns with operating with wind cables.

Do you have concerns about your safety due to the cables within a wind array? If yes, please explain. Response: "Yes, the IACs and export cables associated with a wind farm are large, heavy and carry very high voltage. A clam harvesting vessels fluidizes the bottom sediment with high pressure jets and cuts the bottom with a knife blade similar to a snowplow blade to loosen and collect the clams. A clam dredge can easily get caught on a sub-sea cable, it has happened many, many times in the past. If a wind array cable became exposed and a clam harvesting vessel got hung up in it the safety of the vessel and crew would be put in jeopardy."

Do you have any recommendations on mitigating safety concerns within a wind array in regard to cables? If yes, please explain. Response: "The deeper the cables can be buried the safer they will be. If the cable depth can be monitored the safer, they will be."

Do you avoid existing cables (ex. telecommunications) in your operations today that are marked on charts? Response: "Clam vessel operators will generally avoid existing charted cables."

Would you be comfortable operating over a cable within a wind array if it was marked as buried 6 ft***? Y/N*** Response: "How are we defining "operating over a cable"? Clam vessel operators would not be comfortable towing across a high voltage electric cable, towing perpendicular would be especially dangerous. Towing parallel, in proximity, to a marked cable would be much less dangerous. An operators' comfort level working near or 'over a cable' has no correlation to the actual risk being taken and the subsequent cost to the clam industry. Developing solutions for safe and efficient access to fishing grounds must be about the reduction or elimination of the risks, not the vessel operators' perception of the risks."

If no, 8-10 ft? Response: “Clam vessel operators would not be comfortable towing across a high voltage electric cable, towing perpendicular would be especially dangerous.”

How would cable protection methods, used when cables can’t be buried, affect your operations? Response: “This would be much more dangerous for vessels and crews to operate around.

Have you experienced any interactions with cables to date? Response: Clam vessels have had many interactions with telecommunication cables, both live and discontinued, in the Mid-Atlantic Bight while towing clam gear.”

When and where did the strike occur? Response: “The Mid-Atlantic Bight.”

Was it an active cable? If so, telecommunications or power? Response: “Active and inactive telecommunications cables.”

What was your operational activity at the time of strike? Towing? Response: “Towing.”

Please describe damage to gear/vessel/equipment, if any: Response: **“**Damaged has ranged from minor damage like tearing out the knife blade, to causing the vessel to get the hose or tow line in the wheel and losing control of the vessel to a complete loss of dredge, hose and haul back cable.”

Was cable marked on navigation/map at the time of strike? Response: “All cables are marked. Not all cables are marked accurately.”

Did you report the strike? If yes, Describe the process of reporting. Response: “What is the relevance of this question to understanding and developing solutions for safe and efficient access to fishing grounds within WEAs?”

Were you compensated for damage? If yes, please describe the process of compensation. Response: “What is the relevance of this question to understanding and developing solutions for safe and efficient access to fishing grounds within WEAs?”

3.3.7 Cable Layout Scenarios

Two cable layout scenarios with a wind array were provided (Figure 2). The square box represents the offshore substation platform, and the circles represent the wind turbine generators. The red lines represent the IACs, and the thicker red line represents the export cable. All wind generators should be linked to the substation platform (black square). Example A has a substation in the center of the wind array while example B has a substation on the perimeter of the array.

Based on your operational needs, please explain the benefits or limitations of each layout scenario and the reasons why one might be better than the other for your operational needs. Response: "If the cable rows in Example B followed the depth contours, it would be preferable because it provides for space to make complete tows along those contours, but it wouldn't provide for the operator to change direction when conditions change and make complete tows at 90 degrees to the original tow path which is sometimes critical to being able to operate in an area."

What nautical charts do you prefer to use? Response: "Electronic nautical charts."

Do you believe you will have adequate access to wind array cable routes via preferred nautical charts? Response: "Yes, of course."

Do you see opportunities to consider gear modifications to improve operations within WEA? Response: "No."

What are your concerns with being able to adapt to wind array development? (i.e., other fishing grounds, species) Response: "Our concerns are that adapting or adjusting to wind array development will mean loss of revenues, loss of incomes, loss of jobs and potentially the failure of companies. Co-existence of these two industries, and adaptation by the clam industry, at the industrial scale being imagined by State utilities will not likely be possible. Wind array development will put a lot of structure where there was only open ocean on prime fishing grounds; this structure will severely limit opportunities to harvest clams in the area and lead to loss of access. Loss of access to productive grounds will put additional pressure on a strained industry. Loss of access to productive grounds will accelerate localized overfishing on other fishing grounds. Loss of access for NOAA survey vessels will lead to increased scientific uncertainty and reduced quotas."

Do you have concerns regarding fisheries compensation from wind companies? If yes, please describe your concerns. Response: "Yes. First, compensatory mitigation is very separate and distinct from developing solutions or mitigation measures related to the design, construction, and operation of wind farms for safe and efficient access to fishing grounds within wind energy areas. That said the concern is that the fishing industry is unlikely to receive compensatory mitigation from wind companies for the all the losses suffered due to wind energy. Compensatory mitigation will likely be determined up front and many of the losses won't be fully understood for some time. Regulators are slow to look at the spatial operational needs of fisheries and do the type of analysis on how these operational needs will be impacted which is only the first step necessary to determine compensatory mitigation."

"The ecological systems that surfclams and ocean quahogs rely upon may not be resilient enough to sustain commercial quantities of clams in the mid-Atlantic Bight while being home to wind energy at the industrial scale being considered. It is unlikely fisheries will get a compensatory mitigation plan that accounts for the very real biological and ecological risks to fisheries."

"Note from clam industry members: The commercial fishing industry is one of the most dangerous industries in the United States. Adding wind arrays with its subsea cables carrying thousands of volts of electricity, cable mattings, foundations and the associated structure will increase the dangers and the risks to the vessels and crews that participate should they operate within WEAs."

"Questions 11 through 13 pertaining to the operators' *perception* of risk are not relevant to the actual risks and costs that will be borne by the fishing industry to fish within WEAs if operators do in fact choose to do so. It is unclear how operators' perception of risk will lead to a better understanding to develop solutions for safe and efficient fishing access to offshore wind farms or to the development of technical strategies and tools to minimize the disruption of commercial fishing. The actual risks must be understood."

"The structure and nature of the marine insurance industry willing to ensure fishing vessels is very much backward looking, only fully considering new risks after losses have occurred, then recalculating all vessels undertaking similar risks for subsequent periods in order to cover similar losses plus the additional profit necessary to take on these new risks. Although a vessel owner will be able to pass his individual risk to the insurer, the risk to the industry of additional structure in the water, plus the insurers' profit margin, will ultimately be borne by the fishing industry."

“It cannot be assumed that the wind industry and the clam industry can co-exist utilizing the same grounds while both industries remain economically viable. Fully understanding clam biology and spatial operational needs of the clam industry is key to developing solutions for safe and efficient access to fishing grounds within wind energy company profit or energy targets if it is in fact even possible. These systems and needs are complex and will require complex solutions. The solutions available using the current state of knowledge from a limited school of thought is not likely to achieve the ability of these two industries to co-exist in the same area at industrial scale. Changing turbine layout and cable routes while respecting a developer’s economical energy generation needs may simply not allow many of the mobile bottom tending fisheries to continue to operate profitably or safely in those areas.”

“Not all fishing operations on the local level will have the resilience to survive disruptions of the loss of productive fishing grounds, the localized overfishing of the areas outside the wind energy areas and the loss of quota due to decreased confidence in stock size estimates. When these businesses leave or go out of business they are lost forever. It isn’t as if there will be a vacuum that will be filled by another operator because the system within which allow these businesses operates will no longer support the economics necessary to support the businesses.

Members of the Atlantic surfclam and ocean quahog industry are committed to assist in any way we can to assist in the development of solutions for safe and efficient fishing access to offshore wind farms or to the development of technical strategies and tools to minimize the disruption of commercial fishing. If we can be of further assistance, please do not hesitate to reach out to us through RODA.”

4 Data Assessment and Gap Analysis

Based on the risks identified by the fishing community, an assessment was performed to identify the relevant existing data sets in each fishery and fishing practices utilized in the area of interest to help inform development of mitigation strategies. Fishery-dependent and -independent data sets were reviewed in the region to better understand how existing data may be best utilized. Data sources included (but were not limited to) NOAA Fisheries, fishery management councils, New York State, and other Mid-Atlantic state agencies, BOEM, academic institutions, the Marine Cadastre, and the Mid-Atlantic Ocean Data Portal. Gaps in priority data sets were identified to inform future data collection and modeling efforts.

Fisheries are dynamic and therefore data collection is inherently complicated. There are many different fish stocks targeted, or avoided, requiring different gear types, areas, timing, and intensity. Management regulations, environmental conditions (including climate change) and market conditions each affect fleet behavior and socio-ecological interactions, which are interpreted by interested parties through fishery data. Fishery data sets are considered fishery-dependent or fishery-independent based on whether they are collected from commercial sources during fishing operations, or from scientists conducting resource monitoring that does not co-occur with commercial fishing. Multiple data products have been used to inform offshore wind (OSW) planning or review efforts, which convert these data streams into readily available spatial or numerical representations using predetermined ranges of inputs.

Federal and state fishery data, whether fishery dependent or independent, is generally publicly available unless the release of such data "could be prejudicial or harmful, such as information or data that are identifiable with an individual fisher."[23] This is applied through the "rule of three," which means that data are confidential unless three or more records may be aggregated within spatial, temporal, or other parameters to disguise individual identity details such as fishing locations. This can result in the under-representation of fishing activity in individual grid squares if fishing activity, in the time frame examined, doesn't meet the "rule of three" and is therefore omitted. In addition, fishery participants and researchers collect proprietary data outside of government monitoring programs that the data owners may choose to utilize in OSW engagement.

This assessment describes each of the resources in these categories, with a focus on the Mid-Atlantic region in general and the Atlantic surfclam/ocean quahog and Atlantic scallop fisheries, as these are the focus fisheries for this project.

4.1 Background

Fisheries management restricts fishing activities to ensure fishery stocks are sustainable and protected resources are safeguarded. This management is highly dynamic, varying annual and seasonal quotas impact fishing effort on target and bycatch species by fishery. Where fishing is allowed to occur in any one year also varies, especially for fisheries that have management strategies such as effort controls and access area trips (e.g., Northeast multispecies and scallops). Additionally, many fisheries are managed with gear restricted areas that are designed to achieve management goals such as bycatch reduction or size class selectivity (e.g., windowpane flounder accountability measure established by NEFMC [2014b]). Exemption areas also exist that allow fishing on stocks while reducing bycatch, e.g., monkfish exemption areas where groundfish bycatch is low. Fishermen are further restricted by the type of permit(s) they have (for example, a vessel without a skate permit cannot land more than an incidental catch of skates on a trip). This makes it difficult for vessels operators who have designed their business around one fishery; if management restricts fishing on their permitted stocks, they cannot switch to another fishery without a substantial financial investment to buy a different permit and gear/re-rig their vessel (e.g., a scallop dredge is unsuitable for catching herring). In addition to a permit holder being limited to their single permit type, there are frequently sub-categories of permits within a fishery management plan (FMP), e.g., the monkfish permit has eight different permit categories that dictate how much and where vessels can target monkfish.

Fish biology further influences the behavior of fishing vessels. Fish move and can vary in distribution annually, both at individual and population levels. Changes in fish distribution are typically dictated by changes in environmental conditions including water temperature and prey availability. This applies to target species and bycatch; if a vessel is catching a large amount of bycatch, e.g., skates, it may change fishing locations to reduce bycatch and time spent processing bycatch.

Business plans for vessels are another factor that influences fishing patterns and resultant data. A fishing business will typically draft a business plan after the annual quota is known, which outlines how much product it will sell to various sectors, e.g., restaurants, foreign markets, and the food industry. Several factors can influence the plan and any modifications that might be necessary during the fishing year. These include market price, fuel costs, mid-year modifications to fisheries management measures, and monitoring costs.

4.2 Fishery Dependent Data Sources

There are several fishery dependent data sources available for analysis. However, none of these data sets are without specific limitations. This section describes the available fishery dependent data sources and their limitations: vessel trip reports, vessel monitoring system, dealer data, observer data, study fleet data, automatic identification system, and information derived through documentation of fishermen's (or others') ecological knowledge.

There are often significant limitations to the spatial resolution assigned to fishery dependent data. A major complicating factor for its application to OSW-related analysis is that data collection practices have typically not been designed to inform granular spatial scales. Catch limits are set at the beginning of a season across a stock's range, or subset of that range. In many fisheries, quotas can be sold or transferred to different permit holders, so the exact spot it was caught may be less important to fisheries managers because they understand that fish move around and therefore do not assign quota to a specific statistical area. The "rule of three" further complicates spatial analysis associated with any fishery dependent data set; the behavior of specific fishing vessels or dealers is often irrelevant to processes required under the Magnuson Stevens Act (such as setting allowable catch levels and determining stock health) but data aggregation can mask important effects of management decisions on individual businesses or communities.

4.2.1 Vessel Trip Reports

Vessel Trip Reports (VTR) must be submitted to NOAA Fisheries for each fishing trip made by federally permitted vessels. VTRs document all fishing activity and catches. Vessels notify NOAA Fisheries prior to leaving port and must fill out a VTR in most instances (exceptions include transit only, operating under a scientific Letter of Acknowledgement, or operating as a herring carrier vessel). Whenever the vessel changes chart area, fishing location, gear type, or mesh or ring size during a trip, vessels must complete a new VTR page. VTRs collect the following information: vessel name, permit number, date and time sailed, date and time landed, type of trip (commercial or recreational), number of crew, gear code, mesh size, gear quantity, gear size, fishing depth, number of hauls, chart area, latitude, longitude, tow/soak time, species code, amount kept, amount discarded, dealer permit number, dealer name, date sold, and offloading port for each species caught.

Recent action taken jointly by the New England Fishery Management Council (NEFMC) and the Mid-Atlantic Fishery Management Council and promulgated by NMFS requires all commercial vessels with federal permits to submit VTRs electronically, not on paper, within 48 hours of returning to port. This requirement will apply beginning November 10, 2021. VTRs are also the most ubiquitous data source throughout the region's fisheries; "lobster only" vessels are the only category without a federal VTR requirement over the last ten years.

There are some data limitations associated with VTRs. Area precision of where fishing is occurring is limited to a statistical area, which is a large area. VTRs only require one position per trip. The reporting requirements will change as part of the omnibus action described above but current and historic VTRs have variable reporting times: most were weekly, but some were monthly. This can delay how quickly data are available for analysis. Catch is reported on a trip and sub-trip level instead of at the tow or haul level, which would provide higher resolution of catch.

VTRs are self-reported data; because of this, there is some concern about the accuracy of total catch estimates. There could be some incentive to misreport discards in certain fisheries (although it is not known whether and to what extent this occurs). This behavior is particularly speculated in mixed stock fisheries such as Northeast multispecies where discards are prohibited for certain stocks at certain sizes and vessels must have enough quota for all caught fish. Vessels that catch too much of one species may be forced to lease quota from other vessels or permit banks; prices are set by the open lease market and may be too expensive for a vessel. Accountability measures that become implemented when catch of bycatch stocks exceed a certain threshold may also incentivize misreporting.

4.2.2 Vessel Monitoring System

The vessel monitoring system (VMS) is a satellite surveillance system used to monitor the location and movement of commercial fishing vessels in U.S. waters. Onboard transceiver units send position reports that include vessel identification, time, date, and location. Frequency of reports vary by fishery, e.g., in the Greater Atlantic Region units must transmit a signal hourly or twice per hour for scallop permit holders. VMS requirements vary by region (the Atlantic Highly Migratory Species fishery management plan also has its own requirements. Hourly position pings limit course and speed resolution based on positions, and limit granularity in describing vessel locations between transmittals. Compared to self-reported VTRs, VMS provide significantly more accurate and frequent information regarding a vessel's location.

It is important to note that not all fishery management plans require VMS; some fisheries are not covered by VMS at all (summer flounder/fluke, scup, black sea bass, bluefish, American lobster, spiny dogfish, skate, whiting, and tilefish). With relevance to our study, the sea scallop and surfclam/ocean quahog fishery management plans do require VMS. Some vessels participate in multiple fisheries and therefore may be required to have a VMS unit for one fishery but not another. When participating in one of the fisheries where VMS is not required, the non-VMS fishery trip is represented by a “declared out of fishery” or “DOF-COM” VMS trip code. Because this code encompasses several fisheries, it prohibits the ability to assign a trip to a specific non-VMS fishery using that code alone. This also means that declaration may mask the specific fishery operations when targeting non-VMS fishery species, e.g., a DOF-COM trip code could be used when targeting fluke, or a declared whiting trip could be landing squid under a DOF-COM code. The trip declaration does not necessarily correspond to actual operation, e.g., declared intent may not represent landings as a vessel may set out to target one species but not encounter it in great volume on that trip.

There is limited historical coverage for most fisheries as VMS was required for fisheries at different times, e.g., scallop fishery required VMS on limited access vessels from 1998 and for open access general category vessels from 2005, but it was only required for *Illex* squid starting in 2017. In general, VTR data sets provide longer and more consistent time series than VMS but lack the spatial accuracy that VMS provides.

Other limitations include the difficulties in accurately estimating fishing time or location because operational assumptions (speed and direction) are affected by weather, sea state, mechanical issues, etc. There is also no information on catch rates. The retained catch composition is limited to the target species and some bycatch information, but this is not universal. There is also no information on catch for sub-trips, only for the full trip. Also, not all information is collected from all fisheries.

4.2.3 Dealer Data

Dealer data are used to determine revenue data associated with fisheries. Dealer data has unique elements that are important to spatial valuation when compared with VMS or VTR data, the most relevant being that landings value can be incorporated into analyses as neither VTR nor VMS systems collect any information regarding sale price.

GARFO has developed a Data Matching Imputation System database (DMIS) that merges dealer reports with their VTR counterparts. It is used for quota monitoring and many other activities. Merging these data streams addresses a core limitation of the dealer database—that it does not include any information about the conditions in which the fish was caught (e.g., gear used, area fished, discards, time-in-area, effort, etc.).

4.2.4 Observer Data

Observer data are collected on commercial vessels (or dockside) by trained observers who collect biological data from the catch. In the New York Bight, observer programs are administered by the Northeast Fisheries Science Center and data collection is tailored for various purposes depending on the program and fishery. These data are typically the primary information source on type and number of discards. It also supports stock assessments and protected resource monitoring.

The NEFSC operates multiple observer programs: Northeast Fisheries Observer Program (NEFOP), At-Sea Monitoring (ASM), Industry-Funded Scallop (IFS), and Industry-Funded Monitoring (IFM).

- The NEFOP program collects information on catch, gear, fishing effort, and biological data on vessels operating from Maine to North Carolina with the purpose to estimate bycatch of all federal management species, as well as protected resources such as marine mammals. This program is run at no expense to the fishing industry. NEFOP coverage rates in the scallop fishery vary historically by year, area fished, time of year, and other factors. In 2020, targeted coverage rates were 18% in open areas and 24% in access areas, although rates in previous years were often lower. The realized deployment rate was lower in 2020 because of the pandemic and the lower-than-expected landing per unit effort (LPUE) observed after observers were redeployed, which may have resulted in some trips redeclaring to an access area trip when selected for coverage in an open area trip (Scallop PDT, 2020).
- The IFS program is deployed on Limited Access and Limited Access General Category scallop vessels and collects similar information to NEFOP. Observers monitor catch and provide life-history information and data on finfish bycatch. They also monitor interactions with protected species, which are primarily sea turtles. Specifically, the IFS program collects data on vessel costs, gear used, location of fishing effort, weather data, and catch data for at least 50% of the hauls on a trip. It was initially adopted by NMFS emergency action in 2006 and then authorized by Amendment 13 to the Atlantic Scallop Fishery Management Plan in 2007. Scallop vessels pay for observers through a days-at-sea set-aside program. Coverage rates vary by year, area fished, and permit type, and range from 2.5% to 10% in 2020 (historically it has been up to 20% in some areas). The deployment of observers was temporarily paused beginning on March 20, 2020 due to the COVID-19 pandemic.

- The ASM program for the Northeast multispecies fishery (groundfish) collects similar data to the NEFOP program but does not collect biological samples. The ASM data essentially provides supplemental coverage to NEFOP for scientific, management, compliance, and other purposes such as monitoring annual catch limits and sector allocations. The fishing industry must pay for the at-sea portion of the costs of an ASM. Recently, the NEFMC voted to have 100% ASM coverage in the NE multispecies fishery; however, this is limited to this fishery and does not expand observer coverage across fisheries.
- The IFM program was established in 2019 and currently covers the herring fishery; the at-sea portion of this program is funded by the fishing industry.

Not all fisheries are covered under these programs, and annual coverage rates vary. For example, the surfclam and ocean quahog fisheries have no observer coverage in most years due to the extremely low amount of bycatch in these fisheries.

Historic observer data only provides a sub-sample of the entire fleet. The coverage rates vary by year based on bycatch rates; for the NEFOP program, the Standardized Bycatch Reporting Methodology is used annually to set coverage targets by gear type. The other observer programs coverage targets are set based on management decisions but can also vary. Observer data are not a suitable option to look at historic catch in certain fisheries, such as lobster, because they only had limited coverage until recently. Since humans are involved, there is the potential for operational observer biases in some fisheries.

4.2.5 Automatic Identification System Data

The Automatic Identification System (AIS) is a "shipboard broadcast system that acts like a transponder, operating in the VHF maritime band, that is capable of handling well over 4,500 reports per minute and updates as often as every two seconds." AIS provides information on vessel movement including location and direction, both to shoreside transponders and other vessel operators. The U.S. regulation (33 CFR 164.46) in part states that all self-propelled vessels, at a length of 65-ft or more, engaged in commercial service and operating on the Territorial Seas (within 12-nautical miles of shore) must maintain AIS in effective operating condition. These data can be limited because they do not cover the entire fleet, only vessels greater than 65 ft in length are required to have AIS installed. AIS uses VHF to broadcast signals which can be picked up by shore-based or satellite-based receivers. The reliability of the VHF signal for shore-based receivers can vary with distance to shore, because VHF signals rely on line-of-sight for communications. This limitation is not applicable to satellite-based receivers which are able to collect AIS signals worldwide. Another limitation of AIS data for fishing activity is that vessel operators are permitted to deactivate transponders when further than 12 nautical miles from shore. In addition to the limitations of AIS based on vessel size and distance from shore, these data do not provide historical representation of fishing vessel locations. AIS was only required on the U.S. commercial fishing fleet beginning March 1, 2016.

If used appropriately, AIS may be a helpful tool for more detailed and objective analysis of fishing vessel trawl patterns because of the temporal and positional resolution and the ability to positively identify a specific vessel. However, given the various limitations, AIS is constrained in its ability to provide overall regional fishing effort distribution for OSW planning.

4.2.6 Social Science-Derived Data

Data streams are often generated directly from fishermen's knowledge through social science studies. Typical methods for this type of effort include surveys (telephone, intercept, or targeted) and interviews. This information can be quantitative or qualitative and describes economic or cultural attributes of a fishery. Specific studies have related to prices, costs, market dynamics, economic performance, economic impacts, demographics, individual and community well-being, community dynamics, cultural importance, and other factors.[24] These data can also be collected to better understand fishing operations, ecological conditions, ocean dynamics, and many other topics of interest to various stakeholders.

Social science data has been used to enhance understanding of offshore wind and fisheries interactions in the Mid-Atlantic in several efforts to date. In addition to Subtask 2.2 of this project, the following is a non-exhaustive list of examples.

- In 2019, NYSERDA, NYSDEC and RODA co-hosted a "NY Bight Transit Lanes" workshop and information gathering effort. As part of this project, the planning team administered a survey to 43 surveys representing hundreds of fishing vessels to better understand where fishermen transit in the Bight. These were collated and presented during the workshop to provide fishermen the opportunity to interpret the results. The results were summarized in a mapping tool to support further public comments and discussions regarding the design of transit lanes in future leasing areas (NYSERDA et al, 2020).
- In 2020, RODA's Joint Industry Task Force created a survey for fishermen to identify navigational aids and markers for OSW installations that would best promote safety at sea. The results of this survey were deliberated amongst OSW developer and fishing industry members of the Task Force and jointly presented to the United States Coast Guard (RODA, 2020a).

BOEM has funded a study by Rutgers and other universities (PI: Dr. Daphne Munroe) with the objective to improve understanding of how Atlantic surfclam vessel operators may change fishing behavior in response to long term environmental change, new offshore infrastructure, and fishery management planning. The project involves determining the direct economic impact to the fishery from a range of locations and configurations of wind turbine arrays along with changes in the stock as assessed and interpreted through fishery management advice. It evaluates present day but not future conditions. A core component of the project involves conducting surveys of permit holders to gather information related to fishery captain and fleet behavior and business economics.

4.3 Fishery Independent Data Sources

Fishery independent data are those which do not require the participation or monitoring of fisheries operators to collect. They are typically seen as less subject to bias due to their separation from the economic interest of fishing, but on their own cannot describe items such as fishing behavior that require supplemental information from fishing vessels and operators.

4.3.1 Federal Surveys

State, federal, and university scientists typically conduct fishery-independent surveys over many years to track long-term abundance trends of fishery resources. This enables them to evaluate how past and present fishing activities affect the resource and make predictions about its future based in various management scenarios. In general, these assessment surveys are designed to assess resource health at the scale of a fishery stock or management area. They are typically conducted annually and may not provide information on seasonality or a host of other factors, depending on what questions they are designed to answer. Some surveys occur more or less frequently than on an annual basis; the Northeast Fisheries Science Center's Bottom Trawl Survey is conducted in both the spring and fall of every year.

These surveys often collect biological data and other information used to describe juvenile and adult abundances, fish habitat characteristics, and environmental factors. They are typically very expensive to conduct. Due to limitations in sample size, area, or seasons, stock assessments often combine these data with fishery-dependent data to provide a more accurate picture of stock status. Moreover, since the data are not influenced by specific management measures (e.g., size and bag limits, season closures, and mesh sizes) or socioeconomic factors (e.g., market price, crew information, and trip costs), they present an unbiased accounting of stock health but lack the context with which to interpret fishing behavior.

NEFSC evaluates the Atlantic scallop resource in Southern New England and the Mid-Atlantic through dredge and HabCam (habitat camera) surveys. These collect data used to assess numerous biological parameters of the stock including abundance, distribution, and size-at-age distribution. The federal dredge survey has been conducted using a lined dredge and a random stratified design since 1979. The HabCam was initially developed by the scallop industry and has been utilized by NEFSC for stock assessments, in cooperation with the Woods Hole Oceanographic Institution in this fishery since 2012 (NYSERDA, 2017).

NEFSC surveys a subset of the surfclam and ocean quahog survey area annually, using a commercial-style hydraulic dredge (prior to 2012, the survey was operated with different gear and months). The entire survey area is covered every three years (NEFSC, 2021). Northern and southern survey blocks are delineated by the southern boundary of Georges Bank, with each area surveyed every other year and the third year reserved for gear testing (NYSERDA, 2017).

4.3.2 NEAMAP and Other State-Based Surveys

The Northeast Area Monitoring and Assessment Program (NEAMAP) provides coordination among fishery-independent surveys. It is a cooperative state-federal program to facilitate the collection, analysis, and dissemination of fishery-independent data in Atlantic coastal waters from the Gulf of Maine to Cape Hatteras, NC. Data are collected to support stock assessments and fisheries management, as well as enhance knowledge of the marine ecosystem. Fishery-independent data are provided for use by government agencies, recreational and commercial fisheries, researchers, and others.

In the New York Bight, the NEAMAP nearshore bottom trawl survey is designed to sample fishes and invertebrates from coastal waters in depths of 20–90 ft between Aquinnah, Massachusetts and Cape Hatteras, North Carolina. The main objective of the survey is the estimation of biomass, length and age structures, and diet compositions of finfishes and select invertebrates inhabiting the area. The survey began in 2007 and is conducted aboard the F/V *Darana R* and led by the Virginia Institute of Marine Science. The survey has provided some data on the scallop resource, although they are not routinely incorporated into assessments. It does not collect clam data.

Some states, including New York, conduct additional fishery-independent surveys for certain stocks. For example, the NYSDEC conducts routine Atlantic surfclam population surveys and collects scientific information on surfclam growth and recruitment. The Surfclam Survey Project conducts two surveys, over three years, to determine biomass, total number of individual clams, and recruitment. The survey uses an ocean research vessel for data collection. The compiled data are then used to assess population biomass and establish annual harvest limits.

4.4 Cooperative Research and Programs

NMFS defines cooperative research as "the partnering of the fishing industry, fishermen, and other stakeholders with federal and university scientists to collect fundamental fisheries information." Such partnerships, including those with other science entities such as states and nonprofits, can generate additional fishery-dependent or independent data that would not otherwise be available. Cooperative research often, but not always, involves federal or state agencies and best practices include the industry's involvement in all phases of the research program, including generation of hypotheses, methodology, research execution, and analysis and communication of results. In the Mid-Atlantic, the NEFSC's Cooperative Research Branch is a key coordinator of many of these efforts, which can be stand-alone projects or long-term partnerships.

4.4.1 Academic and Industry-Based Surveys

Additional fishery-independent data are collected by academic or private sector organizations, individually or in cooperation with federal or state governments. There are many examples across fisheries. For instance, the New England Fishery Management Council and MAFMC have established Research Set-Aside (RSA) programs in the scallop, monkfish, and herring fisheries (though the MAFMC RSA is currently on hold). Each year, a select number of pounds of the allowable harvest in those fisheries is "set aside" to pay for research; the landings revenue from those fish are converted to funding to compensate researchers and industry participants. The councils set research priorities through a public process and NMFS administers the competition, technical review, and harvest activities.

The scallop fishery RSA is particularly robust: it reserves 1.25 million pounds of scallops per year, generating approximately $15 million, of which $3 million supports research projects. It funds surveys to augment federal assessments through this program, which have become an integral part of the stock assessment process and has also made significant contributions to bycatch avoidance practices. In particular, the RSA has provided funding to supplemental survey efforts, including long-term funding for: (1) the University of Massachusetts School for Marine Science and Technology's high-resolution drop-camera surveys to track aggregations and recruitment in multiple regions of importance to the fishery and (2) the Virginia Institute of Marine Science's dredge surveys and age-based assessments performed through cooperative research. In addition to these long-term surveys, the RSA program funds numerous projects that meet the current priorities including work on bycatch species.

4.4.2 Study Fleet

The Study Fleet program was established by the NEFSC in 2007 to work cooperatively with fishing vessels to collect high-resolution catch, effort, and environmental data. Currently, there are approximately 50 fishing vessels involved in the program from Maine to North Carolina. These data are limited because they only cover part of each fishery, fleet, and area in which they are operating. The level of data collected on each vessel can vary with some vessels collecting sub-trip level data and others collect haul-level data.

Study Fleet participants can use additional tools to collect and access data. The Fisheries Logbook Data Recording Software (FLDRS) is an electronic logbook to collect detailed fishing effort, catch, and discard data while fishing. Such data include those related to individual fishing effort (e.g., gear, duration, location) and at a trip level (e.g., ports, dealer, landings, etc.), either on a haul level or in the aggregate. However, data generated through this program do not automatically become available for use. The Graphical Offshore Fishing Information System Homepage (GOFISH) is another tool available to Study Fleet participants, which enables them to access their data in FLDRS to create automated visualizations of catch, bycatch, and environmental conditions.

There is no existing Study Fleet activity in either the Atlantic sea scallop or surfclam/ocean quahog fisheries.

4.4.3 Responsible Offshore Science Alliance

The Responsible Offshore Science Alliance (ROSA) is a regional scientific coordination entity created by the fishing industry, federal and state agencies, and OSW developers. It was founded in 2019 as a nonprofit organization that seeks to advance regional research and monitoring of fisheries and offshore wind interactions through collaboration and cooperation. ROSA's objective is to be a trusted resource that enables scientific research, increases efficiency, deepens understanding, and facilitates collaboration.

The organization's vision is "an improved understanding of ocean and coastal ecosystems that allows for informed compatibility of sustainable fisheries and offshore wind energy." The alliance aims to realize this vision by advancing regional research and monitoring of fishery and offshore wind interactions in the waters from Maine to North Carolina. ROSA is engaging fishermen, wind energy developers, fishery scientists, and federal and state management experts in: (1) identifying regional research and monitoring needs, (2) coordinating existing research and monitoring, (3) advancing understanding through collaboration, partnerships, and cooperative research, (4) administering research, (5) improving access to scientific data, and (5) sharing learnings.

4.5 Select Fishery Data Products and Aggregations

Several tools exist for accessing fishery data streams in a user-friendly manner. Each of these products are derived from some or all of the underlying data streams described above.

4.5.1 Publicly Available Mapping Tools

Online resources that display maps of ocean uses are a valuable resource for the regulatory community, private sector, and the public to gain high-level spatial insight into on-the-water activities. Two of these have large collections of maps derived from federal data sets that have been used extensively in marine spatial planning.

4.5.1.1 Mid-Atlantic and Northeast Ocean Data Portals

The National Ocean Policy of 2010 established Regional Planning Bodies (RPB) to develop regional coastal and marine spatial plans.[25] The Northeast and Mid-Atlantic RPBs subsequently each developed ocean action plans that were finalized in December 2016. One component of those efforts included creation of the Mid-Atlantic Ocean Data Portal and Northeast Ocean Data Portal. Many of the functions of the RPBs were transferred in 2017 regional ocean partnerships: The Mid-Atlantic Regional Council on the Ocean (MARCO) and the Northeast Regional Ocean Council (NROC).

In the Mid-Atlantic Ocean Action Plan, the RPB suggested the following use of the data portal: "All RPB member entities should use the Data Portal as an important, but non-exclusive, source of information to help identify potential conflicts, impacts, and potentially affected stakeholders" (Mid-Atlantic RPB, 2016). The Northeast RPB specified that regarding offshore energy "The information in the Plan and the Portal will provide an important beginning step in identifying fisheries and fishing activity that may be affected by these activities" (Northeast RPB, 2016). In placing these caveats about the need to supplement use of the data portals with direct dialogue and additional analyses, the RPBs recognized the limitations of available information and the complex socio-ecological ecosystem in which fisheries exist.

The two portals together currently contain over 5,000 spatial data products showing human activity footprints and resource distribution in the waters of the northeastern U.S., derived from multiple sources including federal, state, tribal, research/academic, and stakeholder databases. They are administered by nonprofit organizations in partnership with federal and state agencies.

Maps displayed on the data portals consist of summary and synthesis products for use by state and federal agencies and the public. The products are specific to requirements and requests from users within each region and are frequently developed with and vetted by topical experts or they are from published and peer-reviewed literature. The intent is to provide regional context, including baseline understanding of the ocean uses and resources occurring in an area, and where to obtain more information. There are a substantial number of maps that display summaries of fishery data, from federal surveys to VMS and AIS products and more.

The data portals host many maps describing fisheries and fish stocks aggregated from fishery dependent and independent data. These maps have been heavily used by OSW developers, the public, and even regulatory agencies to provide information about spatial conflicts between the two ocean uses. The portal team conducted extensive outreach to fisheries managers and representatives in their development; however, due to the limitations in the underlying data and the unavoidable need to define time series and other aggregation metrics, the fishing industry has often been critical of their use. In recent years, the data portal administrators have added additional maps in response to this feedback, including providing additional context to fisheries regulations and exploring possible map products for fisheries with limited spatial data such as lobster and recreational fisheries.

To further respond to these concerns, MARCO, NROC, and RODA recently partnered to engage commercial fishermen in the development of updated maps and data for the data portals. The purposes of the project were to increase collaboration with the fishing industry on the development of products that represent their interests and improve fishing industry trust in regional data products and the data that are being used to inform decisions. Fishery participants considered the need and potential uses for fishery data products, designed, and reviewed draft products, and communicated about the appropriate application and use of final data products that are available on the ocean data portals. The "Final Report on Updating Commercial Fishery Data on the Northeast and Mid-Atlantic Ocean Data Portals" will be released in Fall 2021 and provides detailed information on existing data products and recommendations for future improvements.

4.5.1.2 Marine Cadastre

The Marine Cadastre, like the data portals, provides geospatial data products and online applications for mapping and downloading those products. It is a detailed near real-time data collection and management network with primarily oceanographic data. It contains direct access to over 300 data layers, and the online mapping applications provide basic functionality, including the ability to overlay data sets, draw shapes, measure areas, and to easily share maps. Each also provides map services that enable users to use the data products to create custom maps via their own software.

The Marine Cadastre provides direct access to data housed on the site and data, metadata, and services from the Cadastre are integrated into the data portals. It focuses on data products, primarily from federal sources, that show ocean uses, ocean resources, and administrative areas for the entire country. Those products are often at scales where they provide general context, but there are some data sets that are best available no matter the scale, particularly the administrative (jurisdictions and boundaries) and maritime data. The Cadastre is a joint initiative of NOAA and BOEM.

The data within the Cadastre has different formats depending on the authoritative source from which they were derived and include shapefile and file geodatabase formats. The Cadastre managers also produce thematic web maps and story maps that highlight data sets and put them into interpreted context, respectively.

The Cadastre contains almost no publicly viewable data on fisheries operations. The fisheries map products consist of: (1) Atlantic fishing revenue intensity, derived from the report "Socio-Economic Impact of Outer Continental Shelf Wind Energy Development on Fishing in the U.S. Atlantic," (2) AIS vessel counts for some years, (3) Essential Fish Habitat and Habitat Areas of Particular Concerns, and (4) fish species richness and abundance.

4.5.2 Economic Analyses of OSW and Fisheries Interactions

In recent years, significant interest in the valuation of fisheries impacts from OSW development have led to efforts to calculate ex-vessel fisheries landing values from lease areas. Nearly all these analyses have estimated fisheries exposure by area, vessel, or port to OSW development on an ex-vessel level, but the models lack predictive ability and do not estimate actual losses. Such analyses must be manually updated, and limitations on underlying data sets (VTR, VMS, etc.) impute to their results. One example of such analysis is Kirkpatrick *et al*. (2017), which evaluated fishery data in the Northeast region to estimate the commercial and recreational fisheries revenues typically generated from within the known wind energy areas at that time. Their work on the exposure of various fisheries and ports is continued and updated as part of NOAA's "Socioeconomic Impacts of Atlantic Offshore Wind Development," which is described below.

4.5.2.1 Fishing Footprints

NOAA Fisheries has developed a Fishing Footprints tool, which combines VTR (landings) and dealer data (revenues). This collection of maps provides landings and revenues by year, for multiple species and fishery management plans, and gear types. It was calculated by applying the known value of a fishing trip over an area, which allows overlay onto spatial boundaries such as OSW project areas. VTR trips have a single point that represents where most fishing occurred; NMFS' Fishing Footprints model spreads the location into two dimensions rather than a single point. That surface can then be overlaid and attributed to assess value spatially. The original analyses, currently on the NMFS website,[26] apply an average value to a trip area. It has since moved to primarily utilizing the socioeconomic impacts models described below.

This tool is useful in viewing a high-level representation of economic value and removals from areas. However, it does not provide any context or means of interpretation of the "footprints" themselves. The footprint of a fishery is ultimately determined by: (1) the abilities and constraints of the species and (2) the local environmental conditions at the time of harvest and into the future that will determine additional constraints such as catch rates and the exposure to environmental risks.

Species' own biological requirements result in the distribution, concentration, location, and movement of the stock itself. This has relevance on any time scale, though is often evaluated by year class or longer (particularly in the case of shellfish since ocean quahog live for 200+ years). Local environmental conditions are the other pieces of fishery knowledge that will determine the fishing footprint. Environmental conditions, and stocks' responses to those conditions, are what fishermen must map—on charts or mentally—to harvest in the most efficient manner. Demonstration of spatial and economic activity on a map does not account for the elements, interconnections, and purpose that make up the fishery the “footprint” represents.

4.5.2.2 NOAA's "Socioeconomic Impacts of Atlantic Offshore Wind Development"

This model builds upon the “Fishing Footprints” tool by utilizing DMIS, so that actual landings values can be attributed to spatial locations rather than average values. Its primary purpose is to develop reports summarizing previous fishing activity within each offshore wind energy lease or project area.[27]

These reports highlight annualized landings and revenue by species, gear type, and fishery management plan within each area as well as revenue by port and vessel dependence upon operations in each area. These are limited because of confidentiality rules; if less than three vessels are operating in a grid square their activity cannot be shared, and each of the “percentage of revenue by permit” analyses are displayed as anonymized box plots rather than actual impacts per vessel. The reports can be used to help identify the major species harvested, fishery operations, and ports affected by offshore wind development in each area to help prepare fisheries monitoring plans and socioeconomic impact analysis and are readily available online.

The summaries are based on combining data from VTR and dealer reports submitted by those issued a permit for managed species in federal waters (i.e., outside of three nautical miles from shore). The methods used to determine area fished for each trip from logbook data are similar to those used to develop the Fishing Footprints page described below.

These reports significantly improved understanding at the time of their development and are one of the most comprehensive sources of economic information about OSW and fisheries interactions. However, there are significant limitations to their usefulness.

4.6 Confidential Fishery Data and Related Projects

This section describes some examples of confidential data sources and products derived from such sources that may be informative to understanding OSW and fisheries interactions if appropriate agreements are reached with the data owners.

4.6.1 Business Data

In addition to federal, state, or other externally collected data that can be traced back to an individual trip or vessel, there is a wide range of fishery data that is generated and held by private businesses. The utility of this data for inclusion in OSW planning or analytical efforts depends on its existence, thoroughness, verifiability, and availability. Most importantly, adequate incentives and protections must exist for the owner(s) of the data to allow them to share that data.

Fishing vessels and shoreside operations generate large amounts of data during their operations. Examples of shoreside proprietary data are those related to business sales, profits, losses, overhead and operating costs, information on financial conditions, and employment records. At sea, data from chart plotter, fish finders, GPS, electronic or paper charts, and other sources often include comprehensive information on tow locations and other characteristics of fishing trips and environmental conditions such as weather and benthic features.

Some fishing businesses are also adopting emerging technologies associated with the "Internet of Things," land- and satellite-based mobile networks, smartphones, onboard cameras, image-recognition software, and others, which can provide novel data streams about fisheries and ocean ecosystems. However, there are significant cultural, practical, and financial barriers to adopting many of these technologies (in addition privacy concerns) and they are often associated by fishermen with "outside-in" enforcement rather than benefiting business practices.

Various laws protect information from public disclosure, including the Magnuson Stevens Act and its implementing regulations.[28] NMFS, for its part, has issued an Administrative Order that provides guidance for treatment of confidential data collected or held by the agency (NOAA Fisheries, 1994). Generally, it directs that the agency can only release such data when responsive to the Freedom of Information Act,[29] court order, or subpoena, but this internal guidance is not immune to challenge. Moreover, accidental information breaches can and do occur. When data are provided to a third party rather than a government agency, they are typically subject to nondisclosure agreements, which can provide a good level of protection but may also be complicated and expensive to negotiate.

4.6.2 Fisheries Knowledge Trust

The Fisheries Knowledge Trust is a fishing industry-led effort to bring fishermen's knowledge into the science and management process. The Trust provides infrastructure for regulators, researchers, and fishing industry leaders to crowdsource and interpret fishermen knowledge in a secure, trusted, and scalable way. Through its unique combination of innovative technology and strict governance, the Trust enables stakeholders to leverage confidential information to rapidly develop trusted, scientifically rigorous products that regulators need to make better decisions about our marine ecosystems.

The Trust operates through a multi-step process: (1) fishermen share data and critical tacit knowledge with the Trust through its secure infrastructure, (2) researchers and other stakeholders access that knowledge when approved by fishermen, (3) researchers develop science products based on that knowledge following rigorous confidentiality and methodology requirements, (4) a review panel made up of various stakeholders works with the researchers to ensure all products are scientifically rigorous, and (5) products are used by stakeholders to improve management and other decisions.

NYSERDA funded the first Fisheries Knowledge Trust in the United States to help manage conflicts between fishermen and offshore wind energy development, led by RODA in partnership with OpenOcean Research. Through this project, the Trust is working on two efforts with 50+ vessels to bring fishermen's knowledge to bear to improve the process of developing OSW while protecting critical fisheries. These efforts include permitholders in the Atlantic herring and Atlantic surfclam/ocean quahog fisheries.

4.6.3 Last Tow Reports

In the spring of 2020, Atlantic surfclam permit holders commissioned a series of studies showing operational patterns in the New Jersey offshore wind lease areas (Last Tow, 2020a, b). Following conversations with developers relating to project layout, the clam companies were motivated to supplement their verbal comments with data and analysis. The reports analyzed four factors: (1) trip shape, (2) ship travel path density, (3) travel direction, and (4) proportion of fishing within a given wind lease area.

The reports were able to access individual VMS records from vessels and companies that would otherwise be protected under confidentiality rules. Using that VMS data, the analysts identified trip paths and timestamps, then classified activity as transit or active fishing based on vessel speed. The reports provide unique information on the size and shape of fishing trips, transit density, fishing density, directional patterns, and relative dependence on the wind energy areas by these permit holders.

5 Scenarios Development and Analysis

5.1 Introduction

The objective of this task was to develop and analyze a realistic set of OSW project scenarios to better understand how to minimize access constriction to fishermen and reduce risk to vessels and gear. As a reminder, the overall goal of this project was to develop technical strategies and tools to minimize the disruption of commercial fishing within OSW arrays, while also ensuring economical energy generation and safe operation for developers. Specifically, scenarios were developed to better understand the potential range of technical options for a wind project located within the New York Bight based on fishing operations for the Atlantic scallop and SC/OQ industries. Based on fishermen's feedback in the previous task, the focus was on the technical parameters of an OSW project with the highest relative impact on fishing access for scallop and surfclam dredge gear types, and the developers' relative level of flexibility in adjusting those parameters to make design decisions. A wind energy project cost-benefit analysis was conducted for the most impactful scenarios to consider the needs of both fishermen and developers. In this chapter, the impacts of fishery preferences for layout configurations are explored by examining key performance metrics for a hypothetical wind farm in the New York Bight. Note that this effort only examines a single OSW project with an assumed plant rating (in MW) and total area (acres or km^2); the assessment of multiple projects was out of scope.

5.2 Methodology

Fishing access scenarios were developed by leveraging the understanding of scallop and SC/OQ fishing access needs in the New York Bight as informed by fishing industry interviews and feedback from the previous task. The project team worked together with the PAC to incorporate this input while developing and analyzing a set of OSW project scenarios for different fishing access strategies. Fishing operational needs were considered based on interview feedback regarding dominant towing direction, amount of space required for operations, and interactions with bottom sediments. Wind farm layouts including turbine and array cable positions were also informed by the feedback from the regional fishing industry. Wind farm performance and cost metrics were calculated for each scenario and compared with a baseline scenario to better understand the impacts of each access strategy.

5.2.1 Scenario Development

First, a baselines scenario was defined to represent a generic offshore wind project based on conditions in the New York Bight. The turbine rated power of 12 MW and nominal plant capacity of approximately 800 MW were chosen based on near-term (next one to three years) OSW project deployment trends (Musial et al. 2021). Turbines as large as 16 MW have been announced for development by 2024, but there is a lag between the announcement of a new wind turbine platform and the market saturation of the said turbine platform (MingYang Smart Energy 2021; Musial et al. 2021). Turbine positions were optimized for annual energy production (AEP), and the footprint of the baseline scenario was used as an exterior boundary throughout the remaining scenarios for comparability. Note that the intent of this work is not to make recommendations about minimum turbine spacings, but rather to show relative changes between scenarios.

5.2.1.1 Core Assumptions

As mentioned above, the PAC was consulted to outline a design space for a representative commercial scale OSW project in the New York Bight. The core assumptions developed based on PAC feedback and data sources are documented in Table 10.

Table 10. Summary of Main Assumptions Informed by PAC Feedback and Additional Sources

Parameter	Value	Rationale/Source
Nominal Plant Capacity	800 MW	Representative of commercial scale plant capacities (Musial et al. 2021)
Project Area	30,147 acres (122 km^2)	Use area of baseline scenario for comparability (discussed in Section 5.2.2.2)
Turbine Rating	12 and 15 MW	Similar to announced turbine ratings for near-term U.S. projects (Musial et al. 2021)
Array Cable Type	66 kV	3-core, copper, 66kV cross-linked polyethylene (XLPE) insulated cables with diameters of 630mm and 185mm
Array Cable Burial Depth	6.6 ft (2 m)	PAC feedback
Water Depth	148 ft (45 m)	Representative of NY Bight (BOEM 2022b)
Distance to Shore	65 nautical miles, nm (120 km)	Representative of NY Bight (BOEM 2022b)
Foundation Type	Monopile	Representative of near-term U.S. projects (Musial et al. 2021)
Metocean Conditions	Wind Speed and Wave Height Time Series	ERA5[30] (Hersbach et al. 2020)

5.2.1.2 Scenario Definitions

With a baseline scenario established, the interview feedback from scallop and SC/OQ fishermen collected in an earlier project task was incorporated along with additional feedback from the PAC to represent fishery interests as design constraints for the turbine layout optimization. The layout optimization was conducted with NREL's Flow Redirection and Induction in Steady State (FLORIS) modeling toolbox (NREL 2021). Table 11 summarizes the fishing access scenarios developed along with their intended value to fishermen. The term "string" refers to turbines connected along the same cable. Based on PAC comments, it was assumed that towing occurs roughly parallel to the dominant wind direction within the optimized wind plant. Finally, array cable layouts were designed for the optimized turbine positions and computed costs with NREL's Offshore Renewables Balance of System and Installation Tool (ORBIT) (Nunemaker et al. 2020).

Table 11. Overview of Project Scenarios

Scenario Name	Value to Fishermen	Description
Baseline: Optimal AEP	Reference case	Align turbine rows and cabling with dominant wind direction assuming towing parallel (slightly modified by optimization)
Scenario 1: OSS Relocation	Altered array cable layout in case impacts preferences for towing direction or higher valued bottom	Same turbine positions as the baseline scenario but relocated OSS to opposite side of wind farm to alter the array cable layout. May be more preferable, depending on the factors that determine towing direction (e.g., catch rate, wind direction, wind speed, tidal current direction, tidal current speed, and sea state)
Scenario 2: Widen Rows	Improve fishing access by providing wider spacing between turbine rows	Pack turbines more densely into strings; Reorganized turbine rows and columns (reduced number of turbine rows from 11 to 9)
Scenario 3: 2 nm No-Build Area	Provide more open area for fishing operations—2 nautical mile (nm) no-build area	Incorporate 2 nm (3.7 km) wide no-build area for transit in the wind array layout
Scenario 4: 5 nm No-Build Area (High AEP)	Provide more open area for fishing operations—5 nm no-build area	Incorporate 5 nm (9.3 km) wide no-build area for fishing in the wind array layout (High AEP case)
Scenario 5: 5 nm No-Build Area (Low AEP)	Provide more open area for fishing operations— 5 nm no-build area repositioned	Incorporate 5 nm (9.3 km) wide no-build area for fishing in the wind array layout (Low AEP case)
Scenario 6: Turbine Upsizing	Provide more open space for fishing operations by using fewer, larger turbines spaced further apart	Increased turbine capacity from 12 MW to 15 MW

5.2.2 Layout Optimization

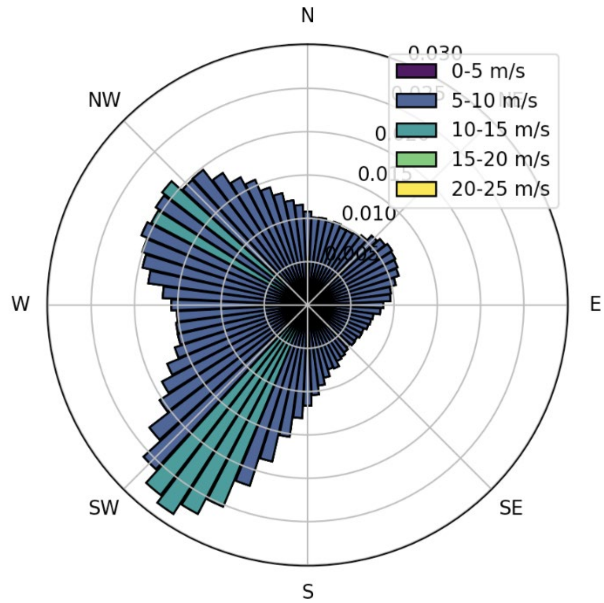
5.2.2.1 Modeling

For this study wind plant performance was evaluated using FLORIS[31] as a function of the turbine layout. FLORIS is NREL's computationally inexpensive controls-oriented modeling tool for steady-state wake modeling and wind plant control optimization (NREL 2021). FLORIS allows for consideration of wake losses dependent on the turbine technology, plant layout, and site-specific wind distribution. For each scenario FLORIS was used to optimize the turbine layout to maximize AEP while constraining the total plant capacity and area in line with the baseline scenario.

The 12 MW and 15 MW turbines were modelled based on the International Energy Agency (IEA) 15 MW reference wind turbine described by Gaertner et al. (2020) (downscaled to 12 MW assuming a constant specific power). Tabular power curve data and documentation can be found on GitHub.[32] Wake effects from the OSS were not considered.

Wind resource data comes from the ERA5 data set covering the period 1979–2020 (Hersbach et al. 2020). A representative wind rose for the New York Bight (taken from the approximate centroid of the wind energy lease areas auctioned in 2022) was used in the analysis (Figure 3); wind speeds were averaged over five-degree bins based on ERA5 data from 1979–2020 in the region. The dominant wind direction in the region is roughly from the west. Winds were determined at the respective turbine hub heights for the scenarios: 453 ft (138 m) and 492 ft (150 m) for 12 MW and 15 MW turbines, respectively.

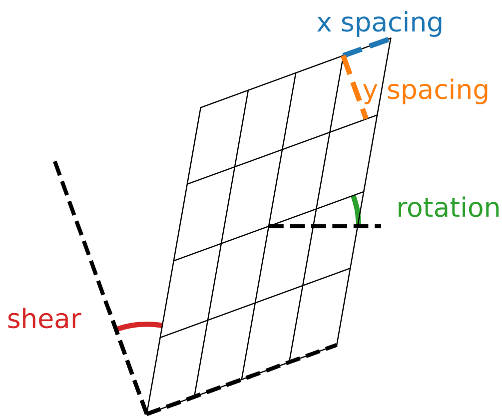
Figure 3. Representative Wind Rose for the New York Bight at 453 ft (138 m) Hub Height



5.2.2.2 Optimization Methods

For the baseline scenario, the 12-MW turbines were arranged in an 11-by-6 square grid. Then, an open-source sequential-least-squares-programming-algorithm optimizer available in the Python programming package SciPy was used to maximize the AEP of the plant by optimizing x and y grid spacing, the rotation of the grid, and the shear angle between subsequent rows of turbines, with a maximum shear angle of 45 degrees and a constraint on the maximum area of the wind plant and the minimum turbine spacing. Figure 4 illustrates these optimization design variables, which are a subset of the variables originally introduced in the boundary-grid wind farm layout parameterization (Stanley and Ning 2019). The footprint of the optimized baseline grid was used to constrain the layout of the rest of the optimized plants for all follow-on scenarios, the area of which was the 30,147 acres (122 km^2) referred to in Table 11.

Figure 4. Diagram Depicting Key Optimization Parameters



The rest of the scenarios were optimized in a similar manner, with modifications of the square grid based on the scenario definitions in Table 11. For each scenario, the design variables were the same (i.e., grid spacing, rotation, and shear angle). For these scenarios, the only constraints were the minimum turbine spacing and the boundary constraint described previously. For the scenarios with different numbers of rows or turbines (turbine rating), it was not always possible to achieve a complete grid of turbines, in which case one row of turbines was incomplete.

For Scenarios 3–5, where a no-build area was included in the plant, the optimization was repeated for every possible location of the no-build area. The reported results only present the best-case and worst-case plant performance with the associated no-build areas in Scenarios 4 and 5, respectively. This helps understand the range of possible outcomes.

5.2.3 Levelized Cost of Energy

Levelized cost of energy (LCOE) represents the unit cost of energy from a power plant over the course of the plant's operational life (i.e., 25 years is assumed for the wind plant lifetime in this study). LCOE is useful for the comparing the total energy cost impact of fishing access strategies within a wind energy development area. LCOE was calculated based on the definition from Short, Packey, and Holt (1995):

$$LCOE = \frac{(CapEx \ \times FCR) + OpEx}{(AEP_{Net} \div \ P)}$$

Equation 1

where:

$LCOE$ = levelized cost of energy ($/MWh)

FCR = fixed charge rate (%/year)

$CapEx$ = capital expenditures ($/kW)

AEP_{net} = net average annual energy production (MWh/year)

$OpEx$ = average annual operational expenditures ($/kW-year)

P = total wind plant capacity (kW)

Note that CapEx may be represented as the sum of turbine, balance-of-system (BOS), and soft costs:

$$CapEx = \ C_{Turbine} + \ C_{BOS} + \ C_{Soft}$$

Equation 2

where:

$CTurbine$ = turbine CapEx

$CBOS$ = BOS CapEx

C_{Soft} = soft costs.

Array cables and their installation costs are included in balance-of-system (BOS) costs, so BOS and soft costs were calculated as described in the following section. For a full description of what is included in BOS costs see Nunemaker et al. (2020). AEP values result from the above optimization performed with FLORIS, and notably only include wake losses and electrical generator efficiency. Other energy losses are neglected, which means that the AEP values presented will be higher than if additional losses are included (and LCOE values will be lower). The total wind plant capacity is adjusted based on the number of turbines and the turbine rating. All other cost variables are assumed to be constant since the focus of the analysis is on the array cable costs. These cost parameters are summarized in Table 12.

Table 12. Summary of LCOE Components and Modeling Methodology

LCOE Component	Value	Method	Sources
FCR	5.82% (real terms)	Obtained from literature	Feldman et al. (2020); Stehly and Duffy (2022)
$C_{Turbine}$	$1300/kW	Obtained from literature	Musial et al. (2021)
C_{BOS}	Varies	BOS Computed with ORBIT	Nunemaker et al. (2020)
C_{Soft}	Varies	Soft costs based on methodology from literature	Beiter et al. (2016)
OpEx	$91/kW-year	Obtained from literature (median value of expert survey)	Wiser et al. (2021)
AEP_{net}	Varies	Computed with FLORIS	NREL (2021)

5.2.4 Balance of System Costs with ORBIT

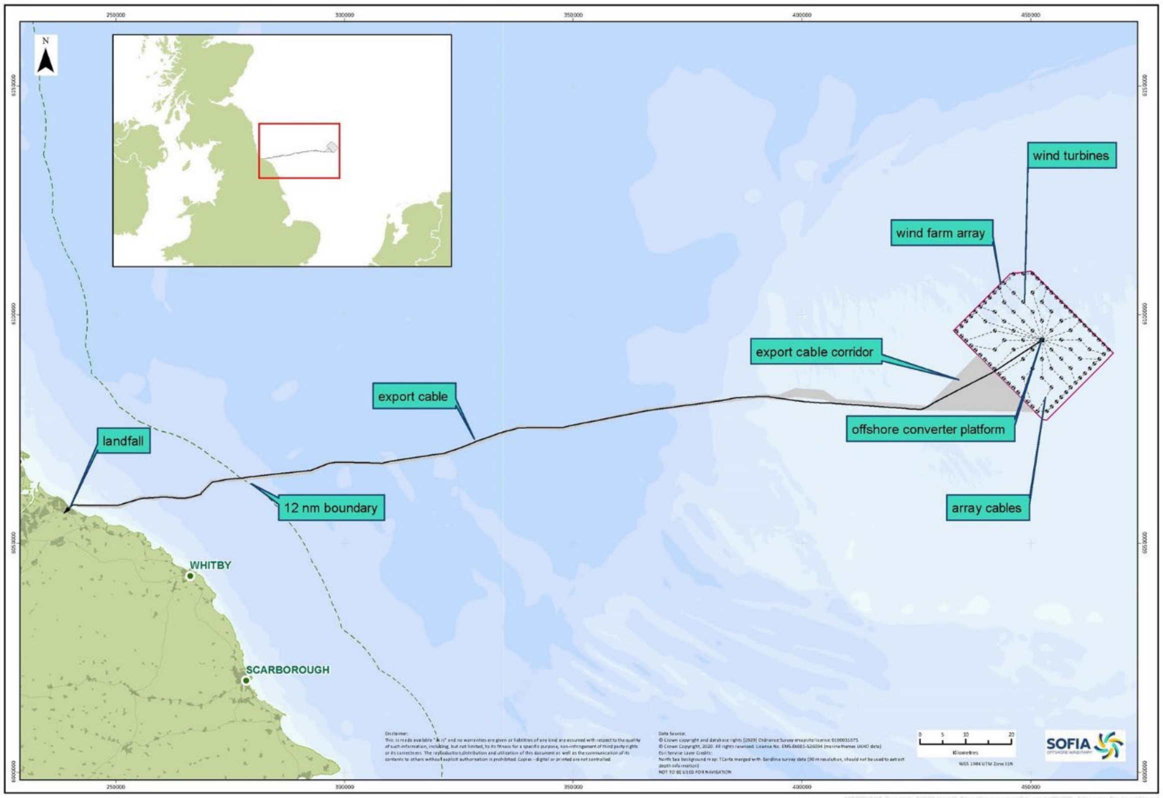
In addition to calculating AEP, the impacts of different array cable routes were evaluated on BOS costs with NREL's ORBIT model. ORBIT is a Python-based, open source,[33] bottom-up offshore wind BOS cost model, which simulates the design and installation phases of OSW projects to estimate costs (Nunemaker et al. 2020). Site-specific assumptions such as water depth and distance to shore were accounted for (Table 10). Soft costs were also computed within ORBIT based on the methodology outlined in Beiter et al. (2016).

The turbine positions within the developable boundary were optimized to maximize AEP, but the array cable layouts were not mathematically optimized. Rather, based on the feedback of the PAC, cable crossings of the possible towing lanes/corridors were minimized between turbine rows (i.e., minimized north-south crossings assuming an east-west towing direction). While burying cables to sufficient depth should prevent interaction with towed benthic fishing gear, aligning inter array cables with predominant tow orientations reduces the number of fishing tows across cable routes, thus improving access for fishing. Where possible between scenarios, the relative position of the OSS within the wind farm was maintained with the same goal of minimizing these crossings. A slight bias towards shore (northwest) was included for the OSS position to attempt to capture the tradeoff between the costs of the export and array cables that developers weigh in their wind farm layout design.

This array cable layout design approach contrasts with many OSW farm designs where optimization of the array cable layout leads to a more central OSS position within the wind farm and array cable strings which radiate out to the edges of the array. This typically produces a cable layout that has a highly varied set of cable orientations and fewer clear seabed lanes. For example, a radial layout design was used at the Sofia OSW Farm in the United Kingdom (Figure 5).

Figure 5. Array Cable Schematic for Sofia Offshore Wind Farm in the United Kingdom

Source: Sofia Offshore Wind Farm (2021)



Minimizing north-south cable crossings was prioritized over maximizing the number of turbines per string based on the electrical current rating of the array cables. For the largest diameter array cable, these limits correspond to maximum of seven and five turbines per string for the 12 MW and 15 MW turbine ratings, respectively.

Based on input from PAC members, the cable burial depth was assumed to be 6.6 ft (2 m), and the seabed/geotechnical conditions were assumed uniform throughout the wind farm area. This feedback also informed increasing the total calculated cable length (and therefore cable material costs) by 5% to account for micrositing or rerouting around obstacles which occur in more complex soil conditions. This added length also helps account for clustering the cables where possible to minimize areas with cable crossings, which in turn, leads to larger areas of seabed unemcumbered with cables. The minimum separation distance between array cables is governed in practice by the need to access the cable for maintenance or repairs. It is assumed that 65.6 ft (20 m) represents a sufficient cable separation distance that will accommodate typical array cable repair strategies which focus on cable replacement of entire cables rather than insertion of a short section with cable joints to existing cables. Wider separation distances would be required if atypical cable repair strategies are utilized.

5.3 Results

The purpose of the analysis was to identify impacts on costs and AEP from implementing fishing access strategies relative to the baseline scenario. The performance and array cable cost metrics from the layout optimization for each scenario are summarized in Table 13. As a reminder, the intent of these analyses is not to make recommendations about minimum turbine spacings, but rather to show relative changes between scenarios.

Optimized turbine layouts and array cable configuration diagrams were developed (Figures 6-12). The effects of the different fishing access strategies on AEP range from -6.4% to +2.0% of the baseline scenario AEP value of 3744 GWh. Impacts on array cable material costs range from -22.6% to + 34.4% of the baseline scenario value of $65.9 million. For the estimated array cable installation costs, these impacts range from -21.1% to +7.2% of the baseline scenario value of $21.8 million. The array cable costs represented between 2% and 4% of the total required CapEx to construct the wind farms in the different scenarios, and an even smaller portion of the total LCOE. The overall impact on LCOE was driven primarily by differences in AEP with values ranging from $57–63/MWh. Note that including other losses in the AEP modeling would lower the total AEP and increase LCOE in all scenarios. This would further lower the impact of array cable costs on LCOE differences between the scenarios.

Table 13. Resulting Performance and Array Cable Cost Metrics from Scenario Analysis

Scenario Name	Minimum Turbine Spacing	AEP (GWh or % change from Baseline)	Array Cable System Cost ($ or % change from Baseline)	Array Cable Installation Cost ($ or % change from Baseline)
Baseline: Optimal AEP	0.63 nm (1.17 km)	3744 GWh	$65.9M	$21.8M
Scenario 1: OSS Relocation	0.63 nm (1.17 km)	0%	+34.4%	+7.2%
Scenario 2: Widen Rows	0.63 nm (1.17 km)	-2.3%	-17.1%	-6.5%
Scenario 3: 2 nm No-Build Area	0.57 nm (1.06 km)	-2.5%	-5.25%	-2.1%
Scenario 4: 5 nm No-Build Area	0.45 nm (0.84 km)	-2.3%	+8.1%	+0.9%
Scenario 5: 5 nm No-Build Area (Low AEP)	0.50 nm (0.92 km)	-6.4%	-22.6%	-7.9%
Scenario 6: Turbine Upsizing	0.72 nm (1.33 km)	+2.0%	-22.4%	-21.1%

The array cable costs represent a small percentage of the total CapEx of an OSW farm project. Table 14 shows the array cable costs in this context and presents the results of the LCOE calculations.

Table 14. Total CapEx and LCOE Results

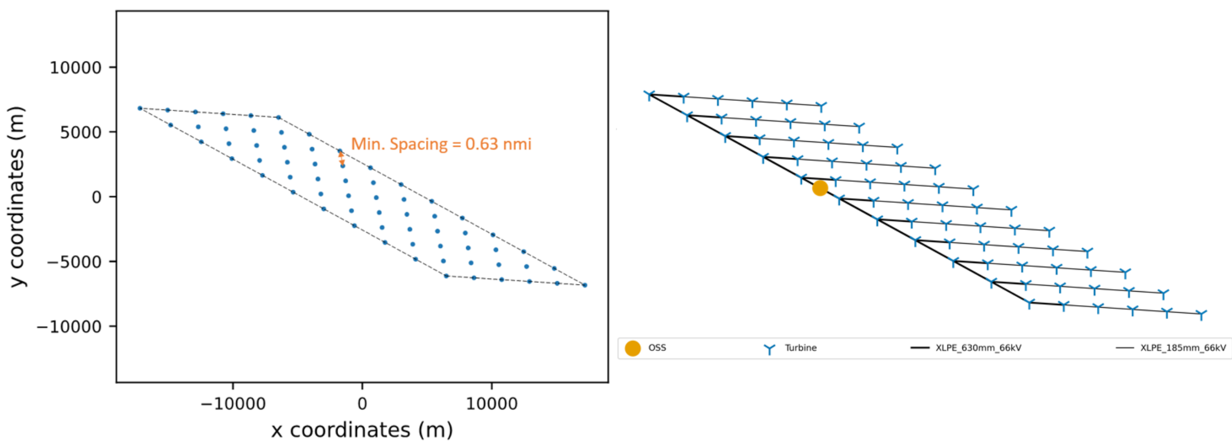
Scenario Name	Total CapEx ($ or % change from Baseline)	Array Cable System Cost (% Total CapEx)	Array Cable Installation Cost (% of Total CapEx)	LCOE ($/MWh)
Baseline: Optimal AEP	$2.589B	2.55%	0.79%	60
Scenario 1: OSS Relocation	1.08%	3.38%	0.83%	60
Scenario 2: Widen Rows	-0.57%	2.12%	0.74%	61
Scenario 3: 2 nm No-Build Area	-0.18%	2.42%	0.77%	61
Scenario 4: 5 nm No-Build Area	+0.24%	2.74%	0.79%	61
Scenario 5: 5 nm No-Build Area (Low AEP)	-0.75%	1.98%	0.73%	63
Scenario 6: Turbine Upsizing	-3.82%	1.89%	0.64%	57

Note: Differences in LCOE are primarily driven by differences in AEP.

5.3.1 Baseline Scenario: Optimal Annual Energy Production

Schematic diagrams show the resulting turbine positions from the AEP optimization (Figure 6a) and the array cable configuration (Figure 6b). Figure 6a shows the turbine positions as blue dots with dot diameters corresponding to the turbine rotor diameter. The minimum turbine-to-turbine spacings are indicated on the figure. The dotted black line shows the wind farm area boundary defined by the baseline scenario that remains the same throughout all scenarios. A black arrow indicates the nearest land. Note that the configuration diagram in Figure 8b is intended to show how the array cable strings connect to the OSS. Array cable conductor diameter and relative position of the OSS within the array are also depicted in the legend in Figure 6.

Figure 6. For the Baseline Scenario (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12.

The resulting AEP for the optimized baseline scenario was 3744 GWh with a minimum turbine spacing of 0.63 nm (1.17 km). The baseline scenario layout in Figure 6 is rotated such that the narrow side of the wind farm is parallel to the dominant wind direction (show in Figure 3). Also notice that the rows of turbines are offset such that the distance between turbines in line with the dominant wind direction is maximized, thus minimizing wake losses, and maximizing the energy production. The PAC provided input on the optimized layouts, suggesting that given the baseline scenario layout, the dominant towing direction would be nearly east-west.

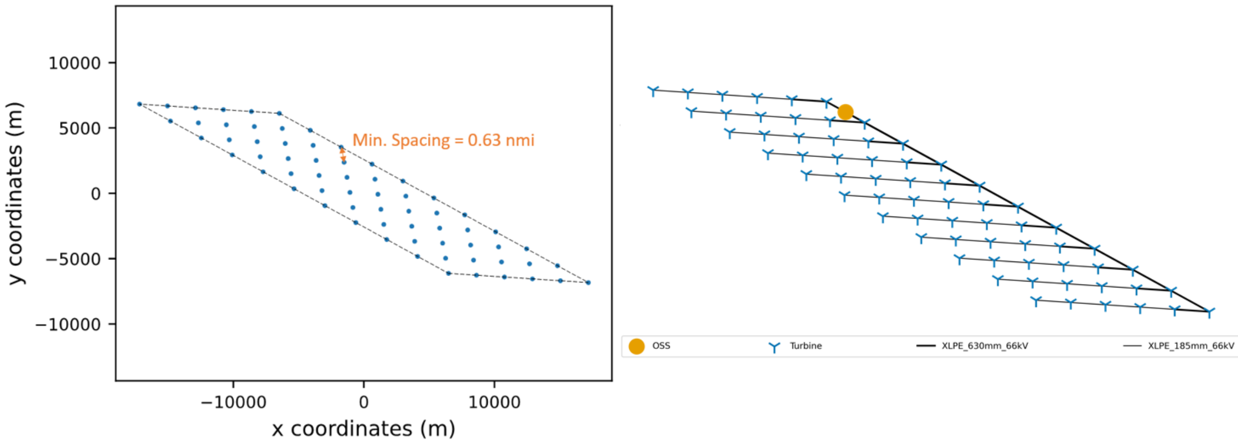
The OSS was located on the western side of the wind farm, and array cable strings were clustered close together on the western edge of the array to keep possible towing lanes clear of cable crossings. In this scenario, prioritizing open towing lanes means that the maximum power rating of the cable is not reached for any of the array cable strings.

The total array cable cost for the baseline scenario is $65.9 million, and the total array cable installation cost is $21.8 million. These represent 2.55% and 0.79% of the total CapEx in the baseline scenario, respectively. This is in line with literature estimates for a representative fixed-bottom project in the United States, where all of the electrical infrastructure (including array cables, export cables, onshore and offshore substations, and onshore spur line) costs make up approximately 12% of the total LCOE (Stehly and Duffy 2022). The total LCOE for the baseline scenario is $60/MWh. The baseline scenario locates the OSS and array cables on the western side of the array, which gives rise to Scenario 1 to offer an alternate array cable layout with the OSS on the eastern side of the array.

5.3.2 Scenario 1: OSS Relocation

Scenario 1 shifts the OSS position and clusters the array cables on the east side of the array (Figure 7). Scenario 1 offers an alternate array cable layout with the OSS relocated, in the event that the layout impacts towing direction preferences or higher valued bottom (acknowledging these are determined by an array of factors including catch rate, wind direction, wind speed, tidal current direction, tidal current speed, and sea state). The turbine positions remain the same as the baseline scenario, as does the AEP (3744 GWh).

Figure 7. For Scenario 1 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

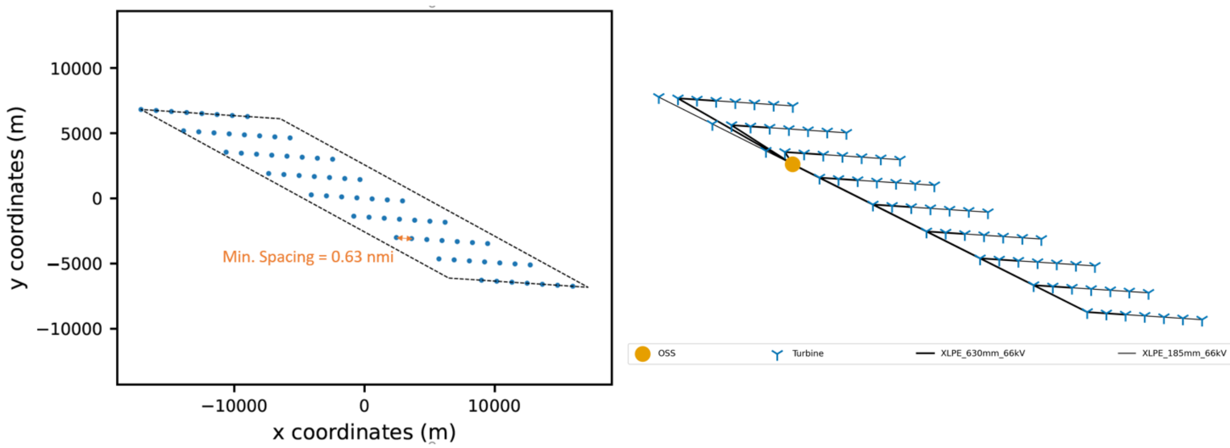
The resulting costs for the array cables and installation are both higher than the baseline scenario at \$88.6 million and \$21.8 million, respectively. The array cable costs increased by 34.4%, and the array cable installation costs increased by 7.2%. They make up 3.38% and 0.83% of the Scenario 1 Total CapEx, which is 1.08% higher than the baseline scenario Total CapEx. Overall, the impact on LCOE is small enough that Scenario 1 has the same LCOE as the baseline scenario of \$60/MWh (rounded to the nearest \$/MWh).

Scenario 1 clustered cables on the east side of the wind farm to minimize crossing possible towing lanes from the opposite direction as the baseline scenario. Positioning the OSS in the northeast portion of the wind farm slightly reduced export cable length, but increased total array cable length, driving up the cost. This highlights the importance of the relative position of OSS among the turbines for reducing total array cable length.

5.3.3 Scenario 2: Widen Rows

Scenario 2 packs turbines more densely into rows to widen towing lanes (north-south distance between rows increases from 0.62 nm (1.15 km) in Scenario 1 to 0.76 nm (1.41 km) in Scenario 2. Figure 8 presents the turbine positions and array cable configuration diagram for Scenario 2.

Figure 8. For Scenario 2 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

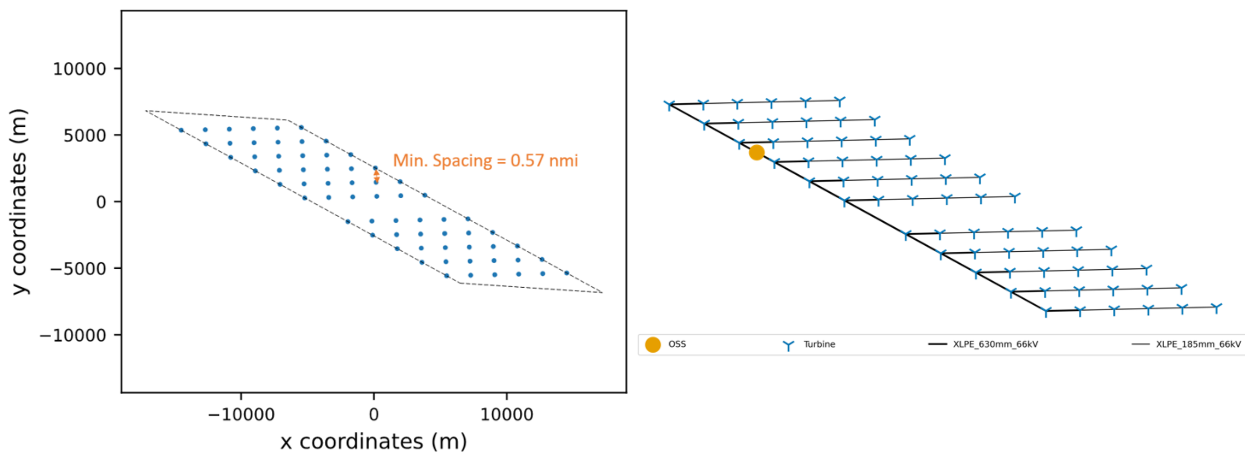
In Scenario 2, the AEP decreased 2.3% relative to the baseline scenario. Array cable costs also decreased 17.1% from the baseline scenario to $54.6 million. Because the Total CapEx only decreased 0.57% relative to the baseline scenario, the lower AEP outweighs the cost savings and leads to an increase in LCOE relative to the baseline scenario by $1/MWh (for a total of $61/MWh).

The array cost decrease results from a reduction in the total array cable length. The additional turbine added to each row means that in most strings the cable power limit is reached, reducing the number of strings and total cable length in the wind farm. As in the baseline scenario the cables are clustered next to each other on the east side of the wind farm to keep open possible towing lanes. The array cable installation cost decreased by 6.5%, likely because of lower total array cable length and a tighter area of turbines reducing vessel transit times between turbine positions.

5.3.4 Scenario 3: No-Build Area, 2 nm

Scenario 3 includes a 2 nm (3.7 km) wide no-build area to enable fishing operations. This decreases the minimum turbine spacing in the rest of the wind farm to make room for the no-build area (Figure 9).

Figure 9. For Scenario 3 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

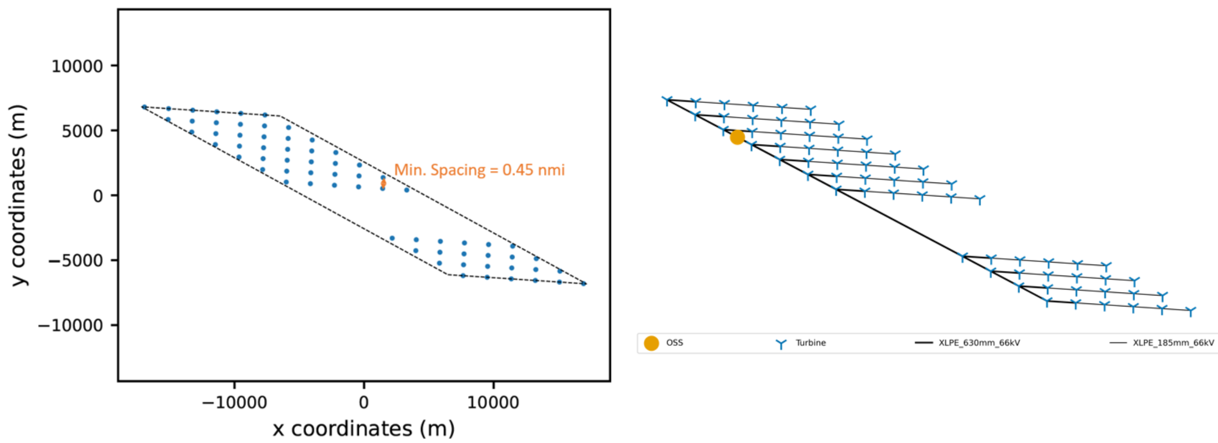
Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

Scenario 3 results in a 2.5% reduction in AEP relative to the baseline scenario and slight decreases in array cable and installation costs (5.25% and 2.1% reductions, respectively). This leads to a total CapEx reduction of 0.18% relative to the baseline scenario. Again, the AEP decrease outweighs the array cost reduction and leads to an LCOE of $61/MWh. The small array cost reductions result from decreased array cable length. As in the baseline scenario, there was an attempt to maintain the relative position of the OSS within the array as well as cable crossings.

5.3.5 Scenario 4: No-Build Area (High AEP), 5 nm

Scenario 4 increases the width of the no-build area from 2 nm (3.7 km) to 5 nm (9.3 km). To accommodate this, the minimum turbine spacing again decreases. To provide bounds, Scenario 4 presents the high AEP optimization result from the 5 nm (9.3 km) wide no-build area (Figure 10) and Scenario 5 presents the low AEP optimization result (Figure 11). Including both cases highlights the range of AEP variation for different scenarios considering a 5 nm wide no-build area.

Figure 10. For Scenario 4 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

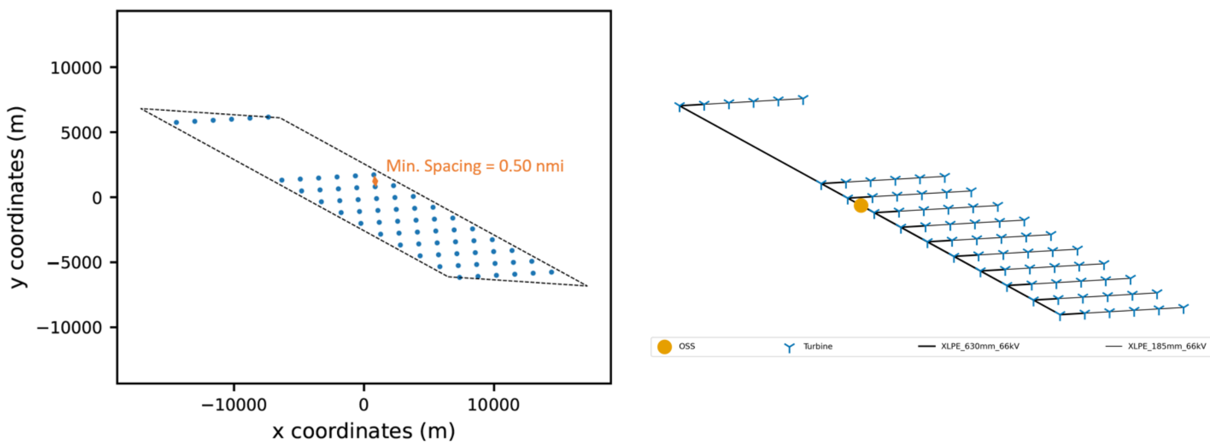
Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

The high AEP case yields a decrease of 2.3% in AEP for Scenario 4 relative to the baseline scenario. Array cable CapEx increases by 8.1% to $71.2 million and cable installation CapEx increases 0.9% to $20.5 million. This increases Total CapEx by 0.24% relative to the baseline scenario and leads to an LCOE of $61/MWh. The cost increases stem from increased total array cable length and AEP reductions which drive the change in LCOE.

5.3.6 Scenario 5: No-Build Area (Low AEP), 5 nm

Scenario 5 presents the low AEP optimization result for the 5 nm (9.3 km) wide no-build area in Figure 11. Note that the analysis considers the full boundary defined by the baseline scenario for locating turbines and the no-build area.

Figure 11. For Scenario 5 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

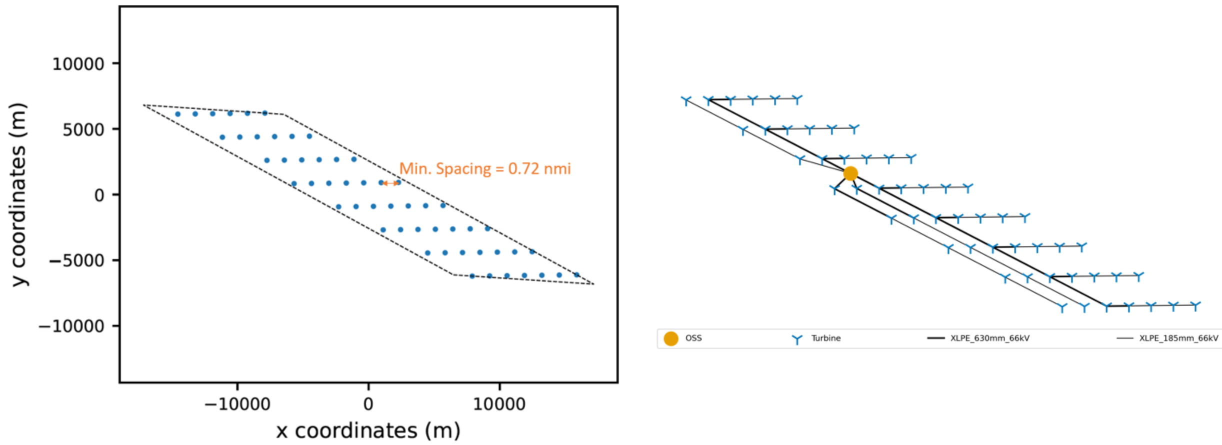
The low AEP represents a 6.4% decrease relative to the baseline scenario, a change of 4.1% compared with Scenario 4. Scenario 5 clusters most of the turbines closer together, leading to greater wake losses. Interestingly, this has a positive effect on array cable costs as the greater density of turbines decreases the total cable length, leading to the cheapest scenario in terms of array cable costs. Total CapEx decreased by 0.75% relative to the baseline scenario, but since array cable system and installation costs only represent 1.98% and 0.73% of the Scenario 5 Total CapEx, their contribution to LCOE is limited. The 6.4% decrease in AEP leads to the highest LCOE of any scenario at $63/MWh.

Turbines are clustered closer to the OSS even though it is in the same relative position in terms of rows. This results in decreases of 22.6% and 7.9% in array cable CapEx and cable installation CapEx, respectively. The greater density of turbines in the southern part of the wind farm also contributes to lower installation costs by reducing the length of cable for burial as well as vessel transit distances between turbine positions.

5.3.7 Scenario 6: Turbine Upsizing

Scenario 6 represents an upscaling of turbine size and increases the turbine rating from 12 MW to 15 MW. This leads to fewer turbines spaced further apart for the same nominal plant capacity (Figure 12).

Figure 12. For Scenario 6 (a) optimized turbine layout (minimum turbine spacing specified) and (b) array cable configuration diagram



(a) (b)

Note: Array cables are connected in series with a minimum separation distance of 65.6 ft (20 m). This distance is below the scale of Figures 6 - 12. The turbine rotor diameter is represented to scale with the blue dots at each turbine position in (a).

Scenario 6 is the only scenario in which AEP increases (+2.0%) relative to the baseline scenario. The reduced number of turbines leads to a decrease in wake losses. Array cable CapEx decreases 22.4% relative to the baseline scenario due to a decrease in total cable length (second cheapest scenario). Since the turbine power rating increases, the number of turbines allowed per string decreases from seven to five based on the current rating and assumed burial depth of the cable. In some cases, it was possible to maximize turbines per string, but the arrangement of the turbine positions made it more difficult to minimize cable crossings. This scenario had the lowest cable installation CapEx (-21.1% relative to baseline scenario) because the reduced number of turbines means fewer installation steps are needed (for example, fewer cable pull-in operations).

The large array cable cost reductions lead to a 3.82% decrease in Total CapEx relative to the baseline scenario. This fact combined with the increase in AEP lead to the lowest LCOE of $57/MWh, the only scenario with a lower LCOE than the baseline scenario (5% lower).

5.4 Discussion

This task analyzed several possible strategies offshore wind developers can use to increase scallop and surfclam fishing access within offshore wind arrays in the New York Bight, including orienting turbine rows with the predominant vessel towing or transit directions, minimizing array cable crossings (assuming the developer adopts this as a cable risk reduction measure), increasing turbine spacings to widen towing lanes, including a no-build area within the array, and increasing the turbine capacity to reduce the number of turbines in a wind plant. These scenarios were defined with input from the Task #1 fishing interviews and the PAC, and they represent a range of possible strategies that could be applied depending on the site-specific and fishery specific conditions represented in the New York Bight.

Potential advantages of these scenarios include reduced chance of damage to the array cables, reduced chance of snagging fishing gear within the wind farm, improved navigation for fishermen, and increased fishable area within the wind farm. If implemented successfully, access strategies may help better utilize shared ocean resources, improve community engagement, and reduce project risk for developers. The ability to implement these strategies successfully relies on stakeholder engagement initiated from the earliest stages of an offshore wind project to develop understanding of the local fishing industry and conditions.

The impacts of the fishing access strategies on wind farm cost and performance of the were quantified by computing AEP, array cable costs, Total project CapEx, and LCOE for each scenario at a generic site indicative of conditions in the New York Bight. The scenarios examined show that, except for Scenario 6: Turbine Upsizing, increasing turbine or no-build area spacing decreases AEP relative to a baseline scenario optimized for AEP. This is due to increased wake losses and leads to higher LCOE in all but Scenario 6 relative to the baseline scenario. Overall, the changes in AEP relative to the baseline scenario ranged from -6.4% to +2.0%. Changes in array cable CapEx ranged from -22.6% to +34.4%, and changes in cable installation CapEx ranged from -21.1% to +7.2% of the baseline scenario costs. One key factor in determining array cable costs were the position of the offshore substation relative to the turbine positions since it impacts the total cable length. This was evident when comparing Scenario 1 with the baseline scenario as the substation position was altered to be more favorable for export cable access.

Array cable installation costs are mainly a function of the total cable length (time laying and associated burial actions), but other installation activities such as cable pull-in operations at the turbine foundations also contribute to costs. The impact of the latter is observed in Scenario 6 where the reduced number of turbines drives down installation costs significantly because of fewer installation activities.

There are competing effects from clustering turbines more densely in one area of the wind farm (Scenario 5). The total cable length decreases, but the energy yield also decreases because of greater wake losses. Since the array cable costs represent only 2%–4% of the Total CapEx required to construct an offshore wind farm, it is likely that a developer would be more concerned with the impact on energy production on the overall project economics. In this study, this impact was captured by calculating the levelized cost of energy for each fishing access scenario and comparing to the baseline scenario. Across all scenarios changes in AEP drove differences in LCOE more than changes in array cable costs, with LCOE ranging from +/- 5% of the baseline scenario LCOE.

Turbine upsizing from 12 MW to 15 MW turbines (Scenario 6) appears to present multiple advantages to fishermen's access and developers' project costs if turbine positions can be more favorably arranged to help reduce cable crossings and open larger areas to fishing. Fewer turbines for the same nominal plant capacity means that there is greater physical separation between turbines, which in turn means wider towing or transit lanes and reduced wake losses. Other impacts such as the footprint of scour protection were not assessed. These trends would likely be amplified if turbine rated power continues to increase beyond 15 MW in the future. Fewer machines should also come lower O&M costs (assuming similar reliability between the two different turbine ratings) and a lower LCOE due to increased efficiency. It is also possible that installation time could drop with fewer machines, but that would depend on there being similar installation times for machines with two different ratings. From a wake/AEP perspective, with fewer machines there will likely be more flexibility on machine placement, with ability to accommodate obstacles on the seafloor or fishing considerations while still minimizing wake interactions.

6 Pilot Project

6.1 Introduction

To further develop technical strategies and tools to minimize the disruption of commercial fishing within offshore wind (OSW) arrays, the pilot project built on inputs from the results of the fishing surveys and the layout configuration scenarios studied in previous chapters to develop a set of route engineering practices that can be used when developing OSW in the New York Bight.

The selected approach was to create a list of regional seabed and environmental characteristics to be found in the New York (NY) Bight and specifically the pilot project area (i.e., seabed features such as ripples, banks, channels, mounds and seabed obstructions, environmental considerations such as currents, scour formation around existing seabed objects, existing infrastructure, and seabed surface sediment types), which was independent of any identified lease areas. Publicly available GIS data sets were mapped where these features and conditions were located or predicted. Many factors need to be well managed and planned for an Offshore Windfarm (OWF) to be successful over its design life. One important factor is well constructed and reliable seabed infrastructure and cabling. This means a set of route engineering practices are needed to match the seabed characteristics to address the engineering needs of the OWF and at the same time to try to limit the impact on local fishing activity (i.e., Atlantic scallop and surfclam/ocean quahog (SC/OQ) fishing).

Prime fishing conditions have been presumed across all of the pilot project area. This prevented any bias in where the route engineering practices would be best employed and ensures that if the geographic distribution of surfclam, ocean quahog and scallop fishing effort vary in the future, the windfarm engineering will still be optimized to limit the impact on fishing regardless of any change in fishing effort.

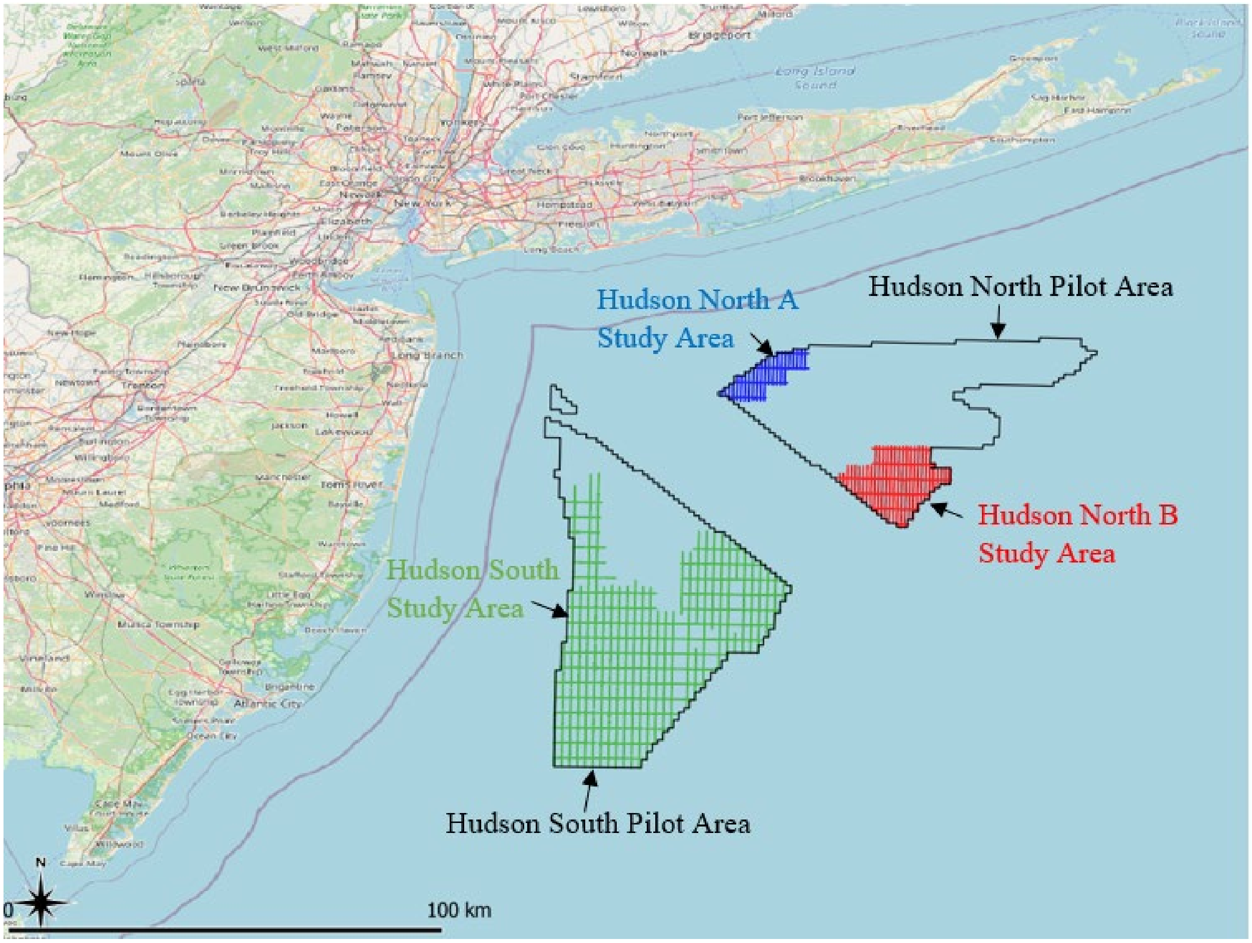
A drawback of the approach adopted is the inability to create a defined set of cable routes or turbine array layouts matched to a real piece of seabed geography. Some hypothetical examples are provided for various ways in which an IAC route could be adapted to various seabed characteristics and optimized for fishing activity for individual or small groups of IACs. This results in an inability to run any financial or energy production analysis on a full set of pilot project IAC routes.

The wider approach adopted for the pilot project helps to avoid conflict with future developers who may feel that a detailed specific site with defined IAC routes sets expectations from other stakeholders, especially if it is in close proximity to their development area. Also, by avoiding leased areas, it removes the potential for our project conclusions to influence currently leased developments.

Part of the criteria for pilot project area selection was to remain inside the existing technological limits of fixed foundations (<60 m) in the New York (NY) Bight region. BOEM call areas were used but excluded already granted leases. Seabed spaces outside the call areas were not considered for OWF development and therefore not relevant to the project. As a result, the pilot areas previously known as Hudson North and Hudson South were selected (Figure 13), which are also known to feature scallop and clam fishing.

The result of the pilot project is a "toolbox" of cable route engineering approaches, which may reduce impacts to surfclam, ocean quahog, and scallop fishing and can be adopted in the future by each individual project's needs building on the earlier chapter outputs.

Figure 13. Boundaries of Hudson North and South Pilot Areas with Locations of Hudson North A&B and Hudson South Study Areas



6.2 Data Sets and Research

Table 15 lists all the data sets used by the pilot project, their associated metadata and how they were used. The data sets are Geographic Information System (GIS) layers which were incorporated into GIS software for analysis.

Table 15. Data Sources

Data set	Source	Description
Bathymetry 1/3rd and 1 Arc second raster data	NOAA National Centers for Environmental Information (NCEI)	Regional bathymetry at 1/3rd Arc sec (approx. 8m) and 1 Arc sec (approx. 24m) resolution, giving continuous coarse bathymetry data across the pilot project areas
Alpine 2017 Survey (For NYSERDA)	NOAA NCEI	Selective bathymetry at 4m resolution, giving a more detailed view of selective strips across all the pilot projects areas
Gardline 2021 Survey (For NYSERDA) Hudson North A&B, Hudson South	NYSERDA	Selective bathymetry at 0.5m resolution, giving a highly detailed view of partial areas across the pilot projects areas, SSS Targets and Magnetic Anomalies. Data coverage shown on **Error! Reference source not found.**5 (Hudson North A&B Study Areas cover approximately 25% of Hudson North Pilot Area whereas Hudson South Study Area covers approximately 75% of Hudson South Pilot Area)
Automated Wreck and Obstruction Database (AWOIS)	NOAA Office of Coast Survey via www.marinecadastre.gov	Wrecks
NOAA RNCs	NOAA Office of Coast Survey	UXO
BOEM Call Areas	NOAA/BOEM via www.marinecadastre.gov	BOEM OSW Call Areas
FVCOM (Finite Volume Coastal Ocean Model) Current Data	University of Massachusetts-Dartmouth and the Woods Hole Oceanographic Institute	Surface and Bottom current data
Georgia Tech Research Corporation Coastal Tidal Currents	Georgia Tech Research Corporation	Tidal currents
Georgia Tech Research Corporation Ocean Currents	Georgia Tech Research Corporation	Ocean currents
Atlantic Seafloor Sediments (the Continental Margin Maps, CONMAP)	NOAA/BOEM via www.marinecadastre.gov	Sediment grain size distributions and trends along U.S. East Coast
BOEM Marine Minerals Information System	BOEM via https://mmis.doi.gov/BOEMMMIS/	Sand resource areas
USGS Sediment Texture data (ecstdb) (2014)	USGS via www.marinecadastre.gov	Seabed texture
U.S. Geological Survey (usSEABED database)	USGS via www.marinecadastre.gov	National seafloor sediments
USGS Seafloor Stress and Sediment Mobility Database	USGS via https://www.usgs.gov/centers/whcmsc/science/sea-floor-stress-and-sediment-mobility-database	Seafloor stress and sediment mobility
BOEM Comprehensive Seafloor Substrate Mapping and Model Validation in the New York Bight from 2017-10-20 to 2019-03-27	NOAA National Centers for Coastal Ocean Science (NCCOS)	Sediment model

As well as these data sources, input from earlier chapters have been used in this report, specifically relating to turbine and cable orientation, spacing and layout design. These are covered in more detail in below.

Visual analysis of the Gardline 2021 side scan sonar targets was undertaken to look for evidence of scour. The OceaniQ GeoCable™ cable database was used to provide information on the number, status, and cable burial of existing cables. Analysis was also carried out on the OceaniQ cable fault database to provide insight into cable faults in the pilot project area.

6.3 Pilot Area Characteristics

6.3.1 Introduction

To determine the best ways in which to engineer the OWF infrastructure within pilot project areas was to first understand the characteristics of the site which might affect the design and engineering works for future OWF's constructed on the sites. The emphasis was on those parts of the infrastructure which have the most important impact on fishing activities. In this case the emphasis will relate to the wind turbine generator (WTG) and offshore substation (OSS) foundations, power cables, and any other materials introduced to the site to prevent scour or protect the IACs.

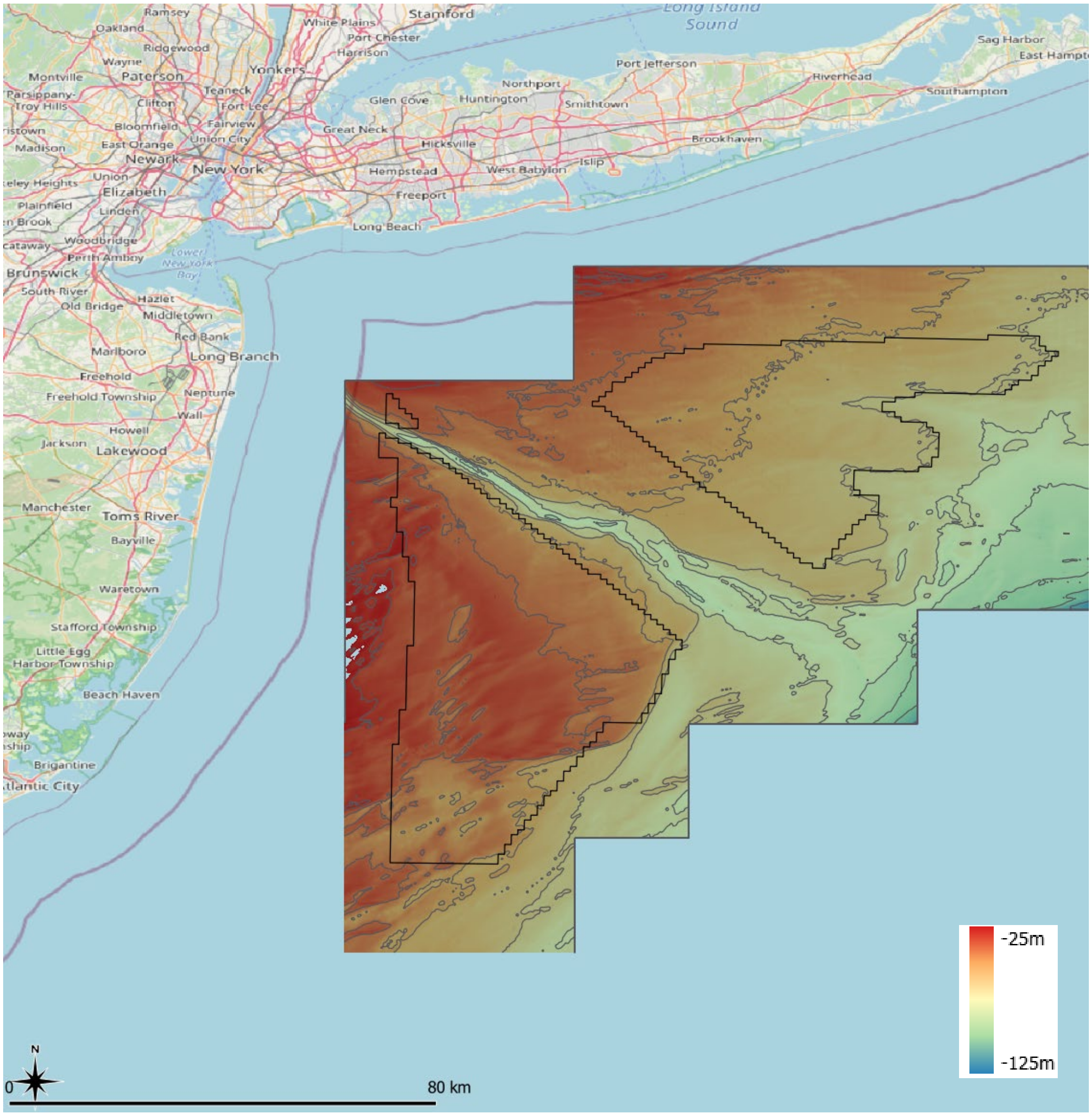
This section of the report describes the physical characteristics which will influence the OWF infrastructure selection and engineering. It covers shallow seabed geology and sediments, sediment mobility, geohazards and the marine current regime. It also looks at the potential for seabed scour and the existing seabed infrastructure and seabed obstructions.

6.3.2 Seabed Sediments

The large-scale bathymetric features noted across both pilot areas are illustrated in Figure 14. This image clearly shows the channel leading to the Hudson Canyon between the two pilot areas. The Hudson South Pilot Area is situated on large sand bank with bed levels ranging from approximately 30 m in the western extents of the pilot area to 50 m on the northern, eastern, and southeastern extents. The seabed within the Hudson North Pilot Area, on the other hand, is essentially flat lying with bed levels noted between approximately 45 m and 60 m.

Figure 14. Seabed Bathymetry of the Hudson North and South Pilot Areas

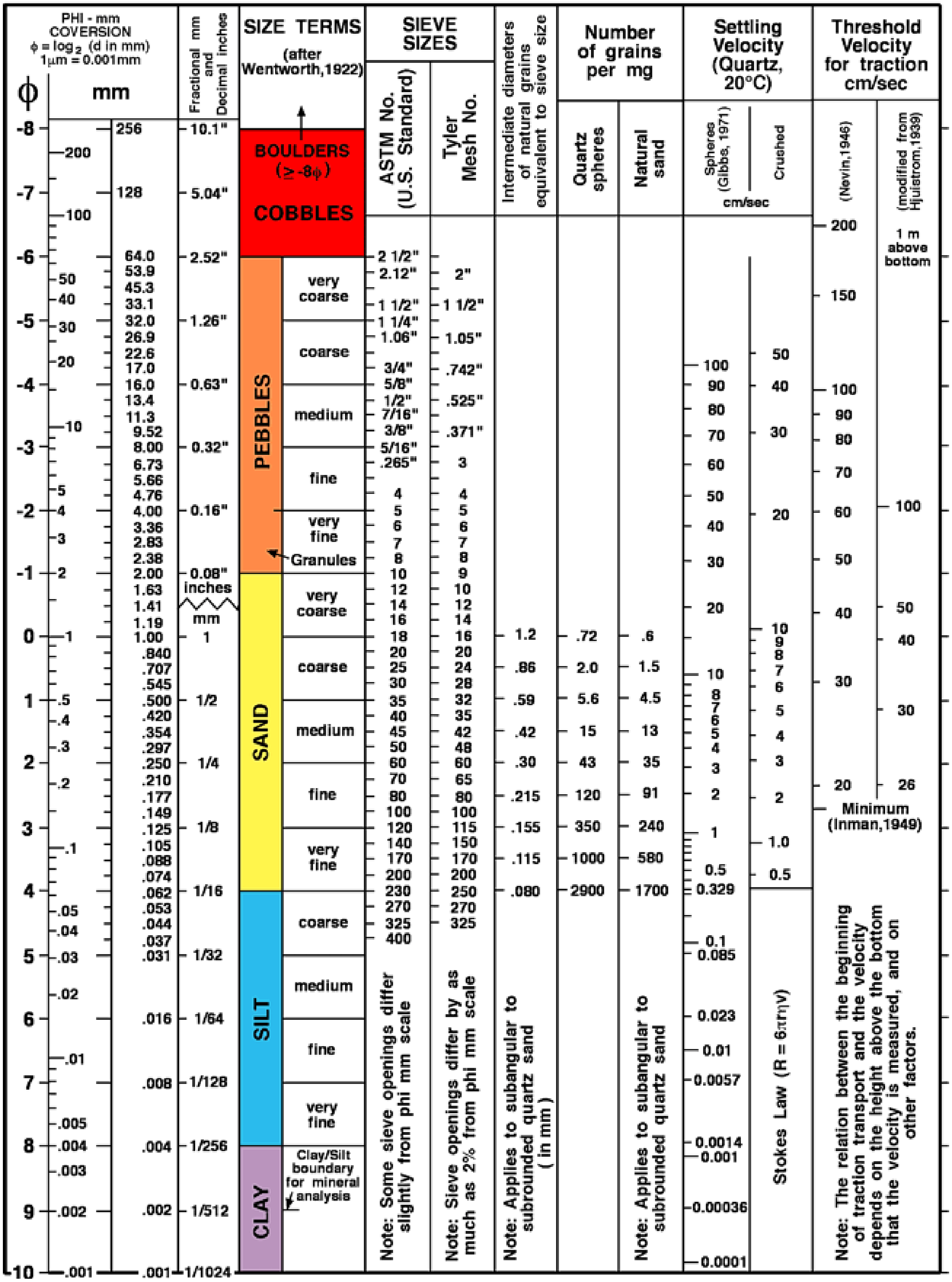
Source: NCEI



The USGS (2006) classification illustrated in Figure 15 was used for describing sediment grain size within this report.

Figure 15. Description of Sediment Grain Sizes Used for Geological Description of Soils and Sediments

Source: USGS (2006)

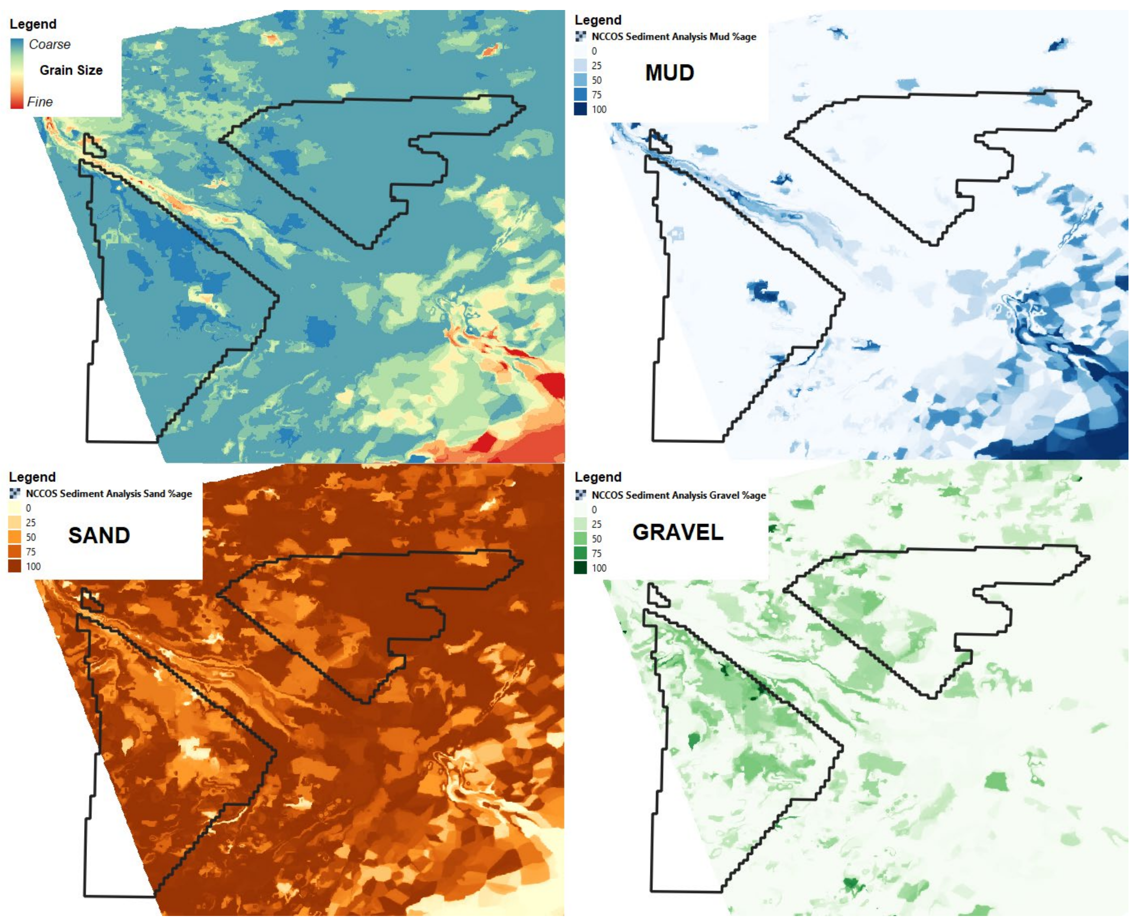


A generalized picture of sediments across the Hudson North and South Pilot Areas is presented (Figure 16). These have been taken from NOAA National Centers for Coastal Ocean Science (NCCOS) data (Battista 2019) which shows comprehensive seafloor substrate mapping and model validation in the New York Bight from 2016 to 2017. This data does not completely cover the southern pilot area but gives a clear prediction that sediments are generally comprised of sands, with varying quantities of gravels in both pilot areas. The data also shows isolated areas of muddier sediments in both pilot areas.

Survey data, obtained by Gardline in 2021 for NYSERDA was acquired in the Hudson North A, Hudson North B and Hudson South Study Areas. The data also confirms the presence of a sandy seabed while indicating the presence of more localized gravelly sands within that area and the presence of numerous mobile bottom tending gear scars almost entirely across the Hudson North A and Hudson North B Study Areas.

Figure 16. Prediction of Surficial Sediment Composition in the Hudson North and South Pilot Areas

Source: NCCOS



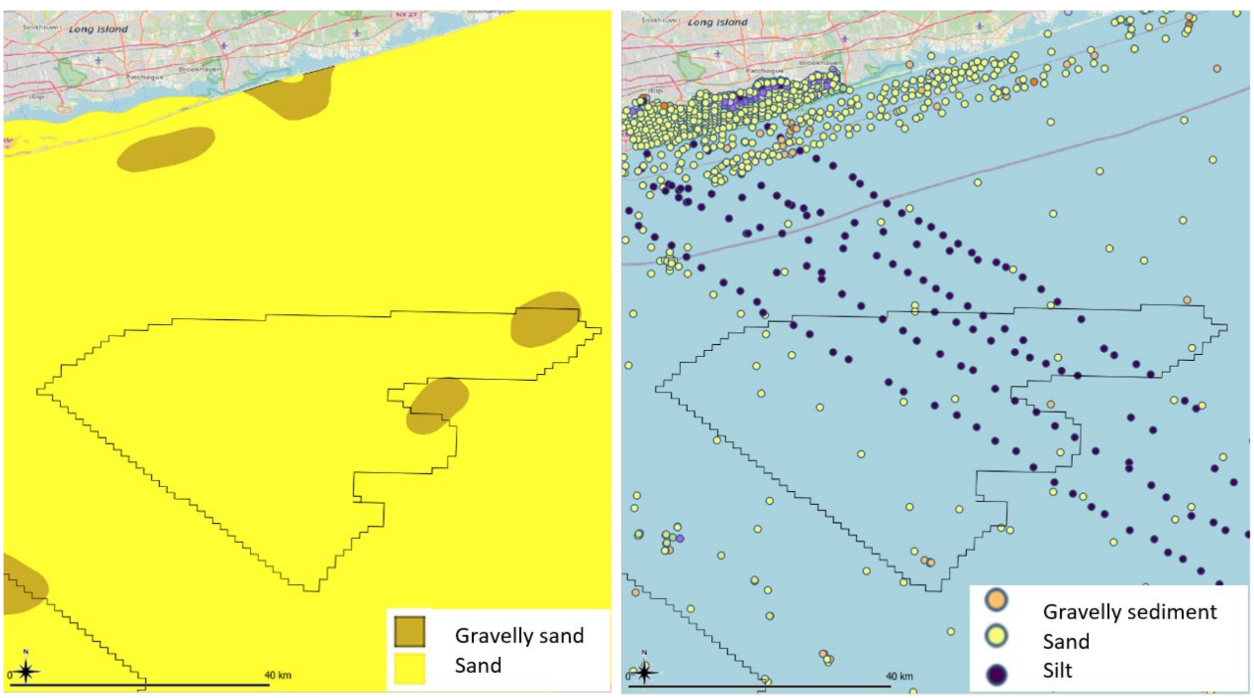
6.3.2.1 Hudson North Pilot Area

According to Atlantic Continental Margin Map (CONMAP) seafloor sediments data, seabed sediments in Hudson North Pilot Area are comprised of mainly sand, with small areas of gravelly sands. The USGS sediment texture data also confirms the presence of these seabed sediments.

Similarly, national seafloor sediments also indicate the presence of sands and slightly gravelly sands across the majority of the Hudson North Pilot Area (Figure 17). However, these data also indicate the presence of a band of silty sediments across the central portion of the pilot area. Figure 17 (left image) presents CONMAP Atlantic seafloor sediments data indicating seabed sediments comprise sand with patches of gravelly sand. Figure 17 (right image) presents national seafloor sediments data from usSEABED database which indicates sediments comprise sand with isolated patches of gravelly sediment with a band of silt in the central portion of Hudson North pilot area.

Figure 17. Seabed Sediments in the Hudson North Pilot Area from CONMAP Data (Left Image) and usSEABED Data (Right Image)

Source: NOAA/BOEM/USGS

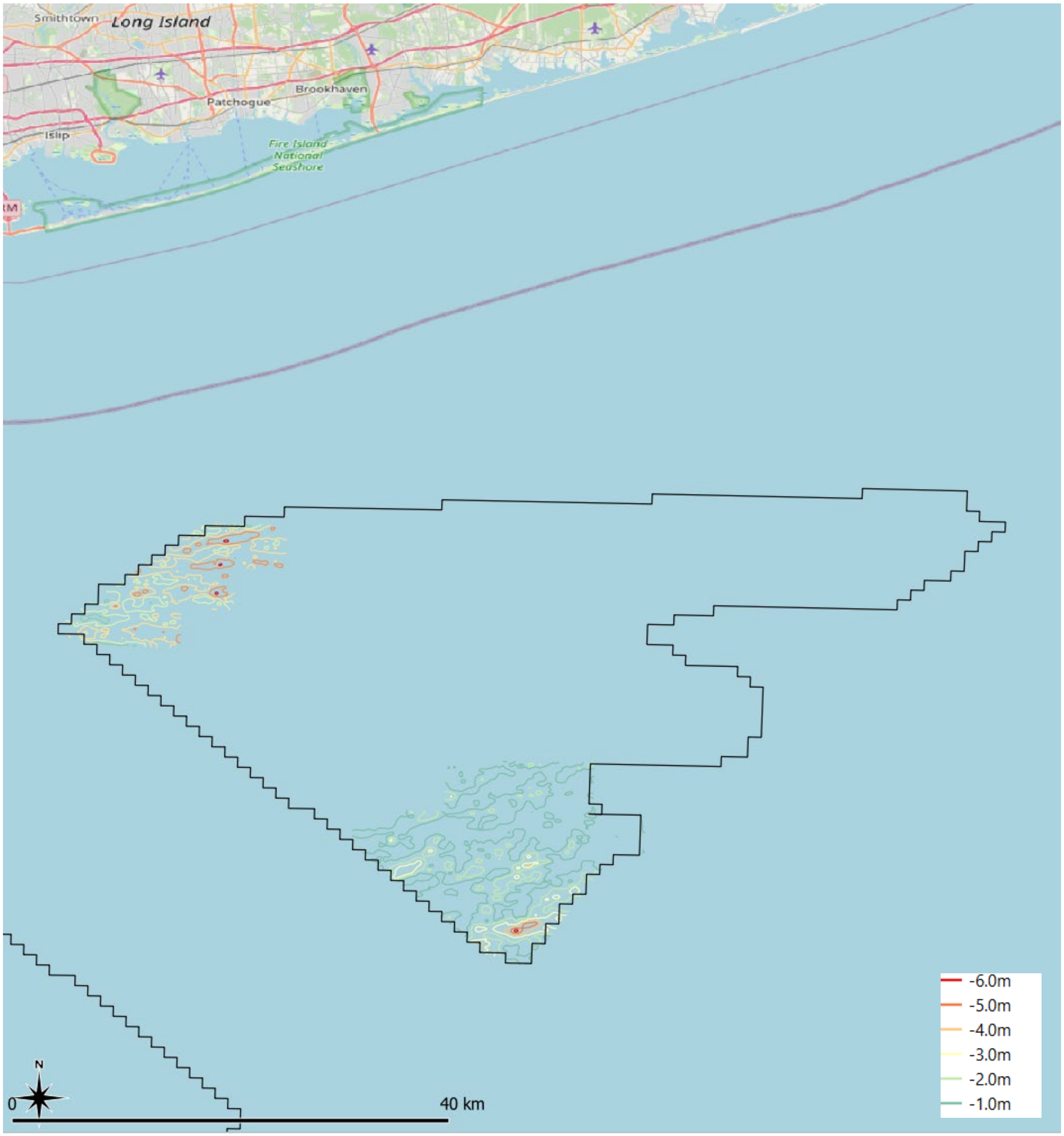


The Gardline 2021 report detailing the results of the Hudson North A and B Study Areas indicate that gravelly sands were generally confined to the bathymetric dips in an undulating seabed. The Gardline report also indicates that these Holocene sands are between 0.5 m (1.6 ft) and 6 m (19.6 ft) thick and are underlain by an acoustically well-defined transgressive channels unit comprising gravels, sands, silt, and clays.

Information relating to shallow soils is very limited in the Hudson North Pilot Area. However, the thicknesses of Holocene sands encountered in the 2021 Gardline survey of the Hudson North A and B Study Areas are illustrated in Figure 18. These appear to show that these sands thicken toward the northwest of the Hudson North Pilot Area; however, this cannot be verified at the time of writing.

Figure 18. Thickness of Holocene Sands in the Hudson North Pilot Area

Source: Gardline (2021)

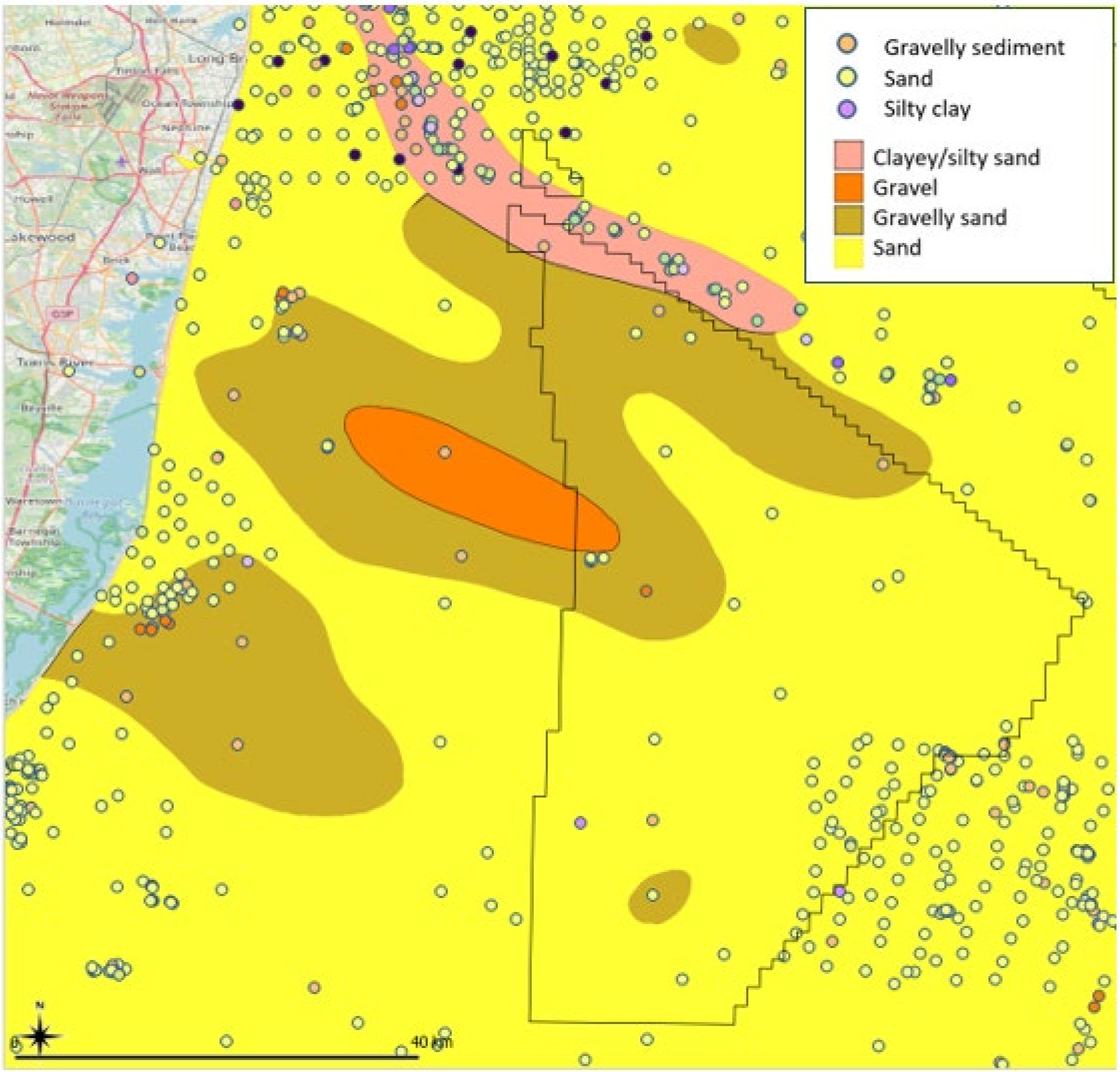


6.3.2.2 Hudson South Pilot Area

Atlantic seafloor sediment data indicates that seabed sediments within the Hudson South Pilot area generally comprise sands (Figure 19). Gravelly sands were noted in the northern portion of the survey area, with a patch of clayey/silty sands noted in the far northern extents of the survey area. Gravels were noted in the western extents of the pilot area. Figure 19 presents CONMAP Atlantic seafloor sediments data (background colored image) overlain with the usSEABED national seafloor sediments data (presented as series of colored dots). Both data sets indicate the presence of sands with various quantities of gravel and occasional lenses of clayey sands. The national seafloor sediments align with this, although the data does indicate the presence of isolated gravelly sands within the sand unit and occasional areas/lenses of silty clay.

Figure 19. Seabed Sediments in the Hudson South Pilot Area with CONMAP Data (Background Colored Image) Overlain with usSEABED Data (Series of Colored Dots)

Source: NOAA/BOEM/USGS

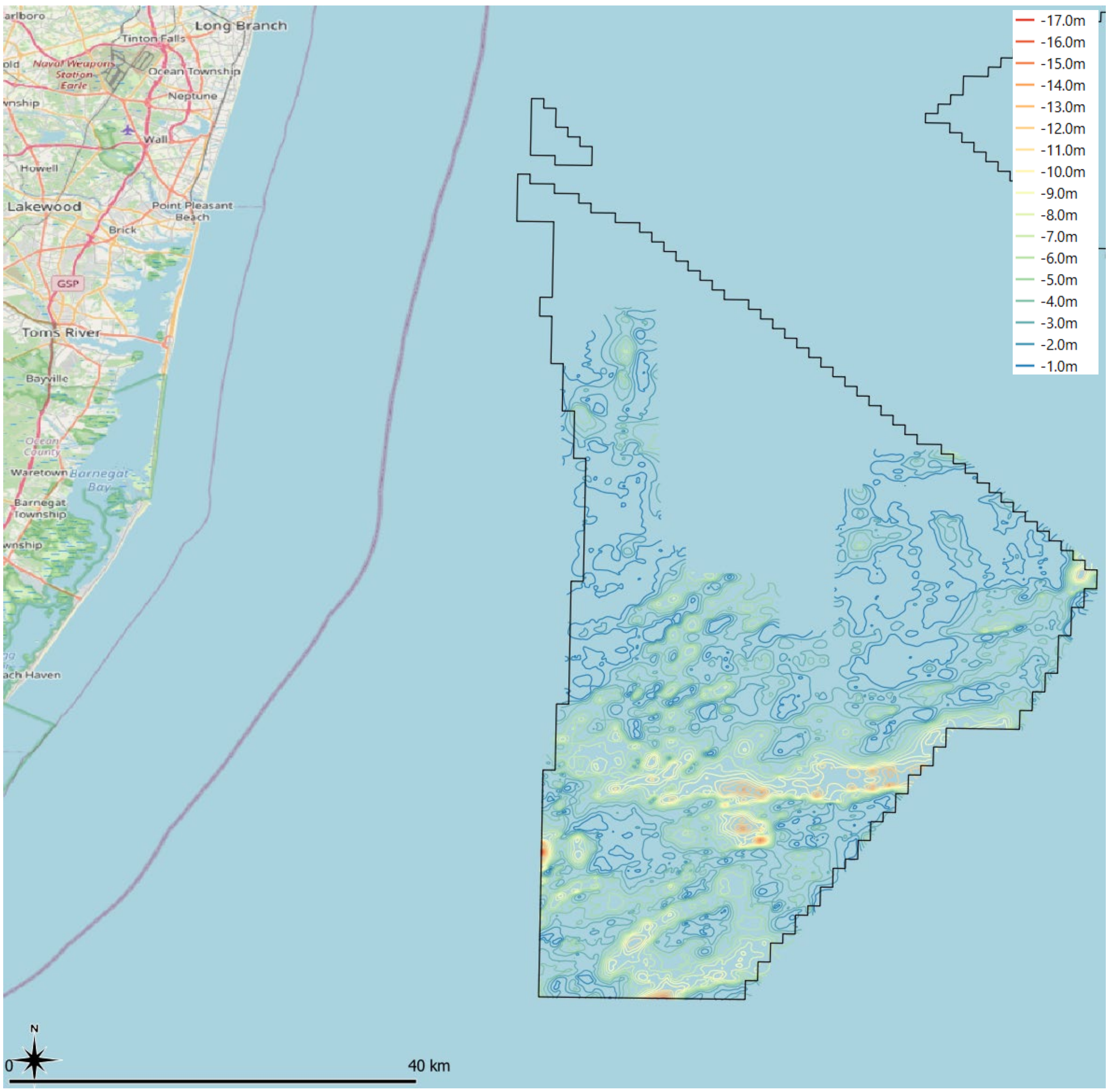


The 2021 survey data, acquired by Gardline, also indicates localized areas of gravelly sands within the sandy sediments and occasional lenses of clayey sands. The survey data acquired covers a large percentage of the Hudson South Pilot Area. The thickness of Holocene sands in the Hudson South Pilot Area is shown in Figure 20 below. The Gardline report detailing the results of the Hudson South Study Area indicates that gravelly sands were generally confined to the bathymetric dips in an undulating seabed. The Gardline report also indicates that these Holocene sands were between 0.5 m (1.6 ft) and 18 m (59 ft) thick and were underlain by an acoustically well-defined transgressive channels unit comprising gravels, sands, silty and clays.

Sub-bottom data indicates that the Holocene sands were between 1m and 17 m thick, with the thickest sediments concentrated in channel-like deposits in the central portion of the pilot area (Figure 20). The image presents the thickness of Holocene sands in meters below seabed within the Hudson South Study Area. This data appears to indicate that thickest deposits are noted in the central and southern portions of the Pilot Area.

Figure 20. Thickness of Holocene Sands in the Hudson South Pilot Area

Source: Gardline (2021)



6.3.3 Seabed Mobility

Seabed mobility is visually identifiable by the presence of bedforms on the seabed. Bedforms take various forms and are identified in Table 16 below. Larger bedforms indicate more mobile seabed although, transportation of the sediment may occur over much longer time frames in the case of sand waves and sand banks. Sand banks can be relatively stable as the movement of these can be over several years. However, large storm events can change the morphology of sand banks and therefore these should be accounted for in the design of windfarm and cable systems.

Table 16. Classification of Bedforms and Gradients

Source: BOEM (2020)

Name	Wavelength (meters)	Heights (meters)
Sand wave	>60	>1.5
Megaripple	5-60	0.5-1.5
Ripple	<5	<0.5

Classification	Gradient (Degrees)
Very Gentle	<1
Gentle	1-4.9
Moderate	5-9.9
Steep	10-14.9
Very Steep	>15

Gardline (2021) survey data covers part of the Hudson North and Hudson South pilot areas as illustrated above. This data indicates the presence of small-scale ripples (less than 0.2 m high with wavelengths of 2 m) across most of the sandy sediments noted within the Hudson North A and B Study Areas. Ripples were generally orientated northwest to southeast, less than 0.5 m (1.6 ft) in height with wavelengths of up to 30 m (98 ft) in the Hudson South Study Area. Three areas of megaripples were noted in the Hudson South Study Area. These were orientated northwest to southeast (west to east in the central portion of the study area) with heights of 0.4-1 m (1.3 to 3.2 ft) and wavelengths of up to 100 m (328 ft).

The regional geological setting indicates the presence of ridge and swale features. (Bedforms such as sand ribbons, blowout pits, and dune packets are also anticipated in this area Geoff et al. 1999). These were not identified in the 2021 survey; however, as the Gardline report indicates, the large line spacing of this survey may mean more small-scale features may have been missed.

Erosion and winnowing of ridge features and deposition of sand ribbons comprising reworked Holocene sediments may occur in water depths less than 40 m (131 ft) (Geoff et al 1999). This paper describes the blowout pits as elongated pits, 0.5-1 km (0.3–0.6 miles) wide and 1–3km (0.6–1.9 miles) long, orientated northeast to southwest and aligned with the current direction. They are described as erosional features advancing southwest by the undercutting of the seafloor sediments. Dune packets or sand waves are present only at 85–100m (278–328 ft) water depth, in the deepest portions of the middle continental shelf.

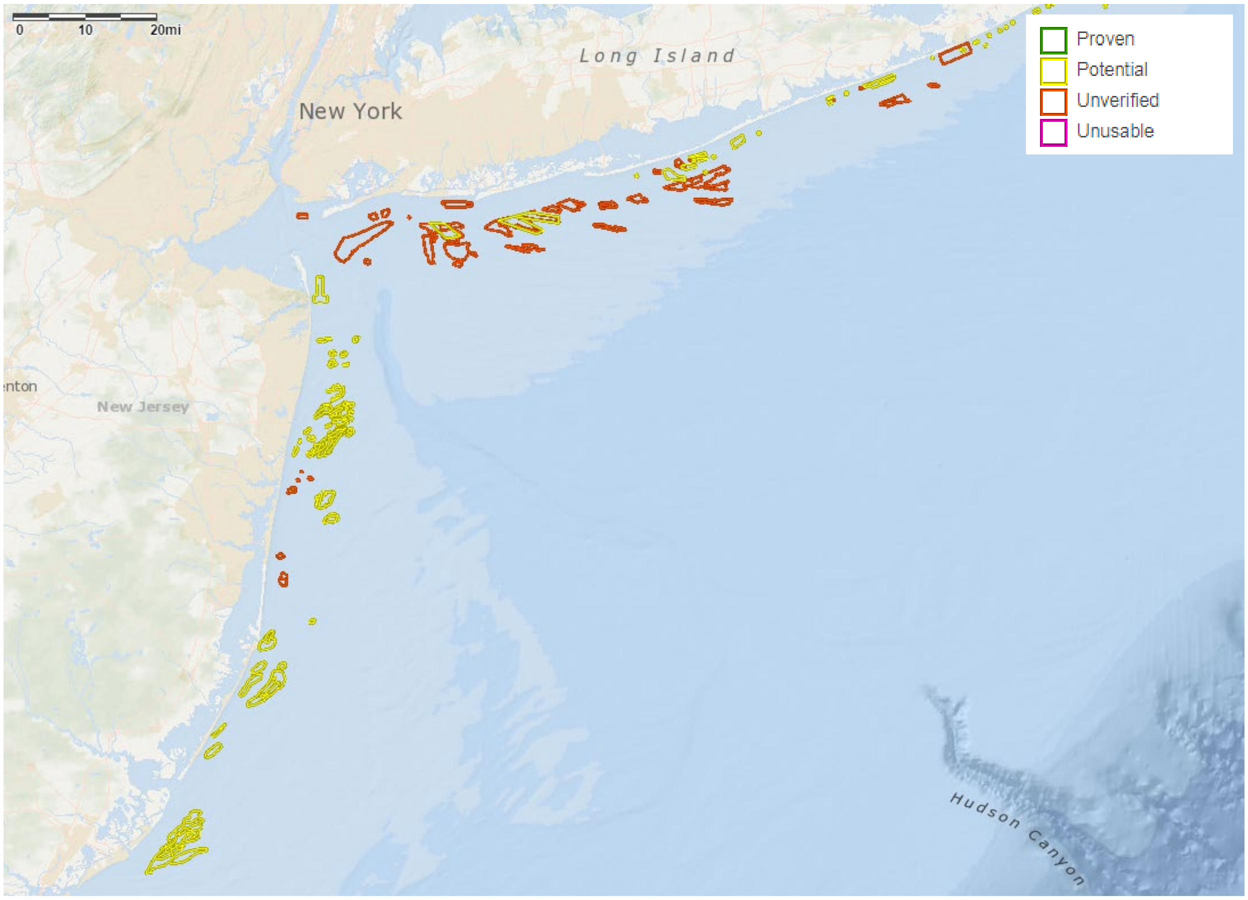
Analysis of bedforms and regional current data indicates that there is no significant tidal or current generated sediment movement anticipated for the Hudson North and Hudson South pilot areas. The largest effects on sediment movement are likely from seasonal storm events which can cause sediment erosion and deposition, localized to the paths of these storms/hurricanes. The effects of storms are most likely to be noted in more shallow waters where the effect of wind generated waves is more severe. Modern sediment transport is generally to the southwest and primarily induced by storms (Vincent et. al. 1981).

The BOEM Marine Minerals Information System (MMIS) database illustrates the locations of numerous sand resource areas noted between Point Judith Neck, Narragansett and Great Bay, Cologne. The database details areas of proven, potential, unverified and unusable resource areas (Figure 21). Those closest to the Hudson North and South pilot areas lie close to the shore of Long Island, New York and New Jersey and are generally classified as either unverified or potential sand resource areas. Potential areas are defined as those whose resource potential has been verified through sufficient geophysical and geotechnical data. However, the thickness/lateral extent of these has not been fully determined. Unverified areas are defined as those hypothesized to exist based on indirect evidence; inferred sediment types, unit thicknesses, and lateral extents have not been confirmed through direct sampling methods.

The thickness of the sand units is not often recorded; however, the areas of these potential sand resource areas vary from 977,500 square feet to 207,182,018 square feet. Three of the potential sand resource areas in the New Jersey area have been evaluated on separate occasions. These indicate a gross increase of between 67,590 and 147,965 cubic yards of sand between 2007 and 2012. While data comparisons are sparce, this may show an indication of the volume of sand deposition possible in the shallower waters around this coastline.

Figure 21. Sand Resource Areas Close to Pilot Areas

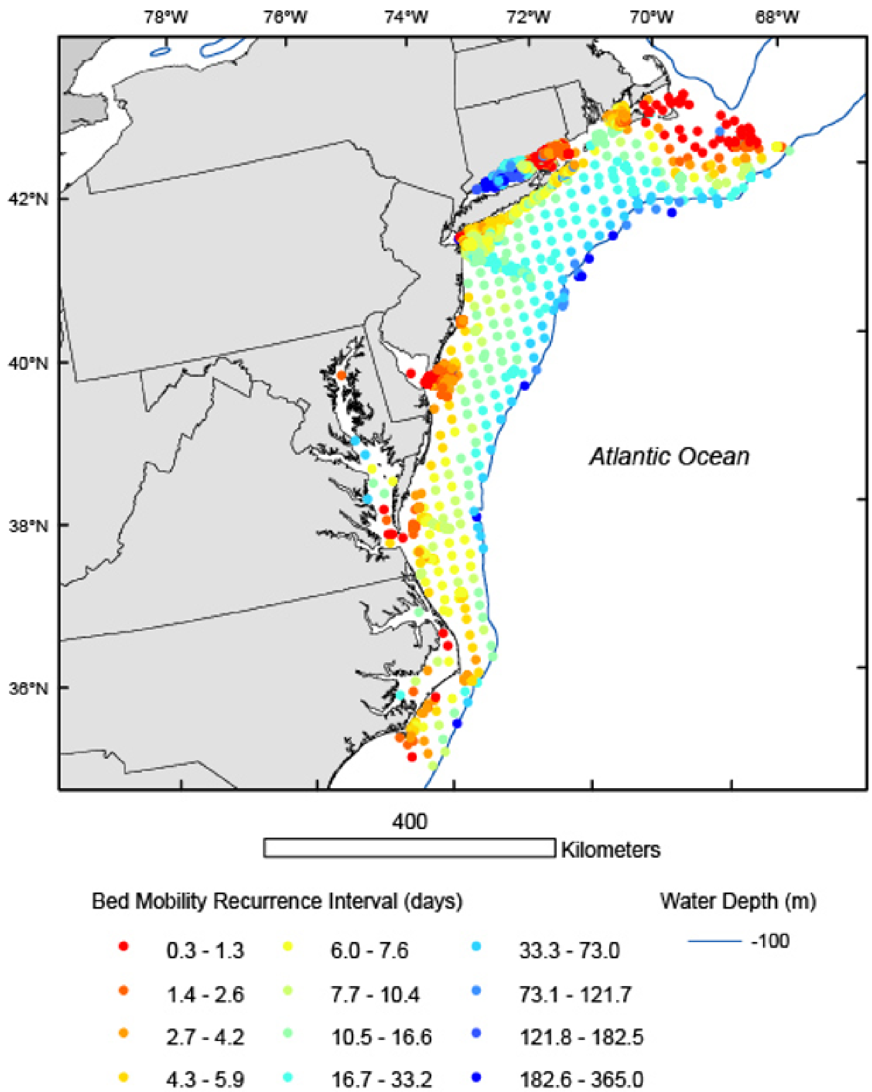
Source: BOEM



Seabed mobility reccurence intervals have been calculated by Dalyander et.al (2012) at locations with sediment texture data in the Middle Atlantic Bight for a one year time period, between May 2010 and May 2011. Recurrence interval is a measure of the frequency of mobility events. Figure 22 illustrates that, in general, bed mobility is more common closer to shore, with deeper, or more sheltered, waters exhibiting much longer periods between mobility events.

Figure 22. Sand Mobility Recurrence Intervals along New York State and New Jersey Coastlines

Source: Dalyamder et al. (2012)



Bed mobility recurrence interval (time between mobility events) at locations with sediment texture data in the Middle Atlantic Bight for the one year time period May 2010 to May 2011. Recurrence interval is a measure of the frequency of mobility events..

This data indicates that sediment mobility reccurence intervals in the Hudson North pilot area ranged from an average yearly movement of 14–28 days per mobility event whilst recuurence intervals in Hudson South ranged from 7.9–26 days (Table 17). This data also indicates the seasonal fluctuations that occur througout the year. Data from within the pilot areas indicate that the mobility recurrence intervals were lowest in summer and highest in Fall. This may be attibuted to the fact that seasonal storms are likely to be the most significant cause of sediment movement along this coastline.

Table 17. Sediment Mobility Recurrence Intervals in Hudson North and South Pilot Areas

Source: USGS

Season	Hudson North Pilot Area (Intervals in days). Average Time Presented in Brackets	Hudson South Pilot Area (Intervals in days). Average Time Presented in Brackets
Winter	12.2-30 (20)	5.6-22.5 (11.2)
Spring	30.6-46 (40.8)	6.1-30.6 (15.7)
Summer	92 (92)	23-92 (67)
Fall	6.1-18.2 (12.4)	7.6-15.2 (10.5)

6.3.4 Geohazards

Seabed hazards are those which may pose a risk to the construction or maintenance of a windfarm and its associated infrastructure. BOEM guidelines indicate that potential natural hazards include:

- Scarp
- Channels
- Ridges
- Bedforms/mobile seabed
- Exposed rocky areas
- Boulders
- Pock marks
- Mounds
- Seabed scars/drag marks
- Submarine canyons
- River channels
- Exposed hard bottom surfaces
- Gas/fluid expulsion features
- Brine seeps/pools
- Diapiric structures
- Seismic activity
- Faults and fault activity
- Slumping, sliding seafloor features
- Steep/unstable seafloor slopes
- Scour/erosion features
- Ice scour
- Volcanic activity
- Deformation and consolidation
- Cyclic loading
- Liquefaction
- Soil sensitivity

In addition to these geohazards, anthropogenic hazards should also be considered. These include the following:

- Wrecks
- Debris and fishing gear
- Cables
- Pipelines
- Ordnance
- Artificial reefs

Finally, subsurface hazards should be assessed in any windfarm design. These include:

- Buried boulders
- Shallow faults
- Buried channels
- Shallow rock
- Shallow gas
- Buried slumping
- Buried hydrates
- Karst areas
- Diapiric structures
- Fluid or gas expulsion

Given the extents of the detailed survey data coverage available for analysis (Gardline 2021), it is difficult to ascertain the full risk to the pilot areas from all these geohazards, anthropogenic and subsurface hazards. The information considered most relevant to the pilot areas are presented in the sections below.

- The 2021 Gardline report indicates that the geohazards present on Hudson North (A&B) and Hudson South Study Area include:
- Bedforms—ripples and localized megaripples
- Boulders—noted in sonar and bathymetric data
- Seabed scars—mobile bottom tending fishing gear scars
- Mounds—possible bioherm features—Hudson South Study Area only
- Shallow gas
- Buried channels and hard ground/bedrock

The Gardline report also concludes that the other geohazards listed above were not identified in the multibeam or side scan sonar data. No geotechnical data was available to assess the potential for deformation/consolidation, cyclic load, liquefaction, or soil sensitivity. This information is also required to undertake a comprehensive assessment of cable burial potential across the pilot areas and, therefore, this cannot be covered within this report. It is recommended that geotechnical information is obtained prior to any developments in the pilot areas.

6.3.4.1 Bedforms and Seabed Slopes

Multibeam bathymetric data was acquired in 2017 for NYSERDA. This data, gridded at 4 m intervals and contoured at 1 m intervals, indicates that seabed slopes in the Hudson North Pilot Area are not considered significant. Maximum slope angles are in the eastern extents of the pilot area and were 2°.

Slope angles in the Hudson South pilot area vary more, due to the presence of large-scale bathymetric features noted within the pilot area (Figure 23). Maximum slope angles in this pilot area were 4.8°. Figure 23 shows NCEI bathymetric data (contoured at 1m intervals) across both pilot areas; areas with steepest slopes in this data set are highlighted at around 4°.

An example of the slope analysis undertaken on the 2017 bathymetric data within the pilot areas is illustrated in Figure 24. Slope analysis of the Alpine 2017 bathymetric data in the Hudson South pilot area indicates maximum slope values lay around 4.8°, which corresponds with slope values noted in Figure 23.

Figure 23. Maximum Slope Angles across Hudson North and Hudson South Pilot Areas

Source: NCEI

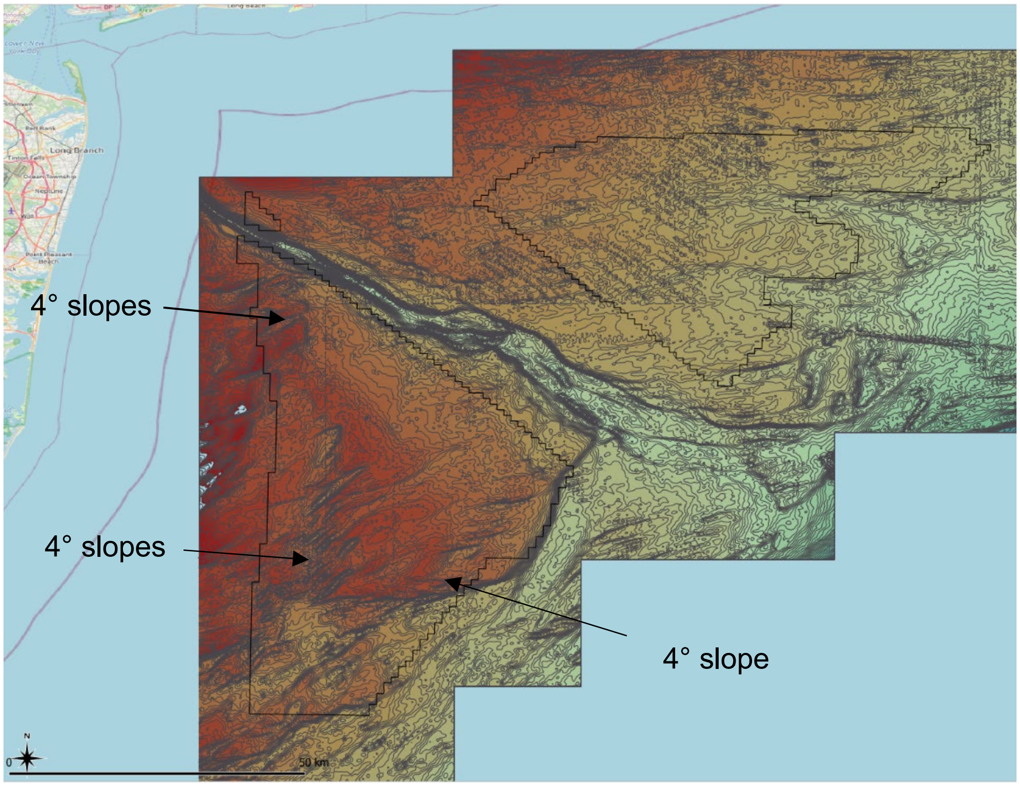
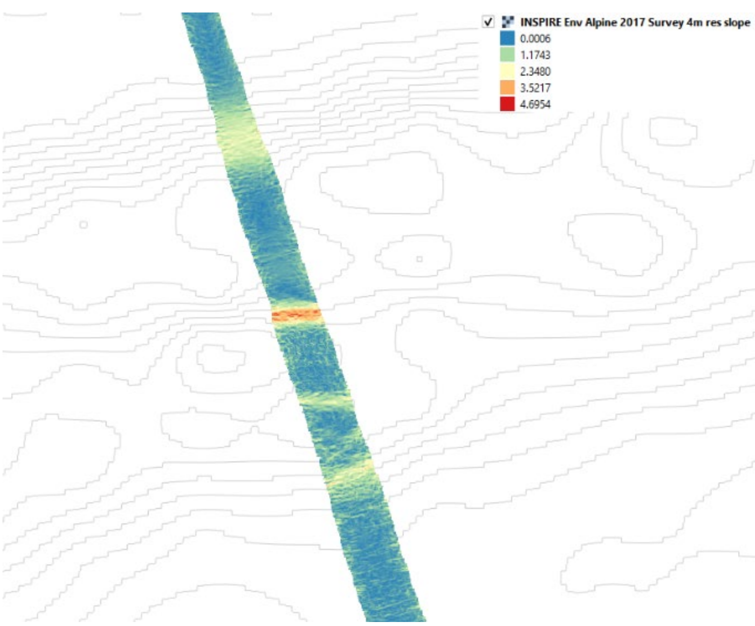


Figure 24. Example of Slope Analysis across Hudson North and Hudson South Pilot Areas

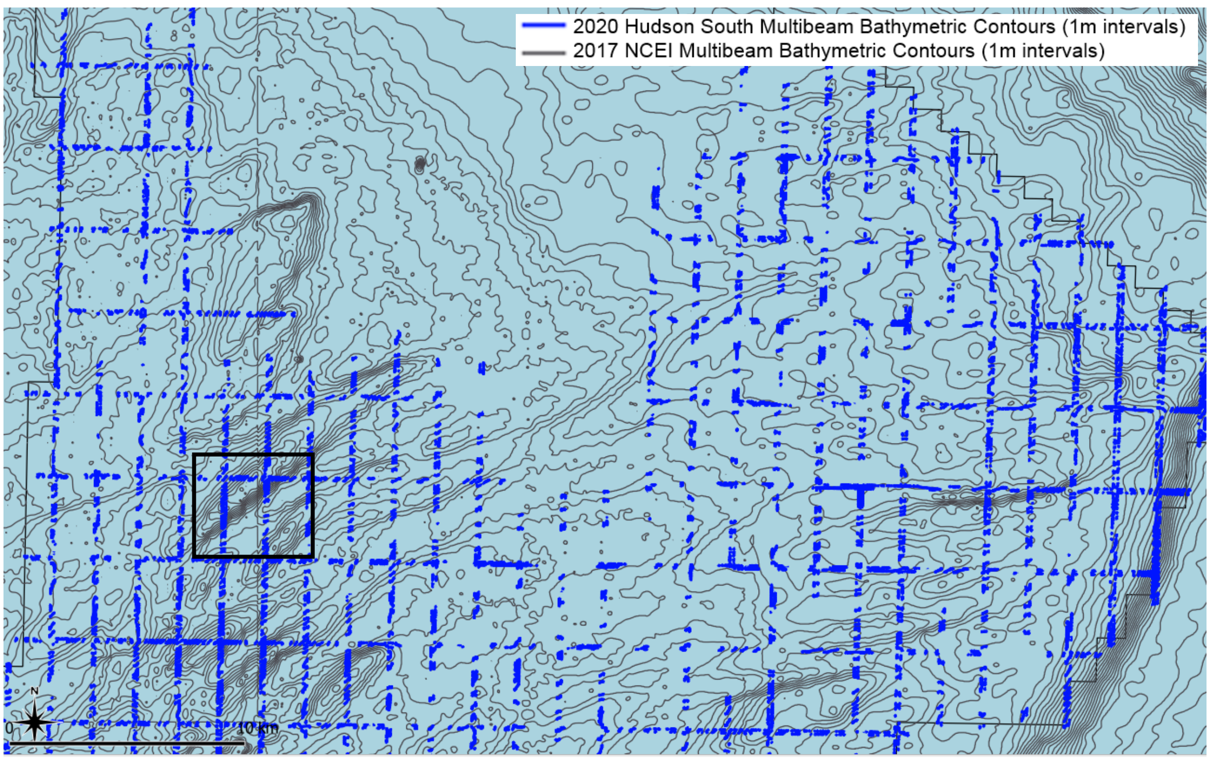
Source: Alpine (2017)



Cross checks of slope angles were calculated on both the 2017 and 2020 multibeam data sets and compared in places where there was coverage of both data sets. This confirmed similar slope angles. An example of the analysis is shown in Figure 25. The maximum slope angles noted within the data sets are well within the working capabilities of cable burial tools. Analysis of the NCEI and Gardline 2020 multibeam bathymetric data also indicates that slope values are similar in both data sets. Areas with the largest slope gradient are denoted by closely spaced contours (such as those within the black box in Figure 25).

Figure 25. Example of Slope Analysis Comparison across Hudson North and Hudson South Pilot Areas

Source: NCEI; Gardline (2021)



The Hudson North Pilot Area appears to be a relatively flat (i.e., bed levels range from approximately 45–60 m across the length of the pilot area) with an undulating rippled seabed. Data acquired at Empire Wind confirms the presence of megaripples near the shared boundary (Battista et. al. 2019) and therefore these bedforms should be anticipated in the western portions of the Hudson North Pilot Area also. These may not have been noted in the Gardline 2021 data due to the coarse line spacing used in the survey.

The Hudson South Pilot Area appears to be situated on a large sand bank which can be clearly denoted in Figure 23 above. The seabed here appears to contain ripples, with small areas of megaripples noted—and are detailed in the "Seabed Mobility" section of this report. The sand bank noted is very large, and the presence of these smaller bedforms, along with the currents anticipated in the area, indicates that it is not likely to be a highly mobile seabed. These minor bedforms are not considered relevant to windfarm design, considerations of cable installation, or WTG/OSS design.

6.3.4.2 Sonar Contacts

A total of 98 sonar contacts were noted in the 2021 Gardline data acquired in the Hudson North (A&B) Study Areas. Of these, 17 were noted to be items of debris, five were noted as fishing pots and the remainder were classified as boulders. The distribution of natural and anthropogenic contacts across the remainder of Hudson North Pilot Area cannot be verified due to the lack of survey data. However, it would be fair to assume that there will be numerous boulders distributed across the pilot area, and further items of debris and fishing gear would also be present.

A further 526 sonar contacts were identified in the 2021 Hudson South Study Area data set. Of these, 75 were noted as items of debris or items related to fishing gear, and three were tentatively associated with the wreck of the Huron, due to their location (these lay within 70–100 m from the published database position for this wreck). The remainder were interpretated as boulders. The distribution of these sonar contacts is noted in Figure 26 and Figure 27 below. It should be noted that this study area does not provide complete coverage of the Hudson South Pilot Area and therefore further boulders and debris should be anticipated here also.

There is no indication of boulders/debris fields within the 2021 survey data acquired in the Hudson North and Hudson South Study Areas survey data. However, it should be noted that these may not have been located during acquisition due to the large line spacing of the survey. The presence of these features cannot therefore be ruled out. Anecdotal evidence from local fishing representatives indicates that boulder fields are likely to be present within the pilot areas.

Figure 26. Sonar Contacts in Hudson North Study Areas

Source: Gardline (2021)

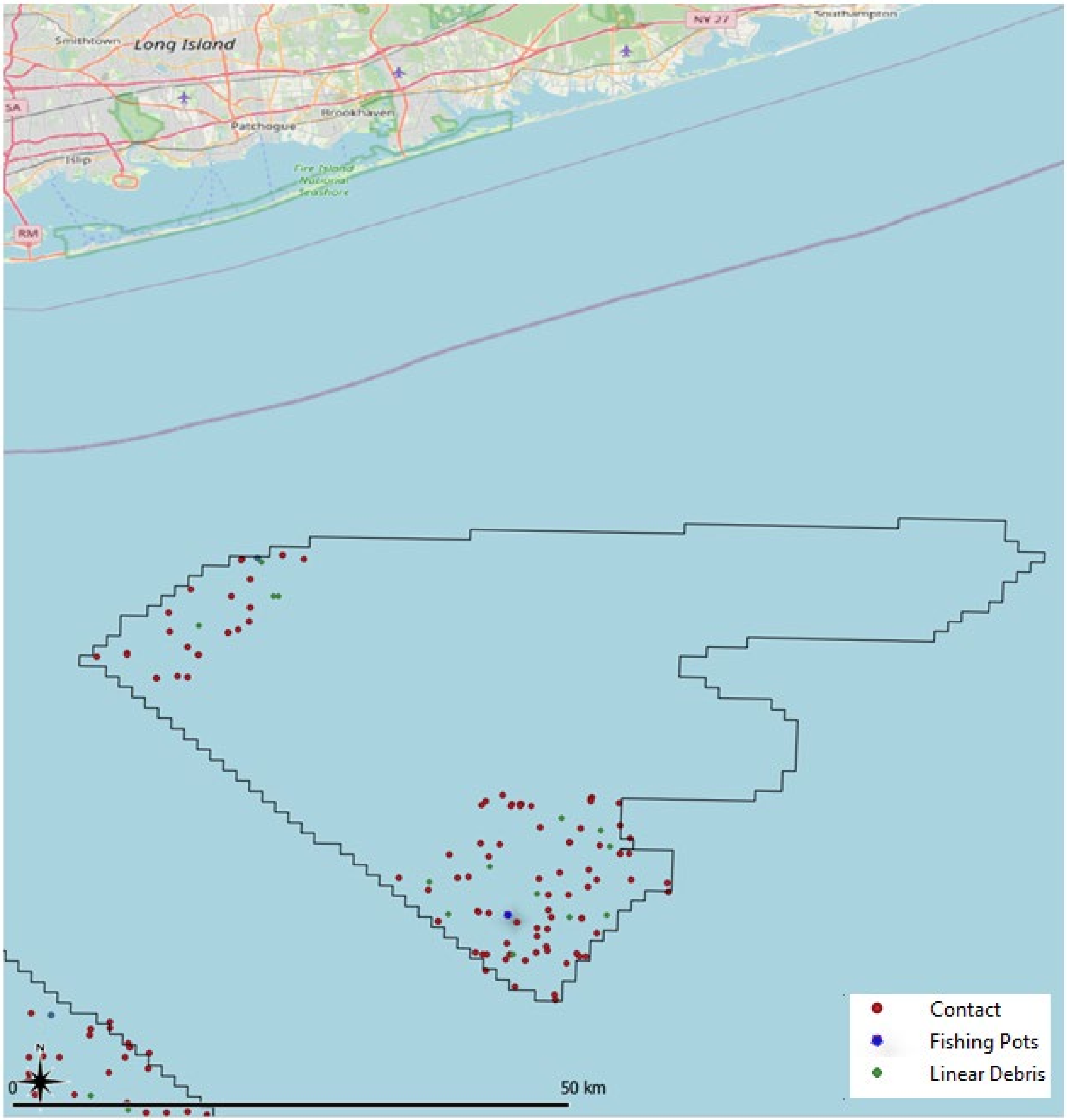
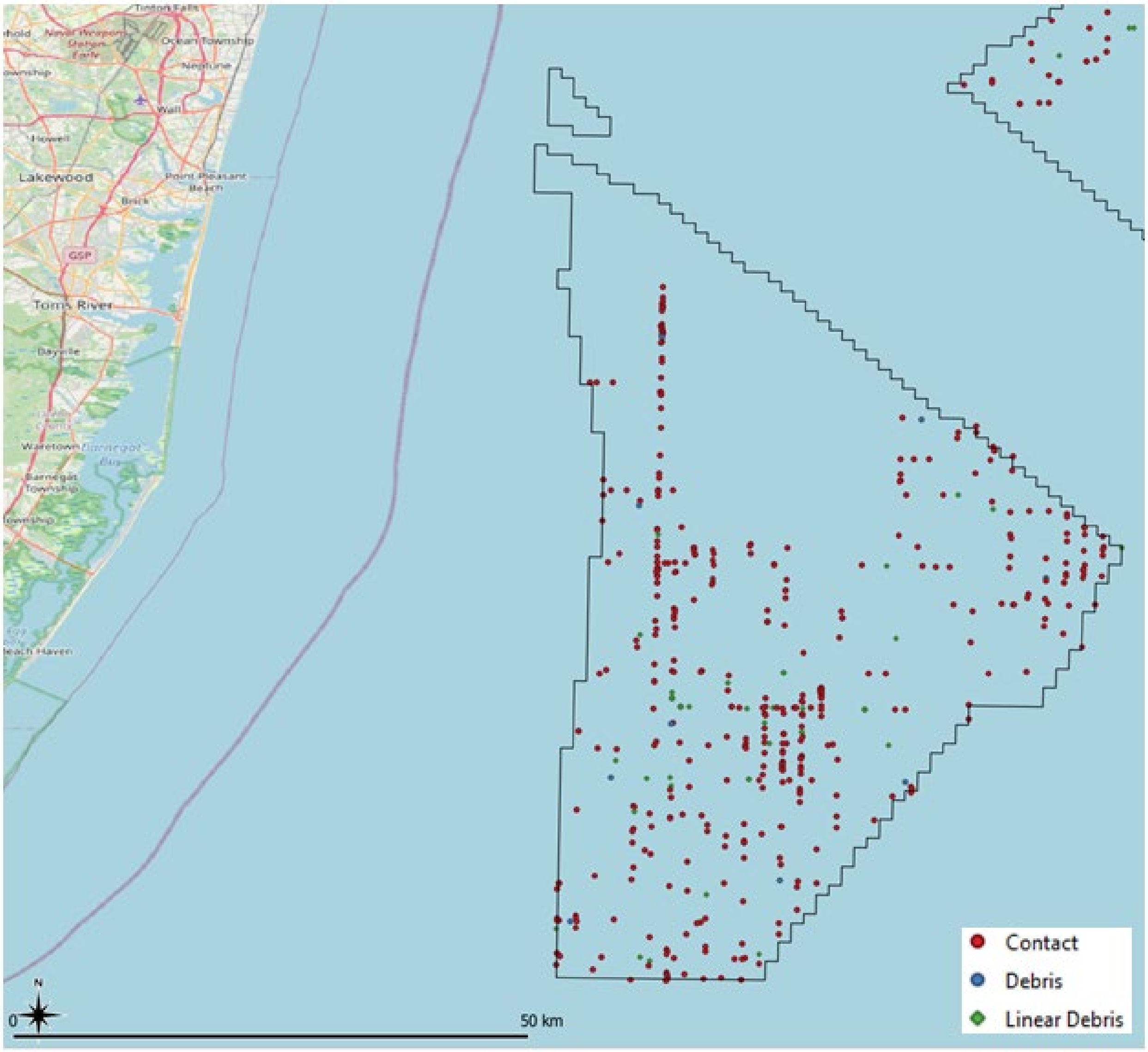


Figure 27. Sonar Contacts in Hudson South Study Area

Source: Gardline (2021)



Mobile bottom tending gear scars (associated with fishing activities) were noted across the majority of the Hudson North A, Hudson North B and Hudson South Study Areas. The Gardline 2021 reports for these study areas indicate that the Fish and Fisheries Study (NYSERDA 2017) confirm this is a busy area for mobile bottom tending activity and recreational fishing activities but that stationary fishing gear, including pots may also be present. Fishing pots were also noted in the Hudson North B Study Area in the 2021 survey report.

Charted wrecks and items of unexploded ordnance (UXO) are also noted in published data within the pilot areas. These are further discussed below.

6.3.4.3 Mounds

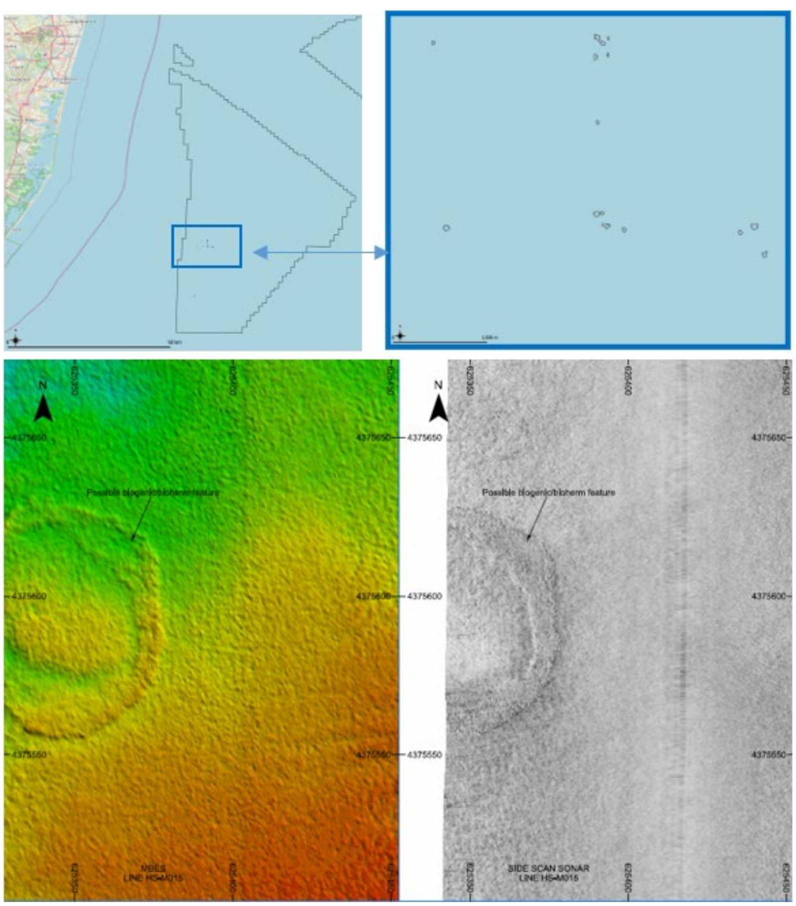
A cluster of circular features were noted in the 2021 Gardline data, and these are located in the western and southwestern portions of the Hudson South Study Area (Figure 28). These have been interpreted as possible bioherm/biogenic features, standing up to 10 cm (3.9 inches) high and 25–80m (82–262ft) in diameter. The report recommends further investigation via camera to confirm this.

Marine Cadastre data indicates that there are reefs off the New Jersey coastline, although none of the reefs lie within the boundaries of the pilot areas.

Figure 28. Possible Biogenic/Bioherm Features in Hudson South Study Area

Based on Multibeam Bathymetric Data (left image) and Side Scan Sonar Mosaic Data (right image), with locations of individual features (bottom image).

Source: Gardline (2021)



6.3.4.4 Shallow Gas

Shallow gas deposits were noted in Pleistocene channels in the 2021 Gardline data. These may indicate the presence of organic matter and biogenic gas in deeper sediments. The Gardline reports for the Hudson North and South Study Areas indicate that no other indicators of shallow gas were noted in the geophysical data acquired there. A desktop study undertaken by NYSERDA in 2019 indicates that organic matter was also found in the Coastal Plain Deposits noted at depth in the pilot areas. These channels are, however, below the depths associated with cable installation and therefore out of the scope of this report.

6.3.4.5 Buried Channels and Hard Ground/Bedrock

Buried channels have been noted in the Pleistocene sediments underlying the Holocene Sands and Transgressive Channels as identified in the 2021 Gardline data for the Hudson North (A&B) and South Study Areas. Several other channels were also noted in deeper layers. These channels are not a consideration for general cable design but may have an impact on foundations for windfarm infrastructure.

Similarly, the top of coastal plain deposits (hard buried ground) was noted to be 8–8.5 m below seabed in the Hudson South Study Area. These are also not considered to be an issue for cable burial but should be assessed during windfarm foundation design and project layout.

6.3.5 Currents

Currents experienced at sea are caused by a combination of the tides, wind shear at the surface, coastal diffraction of waves (longshore drift), wave induced currents, and differences in water density. In shallow regions and around coastlines, the tidal component of a current is usually much more prevalent. The strongest tidally driven and longshore drift currents in the New York Bight are inshore of the pilot areas which lie further offshore. This means that the influence from diurnal tidal currents is quite small for the pilot project areas.

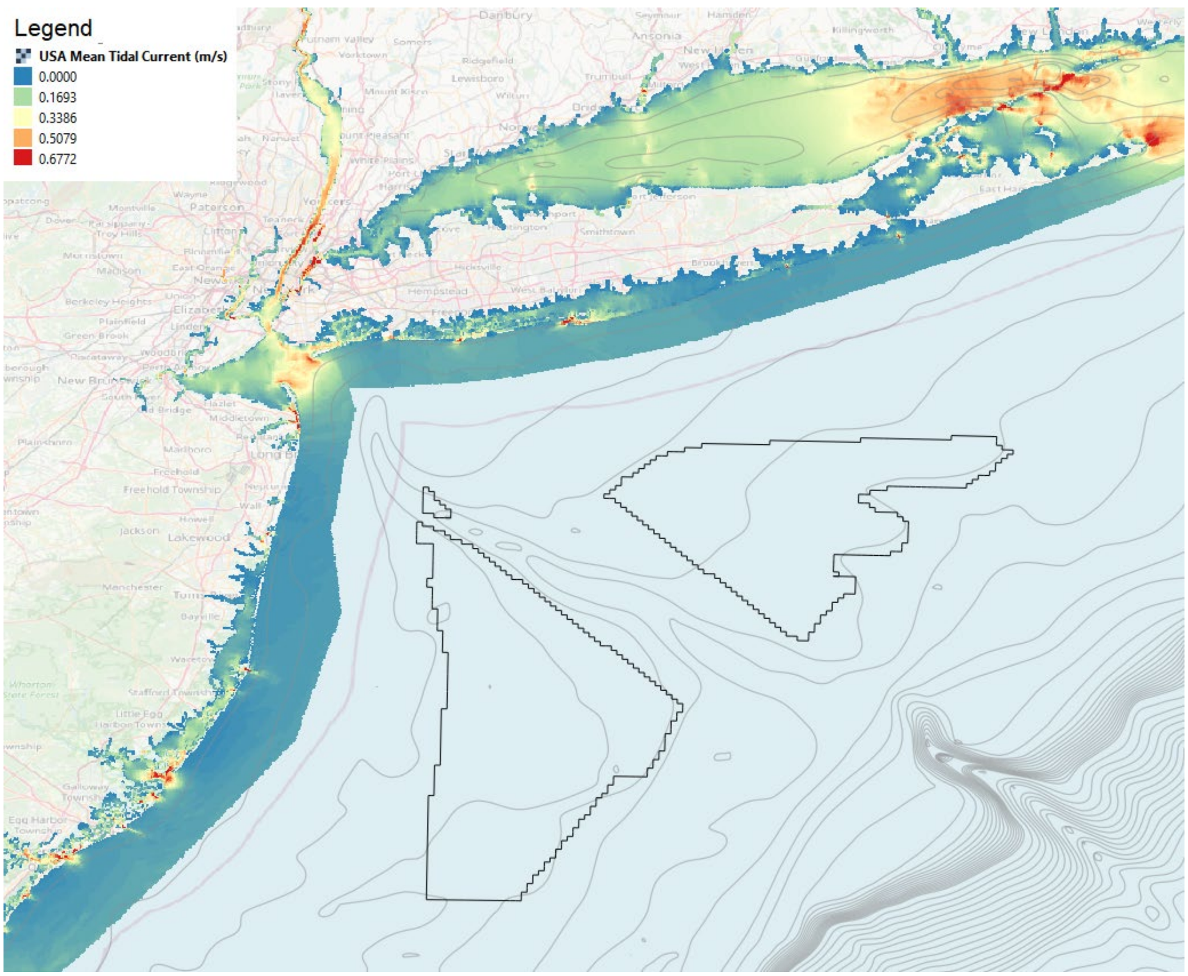
In deeper water where tidal energy is less focused, large-scale oceanic currents exist. These deep-ocean circulation currents, driven by water density differences, are slower but have virtually no input from tidal forces or the wind at the surface. The pilot project areas are well inshore of these deeper oceanic circulation currents.

In 2011 the Georgia Tech Research Corporation (GTRC) undertook an assessment of the potential energy production through tidal power along the whole of the U.S. coast for the U.S. Department of Energy (DOE). Their resulting tidal current model produced a GIS data layer showing average tidal current velocities in meters/second (m/s) (depth averaged).

As can been seen in Figure 29, the strongest mean tidal currents are found close to the coast and concentrated around the headlands, channels, and inlets of Long Island, New York Harbor, and the New Jersey coastline.

Figure 29. Mean Tidal Currents in New York Bight

Source: GTRC (2011)



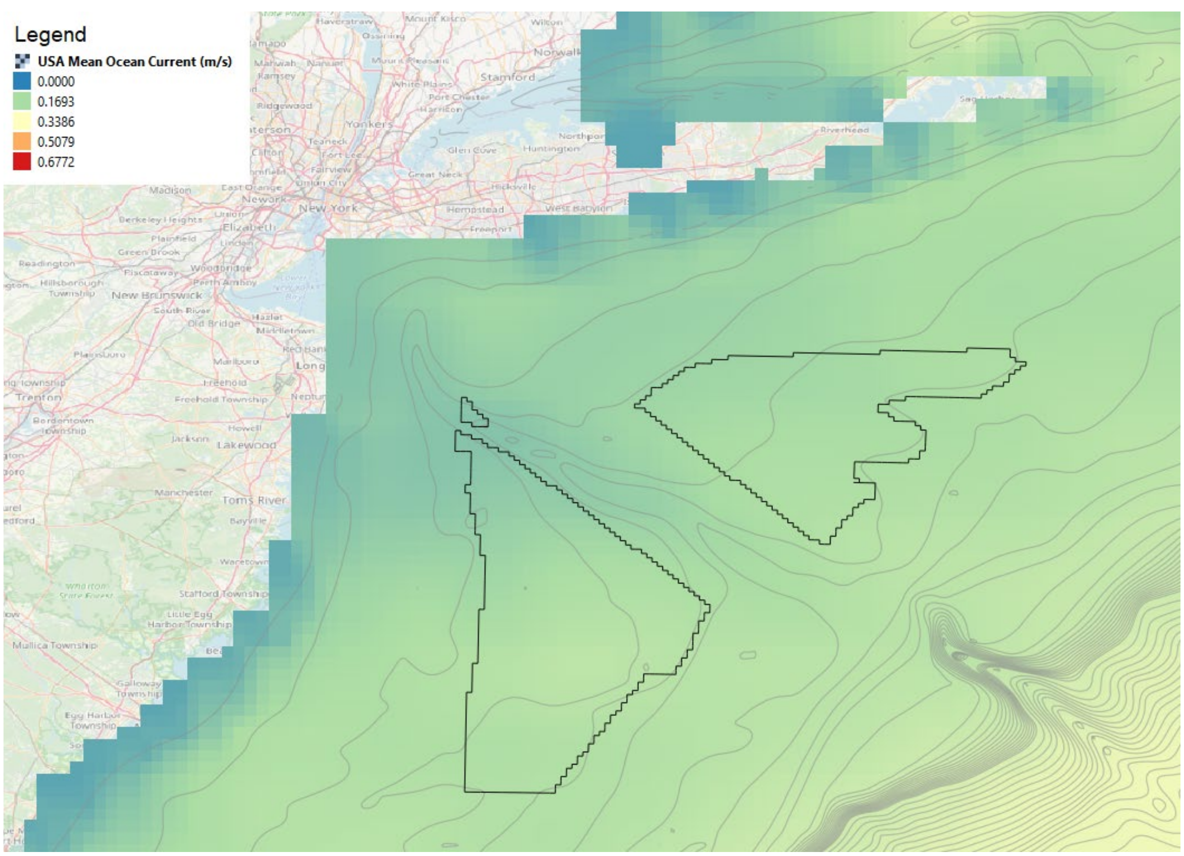
This tidal current data does not reach as far as the pilot projects areas but does demonstrate how the tidal components are concentrated near the coast and not a significant factor across the pilot areas. In 2013 the GTRC extended their assessment of the potential energy production through ocean currents over a wider area around the U.S. coast, again this was carried out for the US DOE.

GTRC used three ocean current models already developed—HYCOM (Hybrid Coordinate Ocean Model), NCOM (Navy Coastal Ocean Model) and ROMS (Regional Ocean Modeling System) and these were then checked against observations from the Global Drifter Program (GDP) to evaluate the performance of the different models especially where they overlapped. For the New York Bight the model used was

HYCOM. In this case the resulting data set does cover the pilot project areas and the mean ocean current strength distribution can be seen in Figure 30, with mean ocean surface currents approximately 0.17m/s across both pilot areas. Both the tidal and ocean current GIS data layers are hosted on the Marine Cadstre website.

Figure 30. Mean Ocean Surface Currents in New York Bight

Source: GTRC (2013)



The currents found in the pilot project areas are mostly driven by two components. The first of these are eddy gyres from the northwards flowing Gulf Stream which lies off the U.S. continental shelf, with its axis some 1,250 km SE of the pilot project areas. Satellites can provide sea surface temperatures and the thermal patterns observable show these gyres are highly variable, but in general follow a westward back-flow motion into the inshore region of the Bight.

The second main component of the currents found in the pilot area are wind driven. The winds from storms in the Atlantic and tropical storms, which pass up the east coast of the U.S. from the Caribbean create waves which pass over the pilot areas. The wind and waves then create surface currents aligned with the wave and wind directions. Unlike the tidal and oceanic currents, the wind and wave forcing are far more varied in orientation, but over long time periods will prevail from the predominant wind and wave directions.

Surface currents can vary dramatically from those found close to the seabed. For offshore windfarms the surface currents are important to construction activities undertaken from surface vessels. Near bottom currents are far more influential in the formation of seabed bedforms and are crucial to the assessment of stability of cables and infrastructure on the seabed. Near bottom currents are also more important in the assessment of the potential for seabed scour.

To understand the overall near bottom and surface currents across the pilot project area, data from a modeling project called FVCOM (Finite Volume Coastal Ocean Model) were evaluated. This model was developed by the Marine Ecosystem Dynamics Modeling Laboratory at the University of Massachusetts-Dartmouth and the Woods Hole Oceanographic Institution (SMAST 2016).

FVCOM has used numerous data sources for annual climatology for currents between 1978 and 2013 in the northeast United States to create a current prediction model which covers the pilot project area. Within the model, both surface and bottom current GIS data layers have been created based on 36 years of hindcast data. The GIS layers for surface and bottom currents show velocity, magnitude, and direction data. The surface currents data from FVCOM can be seen in Figure 31, and the bottom currents in Figure 32. The predominant surface current directions reflect the south to southwesterly backflow direction of the gulf stream eddy gyres mentioned earlier and across the pilot project areas average velocities range from 0.05 to 0.2 m/s (0.1 to 0.39 knots). The bottom currents directions are more variable across the sites, but most tend to face to the south and west. Bottom currents velocities are much smaller than at the surface with a range of less than 0.01 to 0.05 m/s (0.02 to 0.1 knots). Both the surface and bottom current GIS data layers are hosted on the Northeast Ocean Data Portal (www.northeastoceandata.org/).

Figure 31. FVCOM Mean Surface Currents in New York Bight (1978–2013)

Source: SMAST (2016)

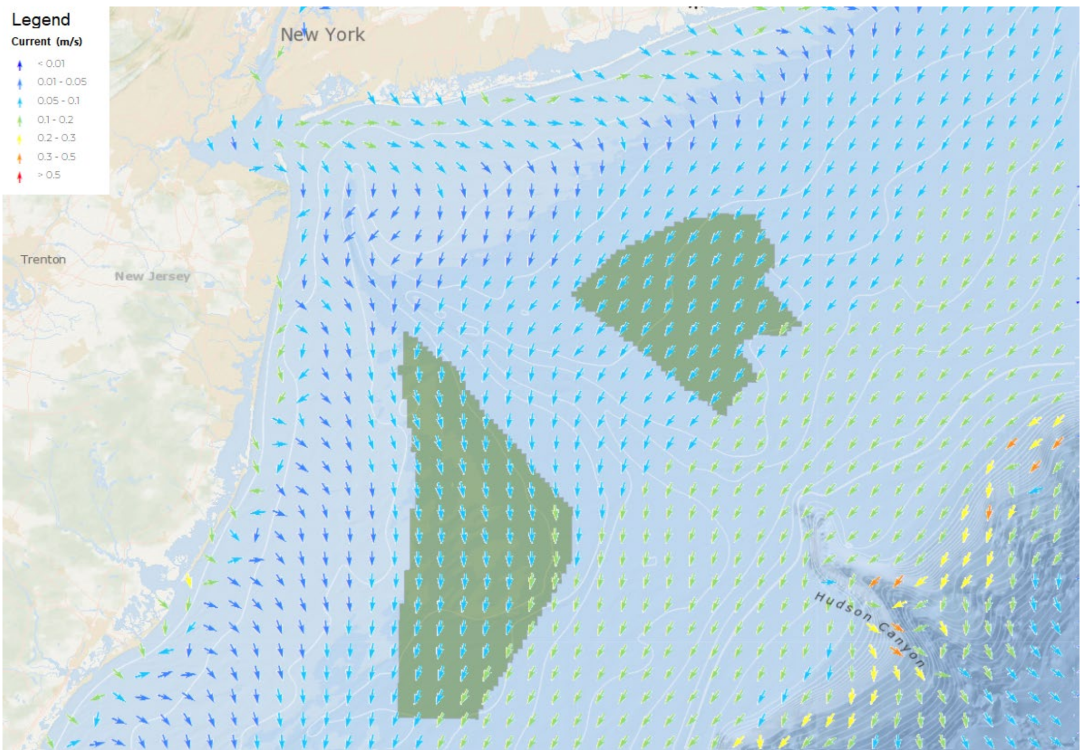
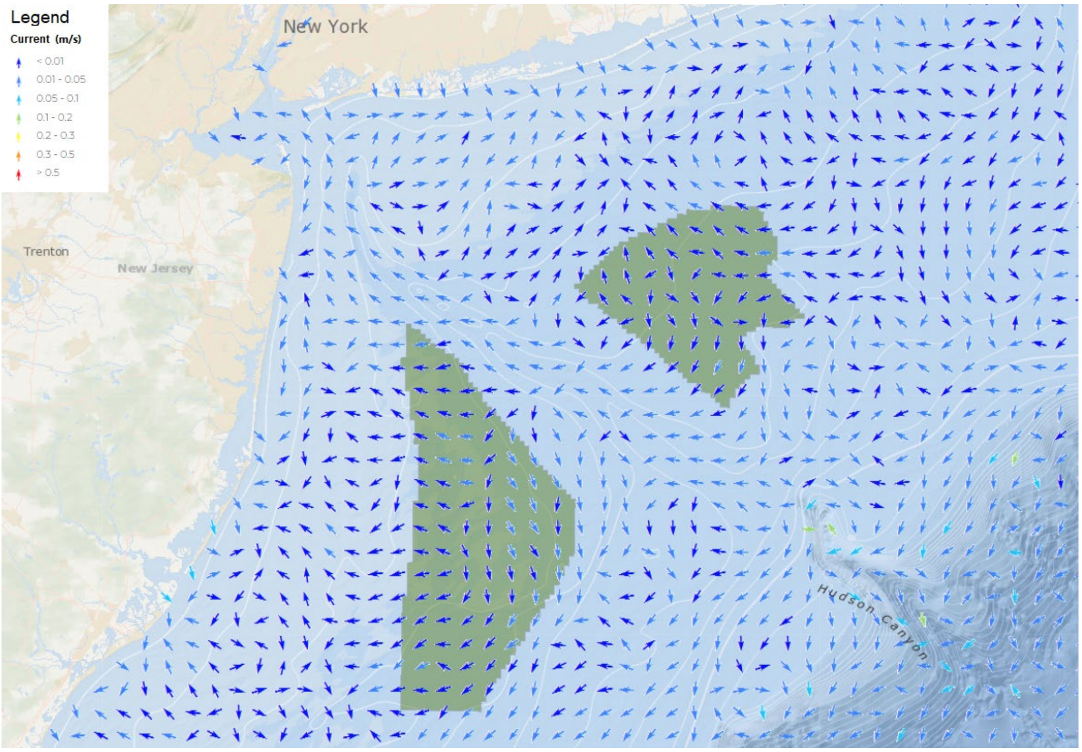


Figure 32. FVCOM Mean Bottom Currents in New York Bight (1978–2013)

Source: SMAST (2016)



Based on the evaluations of the data sets above, the marine current environment is one where the currents across the pilot project sites have a low-average velocity with an overall direction of flow to the southwest. The overall view is highly affected by wind and wave driven currents which will produce high variability in strength and direction over short periods of time, particularly affecting surface currents.

6.3.6 Seabed Scour

Seabed scour is caused by wave and current action causing erosion of the seabed. Natural movement of seabed particles changes around obstacles on the seabed, washing away the sand from one side until a hollow pit is formed. This seabed movement can be problematic for foundation design for WTG's and OSS's and cause variability in the depth of cover over buried cables.

The pilot project evaluated whether seabed scour formed around natural features (e.g., boulders and debris). These were observed in higher resolution multibeam data and used these as analogs for foundations to make assessments for potential and distribution of seabed scour across the pilot project sites. Observations made while analyzing the potential for scour on small features such as boulders are empirical—water can flow over the top, as well as the sides of these features. However, there are no other features available within the study areas, surrounded by adequate processed survey data, to base an analysis on. Observations based on natural objects have therefore been used as an indicator of the potential for scour on larger features such as turbine foundations/other seabed infrastructure and cable stabilization methods in the absence of other features.

Sonar contacts were picked from the Gardline 2021 data and bathymetric data was visually analyzed for indications of scour. The distribution of these is presented in Figure 33 below. In general, potential areas of scour were noted to be very shallow, with only a few of these associated with 1 m/3 ft deep scour. The Gardline 2021 report for the Hudson South Study Area presents a good representation of this and is reproduced in Figure 34 below; in the top image, the 1 m resolution data clearly shows the scour around this contact, but in the bottom image, scour is not visible in the same data shown in 4 m resolution.

In general, the detailed survey data coverage required to assess examples of scour across the Hudson North and South Pilot areas is mostly sparce. While the data acquired for the 2021 survey on the Hudson South Study Area covered significantly more of the Hudson South Pilot Area than the other study areas contained within the Hudson North Pilot Area, the sampling interval of the surveys was very wide and therefore a significant potential for more contacts, both anthropogenic debris and natural boulders exists across both pilot areas.

The 2021 data set does however quantify approximate proportions of sonar contacts which may exhibit scour, versus those that do not have any visual indication of scour. There was a total of 128 sonar contacts identified in the Hudson North A & B Study Areas, and only 14 (11%) of these exhibited a small amount (less than 1 m/3 ft) of scour. Similarly, a total of 526 sonar contacts were noted in the Hudson South Study Area and only 44 (8%) had a visual indication of minor scour (less than 1 m/3 ft) around them. All contacts with visual scour associated in the Hudson North Study Areas were classified as boulders. Most contacts with minor visual scour in the Hudson South Study Area were also classified as boulders, although some were associated with linear debris.

The distribution of contacts exhibiting minor scour is generally quite evenly spread across the study areas as illustrated in Figure 33 below. Example bathymetric images of the areas visually noted to be the most significant in terms of scour across the pilot areas are presented in Figure 35. The scour pit is orientated to the southwest, in line with the general direction currents are anticipated to be in this area.

Figure 33. Distribution of Sonar Contacts and Minor Scour

Source: Gardline (2021); OceanIQ

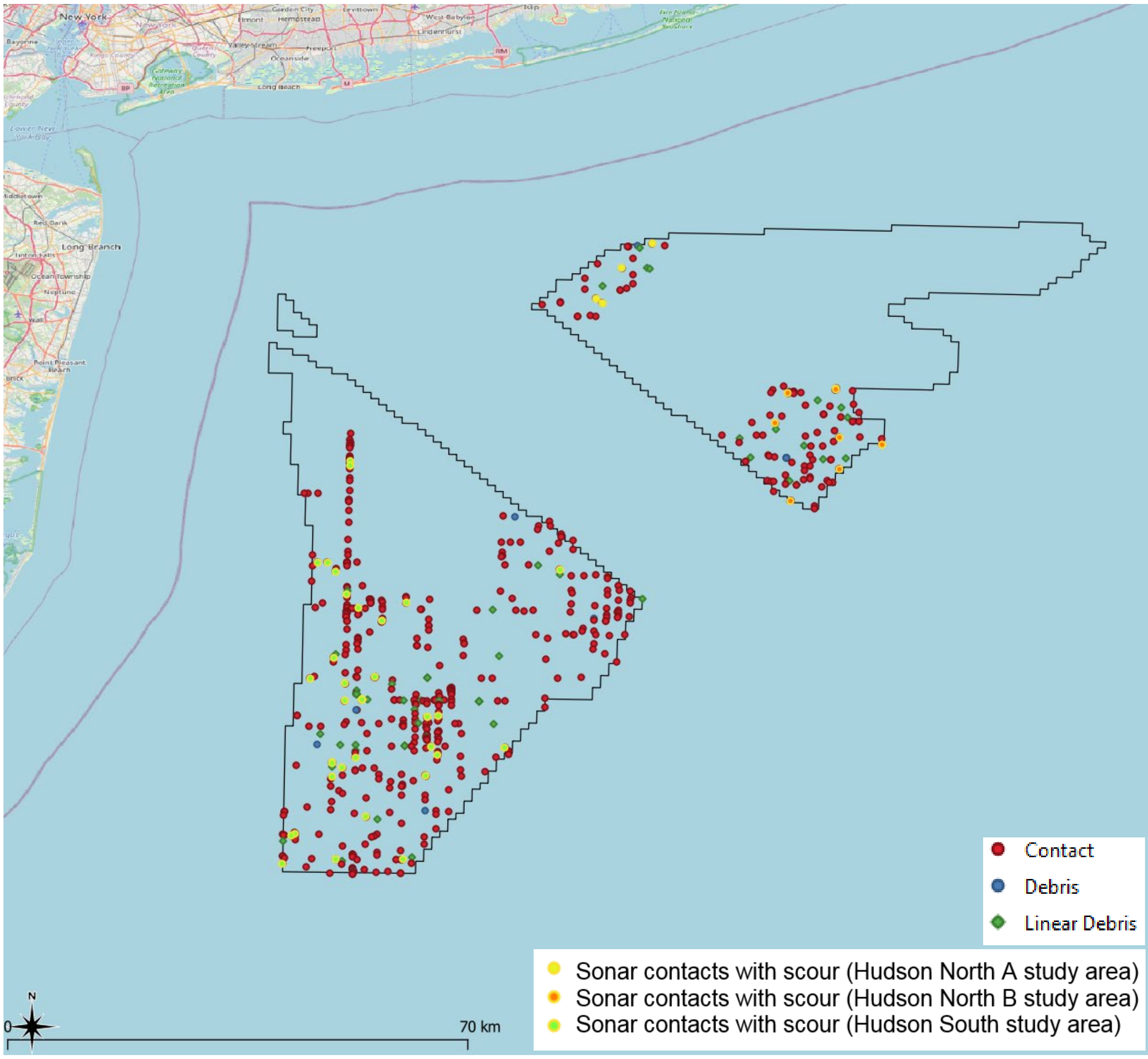


Figure 34. Debris Item with Associated Scour

Visible in 1 m Resolution Data (Top Image) But Not Visible in 4 m Resolution Data (Bottom Image)

Source: Gardline (2021)

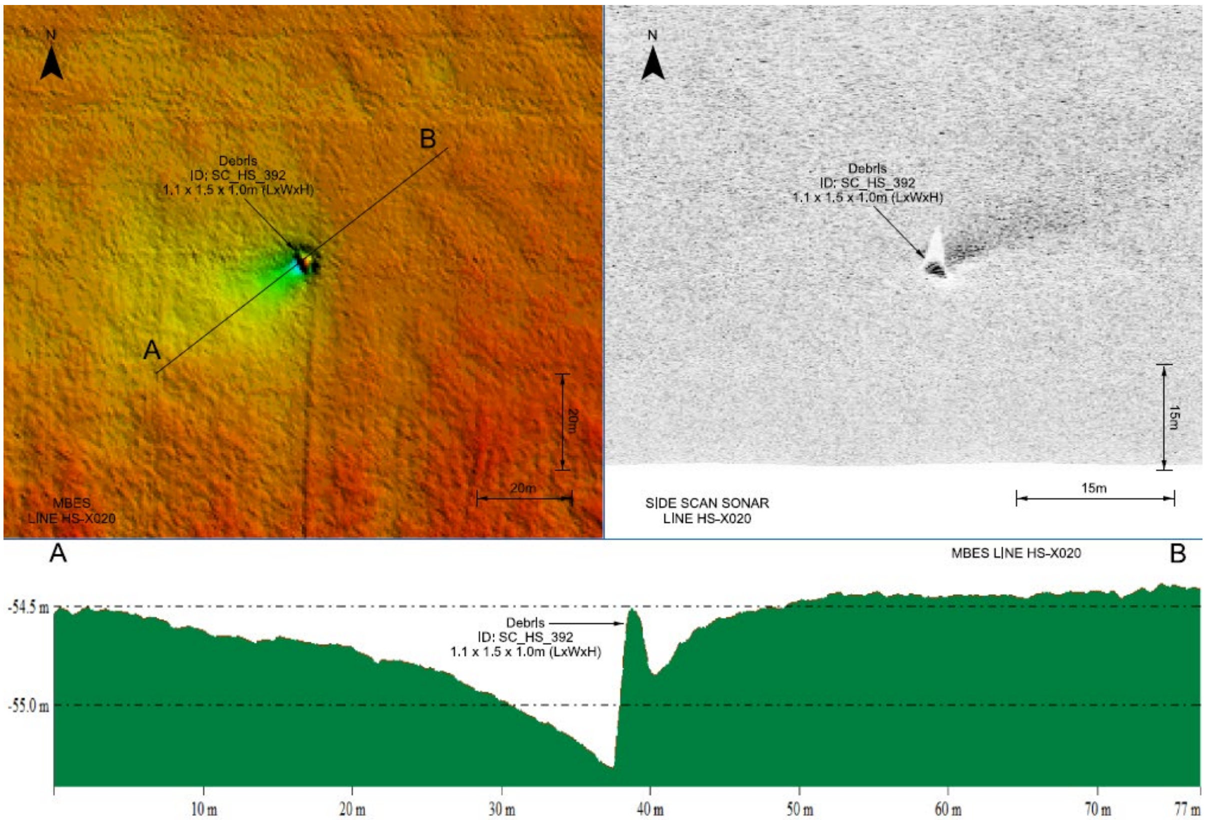
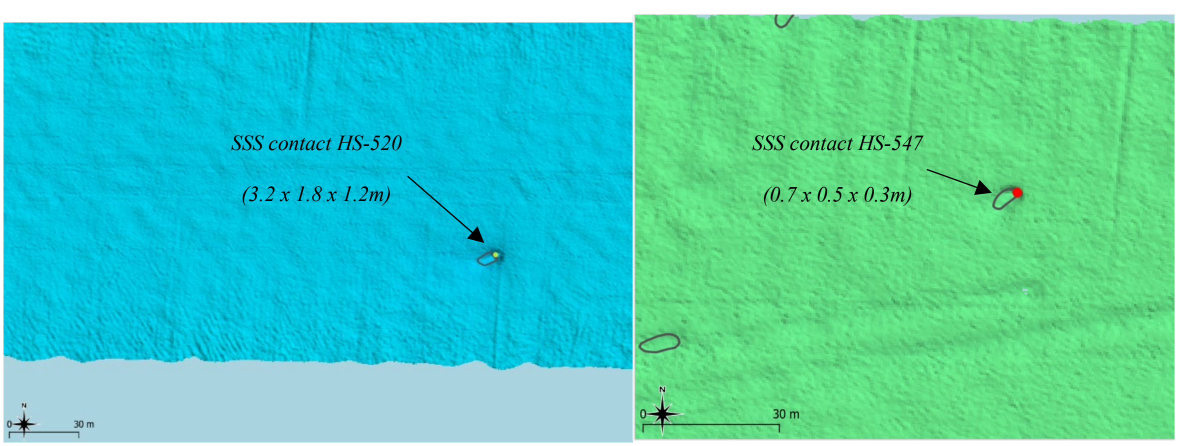


Figure 35. Examples of Sonar Contacts with Visual Indications of Scour

Source: Gardline (2021)



The 2017 Alpine Survey covered the Hudson North and South Pilot Areas in a coarse line spacing; however, the full resolution (1 m gridded multibeam digital terrain model) data files are not provided with any seabed interpretation. Therefore, it was not possible to undertake an analysis of scour on this data set. It would be possible to undertake further analysis across the sites using this data if it was processed and used to identify seabed targets (boulders) and any associated scour. This type of analysis was outside the scope of the report.

Although there is not continual processed data coverage across the entire Hudson North and South areas, the data available indicates that sediment type, water depths and current regime do not vary dramatically across these sites. It is therefore reasonable to expect a similar distribution of scour occurrence and magnitude over the Hudson North and South areas, rather than in isolated portions of the study areas.

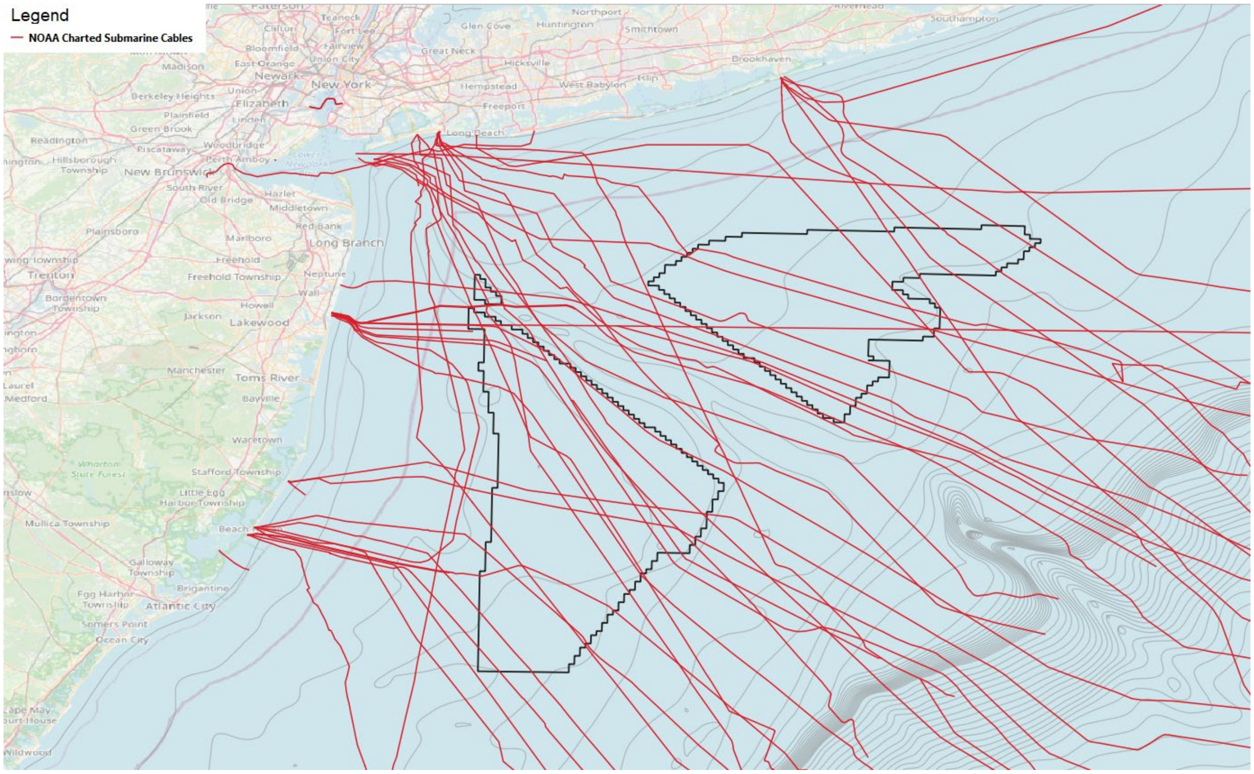
6.3.7 Existing Seabed Infrastructure and Obstructions

6.3.7.1 Seabed Infrastructure

In service infrastructure and seabed obstructions will prevent the siting of WTGs, and OSSs directly over them. They will also hinder the burial of IACs and export cables and may prevent achievement of the full target burial at crossing points. The most common types of seabed infrastructure are submarine cables and pipelines. Submarine telecommunication cables have been installed in the Atlantic since the early 1860's and there is a legacy of both in and out of service telecommunication cables, which cross the pilot project areas. To determine the number of cables and their positions, NOAA marine cable data was used, and the associated GIS database sourced via the Marine Cadastre web portal.

This data layer shows cables taken from 2010 NOAA Electronic Navigation Charts (ENCs) and 2009 NOAA Raster Navigation Charts (RNCs). Some of these include abandoned (out of service) cables and cables since removed. Figure 36 shows all the NOAA charted submarine cables along with the pilot project area.

Figure 36. NOAA Charted Submarine Cables



OceanIQ has a cable database (GeoCable™) which is used for cable route engineering and for other marine stakeholders to obtain cable route data worldwide.

There are approximately 1408 km of telegraph, coaxial, and fiber optic (FO) cables identified by the GeoCable™ database, including 14 in-service telecommunication cables crossing the pilot project sites and 19 older coaxial and telegraph cables, some of which are represented in the NOAA cable data shown in Figure 36. The NOAA data does not contain five of the most recent telecommunication cable routes laid across the pilot areas.

Telecommunication cables carry telephone calls, internet connections and data. These cables are fairly evenly distributed across the pilot project sites. The spatial diversity and separation of telecommunication cables is planned to aid the resilience of the network and to ensure good access for maintenance to the cables.

There are currently no power cables present inside the pilot project areas. This will inevitably change as OWF developments progress in the New York Bight. While IACs are unlikely to affect other IACs there may be situations where the proximity of export power cables serving future OWF's will need to be planned for by neighboring OWF developments.

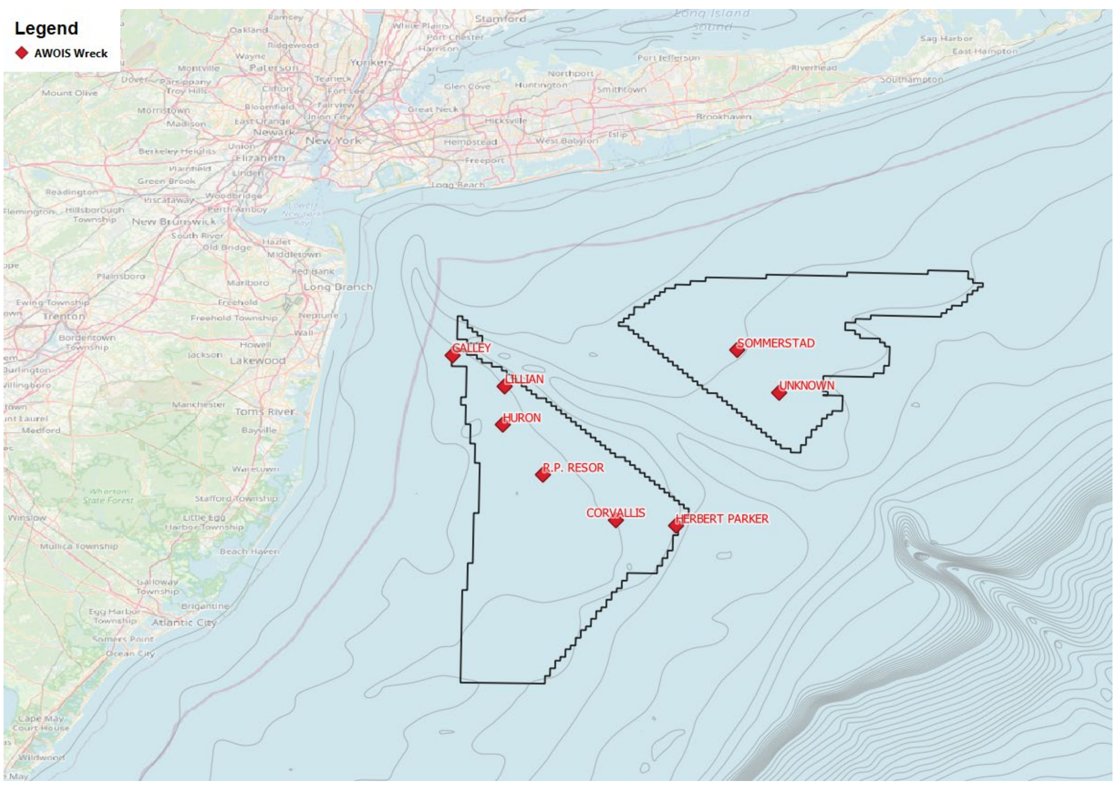
There are currently no pipelines or other existing non-offshore wind renewable infrastructure within the pilot project areas, but this may change as the call areas in the New York Bight are leased and developed.

6.3.7.2 Seabed Obstructions

Two known wrecks lie within Hudson North pilot area. An uncharted wreck, lying in 23 m water depth, is recorded in the southern portion of the pilot area, while the Sommerstad cargo vessel lies in the central portion of the pilot area. The location of both these wrecks are illustrated in Figure 37.

Figure 37. Wrecks and Obstructions

Source: Office of Coast Survey (2022)



A total of 6 wrecks were noted in the Hudson South pilot area (Table 18; Figure 38). These wrecks appear to be evenly distributed along the northern and eastern portion of this pilot area.

Table 18. Wrecks within Pilot Project Areas

Source: Office of Coast Survey (2022)

Vessel Name	Lat	Long	Descriptive Notes
UNKNOWN	40.007272	-72.759475	Feature is an uncharted wreck 09/04/2009
GALLEY	40.112572	-73.674881	Identified as Galley
R.P. RESOR	39.776781	-73.421225	Reported demolished and cleared to 50ft
HURON	39.916781	-73.532897	Barge Sunk 10/12/51 Marine Casualty. position accuracy 1-3 miles
SOMMERSTAD	40.125972	-72.876728	Cargo Vessel 3875GT Sunk 8/12/18. position accuracy 3-5 miles
LILLIAN	40.025111	-73.527342	Water Depth Clear to 19 fathoms Cargo Vessel 3402GT. Sunk 2/27/3
HERBERT PARKER	39.633447	-73.049544	137GT position accuracy 1-3 miles reported through old coast guard records. Sunk before WWII
CORVALLIS	39.650117	-73.216217	Cargo Vessel 2922GT position accuracy 1-3 miles. Sunk before WWII

Four items of charted unexploded ordnance (UXO) were noted within the Hudson North and South Pilot Areas (Figure 38; Table 19). One item of UXO which was not captured in the 2021 Gardline data was charted within the Hudson South Study Area.

Figure 38. Charted Unexploded Ordnance

Source: NOAA, Raster Navigation Charts (2022)

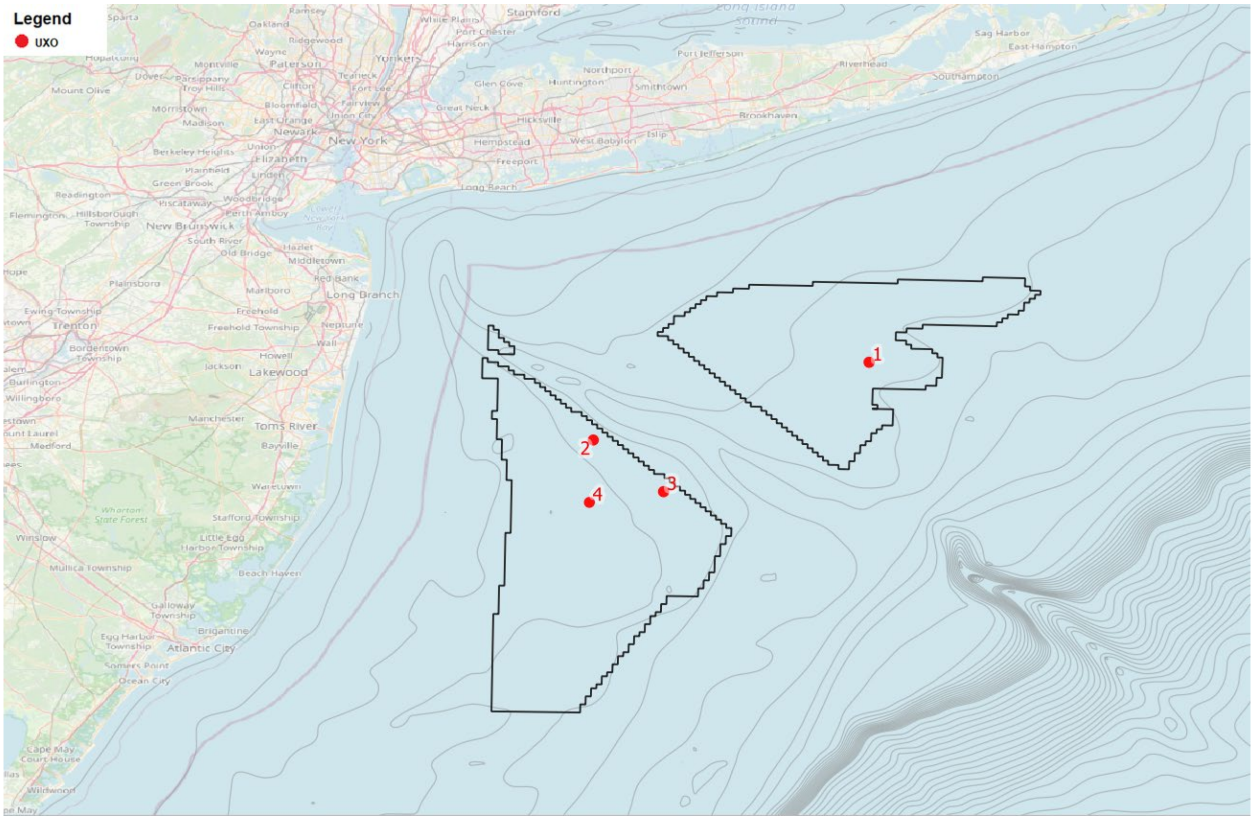


Table 19. UXO Charted Areas within Pilot Project Areas

Ref	Lat	Long	Descriptive Notes
1	40.1244N	72.6465W	Unexploded ordnance (reported 2010) PA
2	39.9169N	73.3812W	Unexploded bomb Dec 1960
3	39.7778N	73.1929W	Unexploded ordnance PA
4	39.7501N	73.3920W	Unexploded ordnance (reported 2017)

6.4 Route Engineering Practices

6.4.1 Introduction

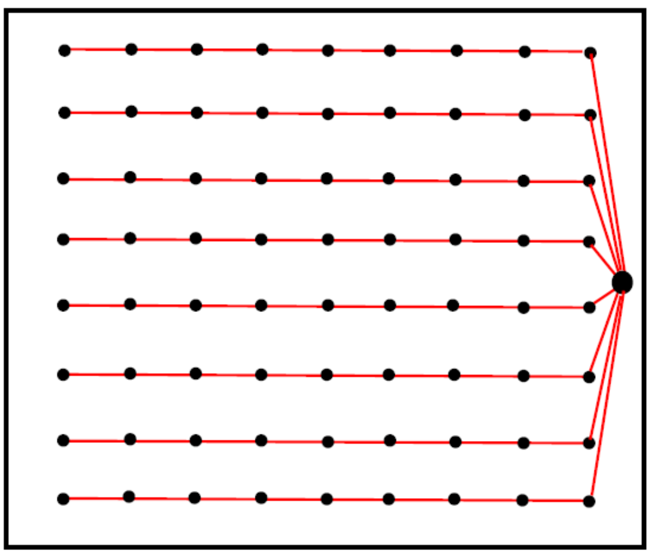
This section takes the seabed characteristics described above and describes practical engineering measures required to protect the OWF infrastructure and ensure the reliable operation of the OWF. Some engineering measures can often be viewed as mutually beneficial to the fishing industry as they prevent interaction with towed fishing gear. Other engineering measures are not mutually beneficial and in these cases the aim of the analysis is to limit the impact on fishing as far as practicable.

Example of engineering practices include microrouting and micrositing, which are terms used within the industry to describe the revision of cable routes and placement of other OWF infrastructure such as WTG foundations after the acquisition of high-quality marine geophysical and geotechnical survey information. The size of such revisions is limited by the extents of the survey coverage acquired.

6.4.2 Input from Earlier Tasks

There are a few key points from the previous study tasks which are worthwhile revisiting to show how they can contribute to the OWF design process in the pilot study area. Relating to cable routes, fishermen interviews conducted earlier in the study resulted in four out of five respondents preferring layout B for cable scenarios which "would allow them to safely operate a tow without crossing a cable." Layout B had IAC strings aligned parallel to each other where possible with the OSS outside the array and the number of cables aligned perpendicular to the array strings minimized. Figure 39 shows layout B for reference.

Figure 39. Survey Questionnaire Layout B From Earlier Project Task



The fishermen interviews also mentioned tow direction for scallop fishermen and stated that "Direction of a tow was influenced by the oceanic conditions such as tide and sea state (if rough conditions then participants indicated they might tow into the waves)." Current and wave directions vary across the site, but the overall current direction is southwesterly across Hudson North and Hudson South.

Initial study tasks also looked at how various strategies to increase scallop and SC/OQ fishing access might affect output and reduce the risk of damage to array cables and snagging gear. The strategies included:

- Orienting turbine rows with the predominant vessel towing or transit directions.
- Minimizing array cable crossings.
- Increasing turbine spacings to widen towing lanes.
- Including a "no-build area" within the array.
- Increasing the turbine capacity to reduce the number of turbines in a wind plant.

The adoption of these strategies should be appraised site by site, but all of them appear to offer improved compatibility of fishing and OWFs.

6.4.3 Seabed Sediments

Seabed sediments across the Hudson North and South Pilot Areas are generally comprised of sands and gravelly sands which are often described as the Holocene sand sheet.

Cable burial is affected by a soil's physical properties and primarily strength parameters such as shear strength for cohesive soils (e.g., clays and muds) and relative density for non-cohesive soils (e.g., sands and gravels). Sediments which are too soft can destabilize burial tools and cause them to sink into the sediments. Sediments which have high-relative densities and shear strengths make cable burial difficult and can inhibit effective cable burial.

The presence of high proportions of gravels within shallow seabed soils can cause an issue for jetting tools as larger granular soils are harder to fluidize and reconsolidate quicker within a jetted trench making it difficult to hold the trench open for long enough to achieve effective cable burial. Similarly, the presence of coarse gravels and cobbles can also impede a plow inhibiting burial potential and increasing the wear rate on the share. Cobbles and boulders can also cause burial issues when at a subsurface level, affecting trench design and causing obstructions that can affect depth of lowering levels, therefore cable burial levels.

Geotechnical parameters of the seabed sediments within the pilot areas are unknown at the time; however, it is anticipated that the pilot project sites will have good burial conditions overall. Holocene sands deposits cover both pilot areas, and these are underlain by a transgressive channel unit comprising gravels, sands, silty and clays. The presence of gravelly sands is anticipated in the bathymetric dips of an undulating seabed (Gardline 2021) and a band of silty sediments is anticipated in the central portion of the Hudson North Pilot Area. However, as described in the seabed characteristics section, the primary constituent of the pilot area is sand. Above analysis indicated that the seabed currents are not considered an issue. Previous sections also detailed historical burial for existing infrastructure in the area and provided further evidence of good burial conditions across Hudson North and Hudson South with no indication of poor or limited burial being encountered at any particular site of the pilot area.

The only areas where it is reasonable to assume that cable burial may be affected by soil conditions are those where the gravel constituent is a higher proportion (e.g., in the central western portion of Hudson South Pilot Area). In these areas cable burial may require multiple burial jetting passes and the progress speeds of the burial tool may be reduced compared to other areas. When engineering IAC routes within an OWF development it might be possible to treat a particularly concentrated gravel area like other seabed obstructions and avoid or minimize interaction as described further below.

6.4.4 Geohazards

Cable route engineering practices take geohazards into account during cable route design. A list of BOEM guidelines for likely geohazards was previously noted, although most of these are not considered relevant for the Hudson North and South Pilot Areas. Best engineering practices for geohazards are discussed in this section of the report.

6.4.4.1 Bedforms

Seabed mobility discussed above indicates that the bedforms noted in published data across both pilot areas comprise ripples and megaripples. These bedforms, and their associated slope gradients are not considered to be an issue for cable burial or windfarm design. In general, seabed ripples and megaripples are only considered to be an issue for cable route engineering practices, if the slope of a megaripple is greater than 1m (3.2 ft) and has a significant slope angle. Even in these circumstances, the cable can be routed in a similar fashion to sand waves.

Bedforms such as sand waves are not anticipated within the pilot area. However, sand wave crests can be a significant factor for cable installation as the burial tools all have limitations to slope angles that they can function at before becoming unstable. Good engineering practice generally implies that cables are routed along sand wave troughs or if this is not possible to route across the crests of the sand waves perpendicularly. Routing through troughs also ensures the cable is more likely to remain buried as sediment movement will push the sand waves over the cable in time, providing more cover until the next trough passes by.

Bedforms such as sand banks can be relatively stable for extended periods of time as they are generally slow-moving features. However, significant storms can cause sudden shifts of the lateral extents of these and therefore windfarm design would need to take this into account. Wind turbine generators are generally not situated close to bank edges, unless specifically engineered to tolerate enhanced sediment movement, as they can become unstable in the case of a shift due to significant storm events. Routing of cables near the lateral extents of sand banks should be done with caution due to the risk of cable exposure after natural events.

Slope limitations for burial tools vary between the various plows and jetting tools used in the industry. For example, the Global Marine Group Q1400 Trenching System has a pitch and roll capacity of 15°. Similarly, the IHC Power Cable Plough has a vertical tow angle of 15° whereas the SMD Heavy Duty Plough has a steering limitation of 12°. Other burial tools in the industry have limitations closer to 10°.

These limitations are only considered valid for sustained slopes over distances greater than 1 m (3.2 ft). The seabed can often exhibit short slopes with high slope values greater than 15°. However, plow skids or ROV tracks can often negotiate these with ease, simply because the size of the tool is significantly bigger than the short distance over the slope encountered. Another consideration is that while slopes greater than 10–15° are a limiting factor for most burial tools, slopes can be modified to reduce the slope angle by dredging the seabed before burial operations take place. This is, however, a costly exercise but has been utilized in some parts of Europe with success where the seabed is not too hard (e.g., Race Bank OWF) (Orsted 2018).

6.4.4.2 Sonar Contacts

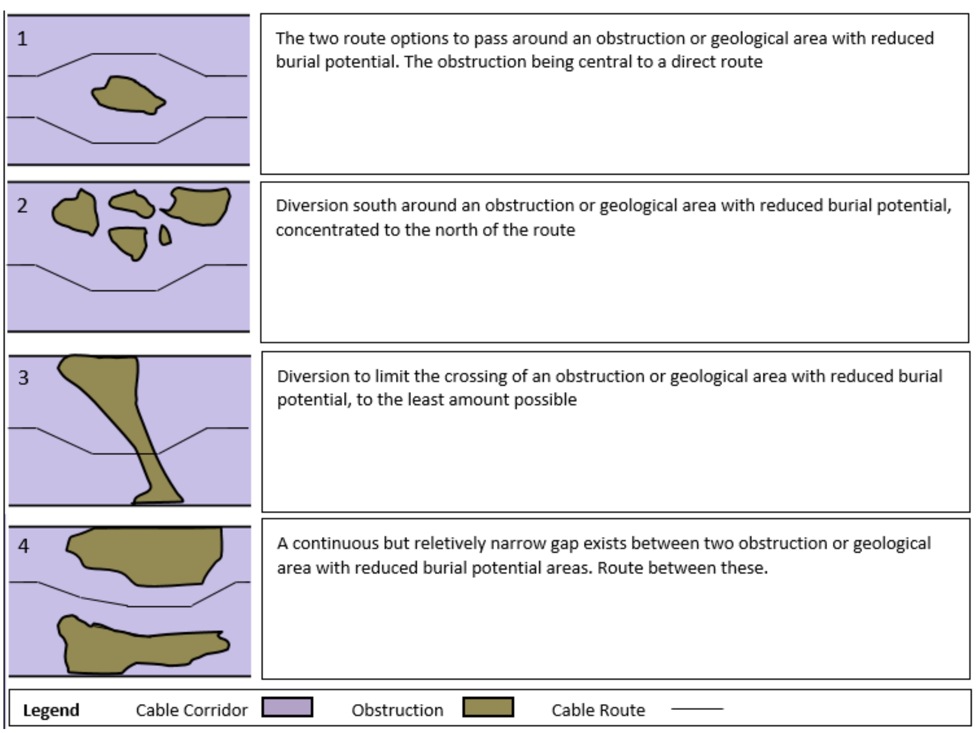
The evidence from previous sections indicated that while there are numerous sonar contacts noted in the 2020 Gardline data within the Hudson North and Hudson South Study Areas, these are widely scattered and do not appear to form designated boulder fields. It should therefore be possible to avoid individual sonar contacts when engineering the cable routing, WTG/OSS positions, and foundations of a new OSW development.

Figure 40 below illustrates the different ways in which a cable can be routed to avoid, or minimize contact with, seabed obstructions. The presence of dense boulder fields, rock outcrops, wrecks and areas of harder seabed sediment etc. can all potentially impact the cable routes, causing minor adjustments to route lengths. Options such as surface laying sections of cable and providing subsequent cable protection, can be investigated as potential alternative options in areas where it is not possible to route around such features.

Individual boulders/debris items can also be removed from the seabed in areas where it is not possible to route around these features. Similarly, broader clearance of a route can be undertaken in areas of boulder/debris fields where avoidance is problematic and the abrasion risk to the cable is high. This process is often called a pre-lay grapnel run (Tetra Tech Inc 2020).

A suitable separation distance is calculated when routing around an object. This distance provides adequate separation between the cable and the obstruction(s) in the surrounding seabed to allow for cable repair bights (omega shaped areas of cable repair) and to ensure that surrounding debris does not hinder the burial of the repaired section of cable.

Figure 40. Routing Options for Seabed Obstructions



6.4.4.3 Mounds

In Europe it is common to undertake an environmental and benthic assessment of a development area ahead of any installation. As the OWF market is relatively new, it is not currently clear how potential biological features are treated by environmental authorities in the U.S. Should these mound features, noted in the 2021 Gardline data, occur in a future OSW development site, they should be reviewed by the appropriate environmental regulatory authority as they may trigger the need for specific environmental permitting requirements when development occurs near these locations.

The presence of mounds therefore has the potential to impact individual WTG and cable route positions within an OSW development; however, these can be routed around in a similar fashion to seabed obstructions indicated above.

6.4.4.4 Shallow Gas

Shallow gas deposits have been noted in Pleistocene channels of the pilot areas. These may indicate the presence of organic matter and biogenic gas in deeper sediments. Areas of shallow gas deposits should be considered in cable routing design. However, the deeper deposits noted in the pilot areas are considered more of a risk to wind turbine generator and OSS foundations. Therefore, it is recommended that this is investigated, and engineered for, by the foundation design engineers for any wind turbine generators sited in future OSW developments in the pilot areas.

6.4.4.5 Buried Channels and Hard Ground

The presence of burial channels should be considered in route engineering practices and channel infill deposits can often be softer than surrounding sediments. If undetected, these sediments can destabilize the burial tool, causing it to sink into the sediments.

Knowing the lateral and vertical extents of channel deposits, and the geotechnical properties of these deposits in relation to the surrounding seabed, allows an assessment of whether the planned burial tool is suitable or whether another tool may be considered more appropriate for the task.

Buried channels have been noted in the Pleistocene sediments within the Hudson North and South Study Areas. The depth of these channels is more likely a consideration for wind turbine generators than for general cable design. Therefore, this should be assessed in the foundation design for structures within the windfarm.

Similarly, the top of coastal plain deposits (hard buried ground) was noted to be 8–8.5 m below seabed in the Hudson South Study Area. These could also have an impact on foundation design and therefore should be assessed by a specialist.

6.4.5 Currents

In general, currents across the pilot project sites have a low-average velocity with an overall direction of flow to the southwest. Wind and wave driven currents will produce high variability in strength and direction over short periods of time, particularly affecting surface currents. However, these are not considered a significant risk to cable burial design.

These low currents should present no significant issue to cable burial tools in an open seabed or the construction of WTG and OSS's. Localized changes to current patterns should, however, be considered when the wind farm installation is completed. The presence of wind turbine generators on the seabed can amplify local currents, causing localized eddy effects, and areas of localized scour downstream of the prevalent current direction.

Based on the FVCOM current data, no specific engineering practices are required within the pilot areas for IAC routing, given the anticipated current conditions noted. Site specific measures may be required around WTG/OSS foundations, but these can only be engineered after the risk of scour has been assessed, and foundation bases and cable protection systems (CPS) have been designed.

6.4.6 Wrecks and UXO

There are 8 wrecks charted in the Hudson North and Hudson South Pilot Areas, although the position of these have not been verified using the higher resolution geophysical survey data acquired in the area (Alpine 2017; Gardline 2020) due to the coarse line spacing utilized on each survey.

Cable route engineering practices for areas of wrecks and UXO are very similar to those of seabed obstructions. Areas containing wrecks should be avoided as far as possible through micro-routing as they pose a risk to the cable from reduced burial, and increased abrasion. Some wrecks are of archeological and ecological importance and designated exclusion zones for cables may be declared around them.

A total of four items of UXO were charted within the pilot areas. Although limited, the presence of these items of charted UXO may indicate the requirement for a site specific UXO survey prior to windfarm or cable installation. This survey should be designed in accordance with advice from a specialist contractor, who will assess the risk from the likelihood of the UXO threat item buried to a specified depth. The survey line spacing and system configurations will be designed to detect potential items of UXO which meet this risk criteria.

Areas of UXO should be avoided as far as possible, as they can pose a risk to life, operations, and burial equipment. As indicated above, UXO consultants should be employed to assess the risk of these items of ordnance/potential ordnance, and an appropriate exclusion zone should be honored. There may be some limited cases where avoidance of UXO cannot be undertaken. Specialist contractors should be employed to assess and advise on the potential for surface laying cable within an exclusion zone away from the main item of ordnance/potential ordnance. In some cases, the specialist may advise removal of the item from the area by extraction or diffusion.

It is usual for specific UXO-based risk assessments to be undertaken for all activities required on an OWF development when there is a potential for UXO. Risk levels must be As Low and Reasonably Practicable (ALARP) before cable installation activities take place. Recognition of this is normally marked by the issue of ALARP certification by a UXO specialist consultant for the IAC routes after any UXO survey and avoidance has been achieved.

6.4.7 Seabed Infrastructure

There are several telecommunication cables in the New York Bight, with 1,408 km of them passing through the pilot projects sites. This section describes the engineering practices used to ensure cables do not detrimentally affect each other, in terms of their proximity, interaction, and condition. Cable route engineering methodologies are described below to reduce the potential for interaction with mobile bottom tending fishing gear.

The presence of existing telecommunication cables offers an opportunity when considering the OWF layout design discussed in chapter 3. Minimizing cable crossings is often a primary aim when designing new cable routes and sufficient space needs to be left between cables for maintenance operations on existing third-party cables (Red Penguin Associates Ltd 2012). Existing cable routes often form de-facto corridors through an OWF array, and this can provide a preferred access point or transit route for other mariners, including fishing boats.

6.4.7.1 Cable Recovery

Some out of service (OOS) cables are actively removed from the seabed to recycle their materials, causing the status and presence of cables to change over time (Mertech Marine 2022). Nineteen of the cables in the pilot project areas are believed to be OOS at this time. The most common way these are dealt with is to remove a section of the existing cable before the new IAC is installed.

International Cable Protection Committee (ICPC) Recommendation No. 1 (ICPC 2020a) states that where a new cable crosses an OOS cable in the area where burial is planned for the new cable, the OOS cable may be recovered so that the new cable can be buried without obstruction. In this instance, a short section of the OOS cable is cleared during a route clearance operation. This allows sufficient space for a cable burial tool to pass and bury the new cable at that point and achieve uninterrupted cable burial, which is beneficial to the cable owner and other marine stakeholders including the fishing industry.

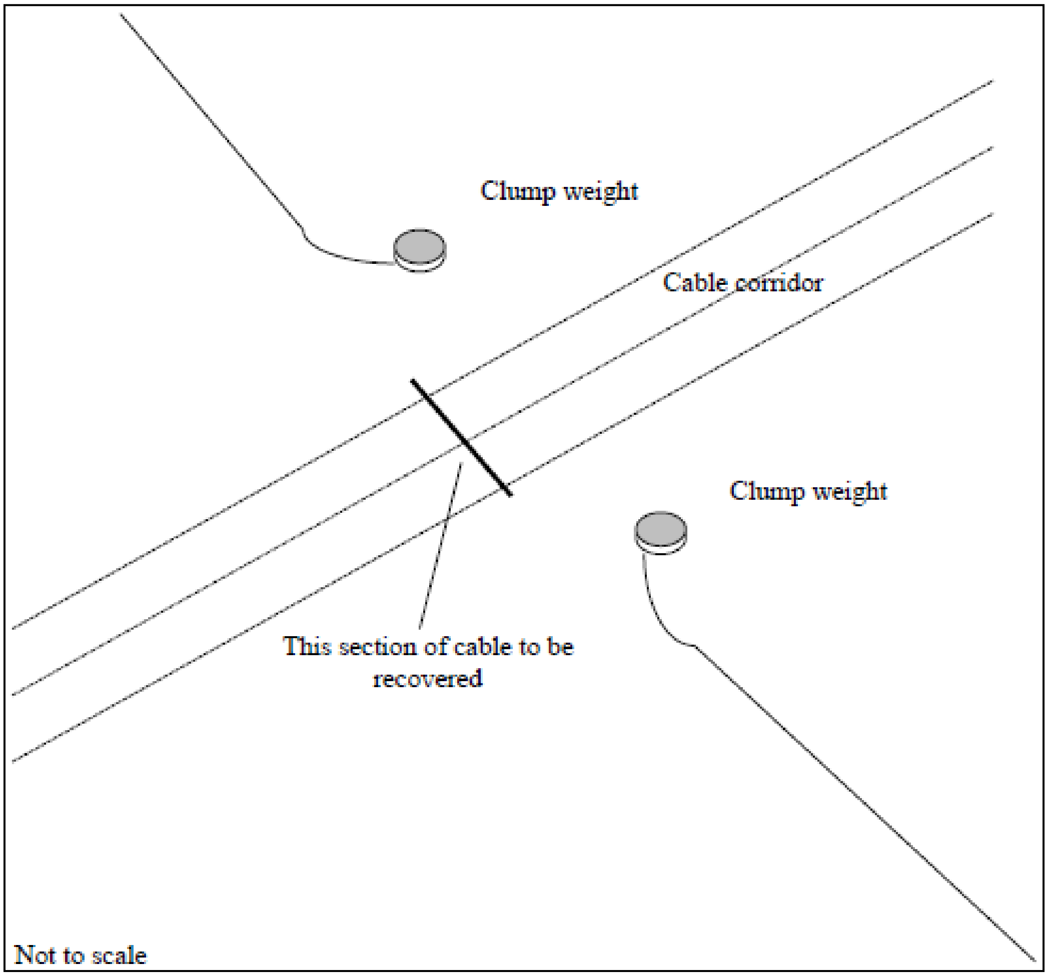
If possible, recovery operations should aim to leave the remaining section of the OOS cable in no worse condition than it was prior to the recovery, thus minimizing future interference to other seabed users including fishermen. One common method to achieve this is to weight the cut ends of the cable with chains or clump weights and lower them via slip ropes to the seabed while maintaining tension on the cable (Figure 41). This helps to reduce the risk of snagging with fishing gear.

It should be emphasized that while this is considered to be best industry practice, liaison with the OOS cable owner and the fishing community as part of the marine stakeholder engagement is recommended to ensure that this approach to clearance of OOS cables is mutually acceptable.

If an OOS cable is no longer in use, any liabilities for this cable will remain with the owner. Therefore, any change to an OOS cable condition, such as burial, location, or additional materials, from the installation of a new subsea cable is still something existing cable owners may have a legitimate concern with regards to their liabilities.

Figure 41. Treatment of OOS Cable Ends During Cable Recovery Operations

Source: ICPC



6.4.7.2 Cable Crossings

There are currently 14 in service telecommunication cables within the pilot project sites. Where future OWF development layouts and string configurations require IAC routes to cross existing cables, they need to be engineered to minimize the effects their proximity and interaction can have on each other and their physical condition.

It is expected that, new cables beyond those identified in the report will inevitably be installed for telecommunication and power transmission purposes within the project area.

ICPC recommendation No 2. “Recommended Routing and Reporting Criteria for Cables in Proximity to Others” (ICPC 2020b) covers many aspects of cable route engineering best practices, which has been developed and updated by international cable owners and installation contractors over many decades. Another ICPC recommendation which is helpful when designing crossings is ICPC recommendation No 3. “Criteria to be Applied to Proposed Crossings of Submarine Cables and/or Pipelines” (ICPC 2014).

Many topics are covered by these ICPC recommendations, but the main ones of interest are:

- Apply the preferred crossing angle at crossing points (90°). This ensures operational and maintenance activities are not compromised by either party. In the case of a power cable crossing, 90° is the best angle to minimize induced currents through the power cable’s EMF.
- Ensure the compatibility of types of cable armor wires and outer coverings and the risks from abrasion.
- Determine appropriate setback distances of crossings points from key telecommunication cable plant such as repeaters and branching units.
- Utilize closest parallel route separation distances so that operational and maintenance activities are not compromised by either party—ideally three times water depth.

None of these recommendations have a direct impact on fishing activities, but they are the route engineering factors which will influence route design around third-party cables which could impact fishing if the installation of new cables create risks that were previously not present.

At the crossing, the new cable is unlikely to maintain its target burial depth as the existing cable is likely to be at or near the same depth. It is common for power cable owners to require physical separation from cables crossing their cables to prevent any interaction, as well as damage through abrasion of one cable on the other. For this reason, additional cable protection is common at power cable crossings.

The key to minimizing the quantity of additional protection materials at a crossing is to have a good understanding of the seabed levels, seabed geotechnical properties and existing burial depth of the existing cable. This is crucial if the objective is also to limit the risk posed by the additional protection measures to mobile bottom tending fishing gear. Therefore, it is recommended that depth of burial surveys are carried out over existing cables as part of the OWF developer’s preconstruction marine surveys to verify the depth of existing cable burial, the local seabed surface and seabed conditions.

It may be possible to achieve reduced cable burial for the IAC over the existing cable while maintaining separation if the existing cable is buried deeply enough. This requires the existing cable owner to agree to a burial operation (most likely by jet trenching) to be carried out over their cable asset. Should this be a feasible and acceptable methodology to both parties, it could result in the fewest additional cable protection requirements.

In other crossing scenarios a combination of poly duct, rock and grout bags, loose rock berms, and concrete mattresses may form part of a crossing design. These materials are described with example figures provided below.

A more typical crossing design uses a foundation layer laid over the existing cable on the seabed, with the IAC laid over this, covered by a poly duct and a further top layer laid over the top. Both the foundation and top layers can be concrete mattresses or loose rock (Tetra Tech Inc 2020).

As well as the ICPC design recommendations mentioned, the concept of mutualized cable crossings can offer several advantages to the fishing industry, developers, and the existing asset owner.

Mutualized crossings are defined as the grouping of several crossing points so that the crossings are effectively located at one position. A depiction of how some theoretical IACs make direct crossings over in service third-party cables within an array are shown in Figure 42. A mutualized crossing design groups the crossing points so that the cables cross in very close proximity to each other while retaining a minimum separation distance, as agreed by the OWF developer and installer. A conceptual design for mutual crossings is shown in Figure 43. The position of the mutual crossing points is flexible and should be influenced by OWF layout, orientation to the third-party cable and micro routing considerations.

Figure 42. Direct OWF Array Crossings Over a Third-Party Cable

Source: OceanIQ

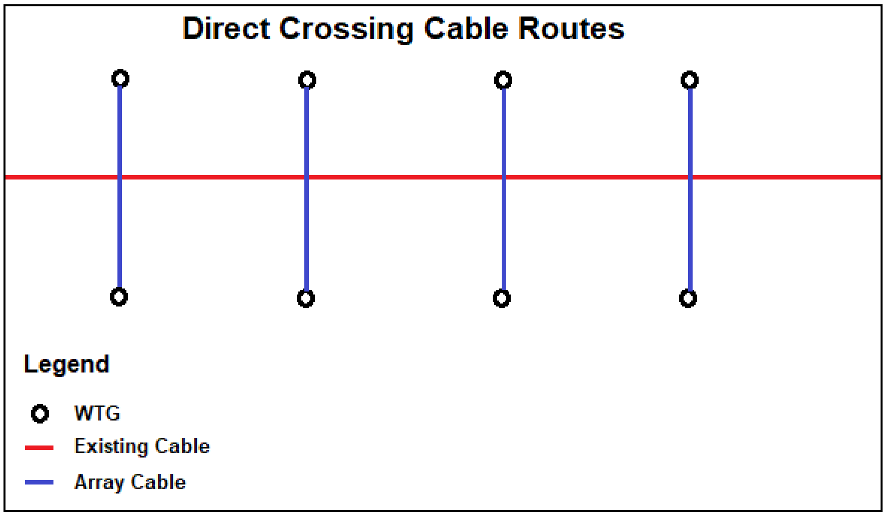
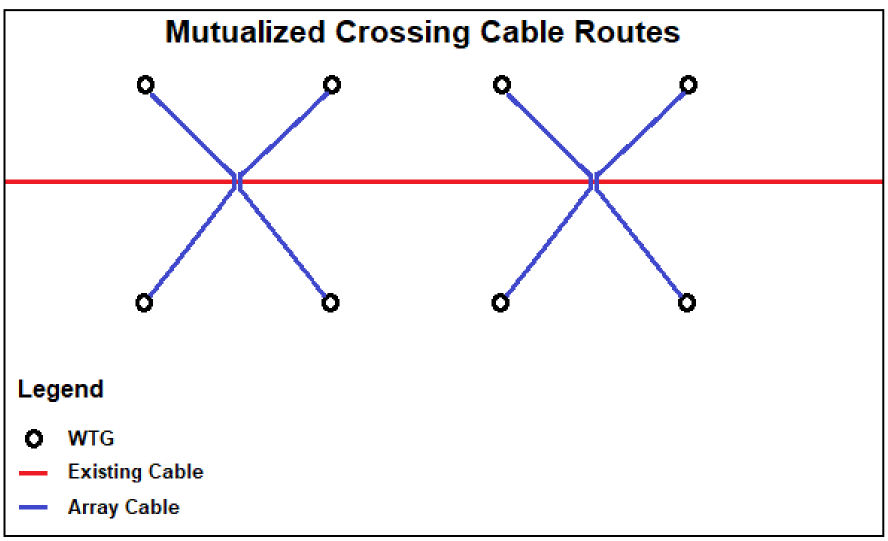


Figure 43. Mutualized OWF Array Crossings over a Third-Party Cable

Source: OceanIQ



The benefits mutualized crossing cable offer are:

- The number of crossing points is reduced resulting in fewer locations with potentially additional cable protection (concrete mattresses, poly duct, rock bags, rock berms).
- A reduction of the overall seabed footprint and quantity of any additional cable protection materials through shared use over one crossing position.
- The existing cable is typically encumbered by less frequent crossings offering better access for cable maintenance and repair.

The main disadvantage is the longer overall cable lengths required to achieve a mutualized design which could raise costs to installers.

6.4.7.3 Cable Proximity

The proximity of IAC's to each other is most likely to be a consideration closer to OSS's where the first IAC's in a string by necessity have to converge on the OSS. In these areas developers favor achieving cable separation as soon as possible to reduce the probability of an accidental dragged anchor or another third-party interacting with multiple cables. This is at odds with fishing aims which are typically to maintain as much open seabed to fishing as possible. In some areas of the world cables are consolidated in corridors or specified areas. Often in order to offset the risks to cables in these zones, marine activities such as anchoring, and seabed contact fishing gears are banned (Australia Communications and Media Authority 2022). Elsewhere in arrays the IAC's are typically well separated by necessity, in order to connect the widely distributed WTG's.

There are practical limitations to cable proximity related to the maintenance and repair of cables and how the cable lies post repair on the seabed. This requires enough seabed space to lay a repair bight. These topics are discussed in detail by the UK Crown Estate's Cable Proximity Study (Red Penguin Associates Ltd 2012) and Export Transmission Cables for Offshore Renewable Installations Report (The Crown Estate 2012). There are also limitations related to the seabed footprint of the burial tool. It is poor practice to allow a burial tool's tracks or skids to ride over adjacent cables while burying them, as this risks damaging the adjacent cables.

6.4.8 Scour

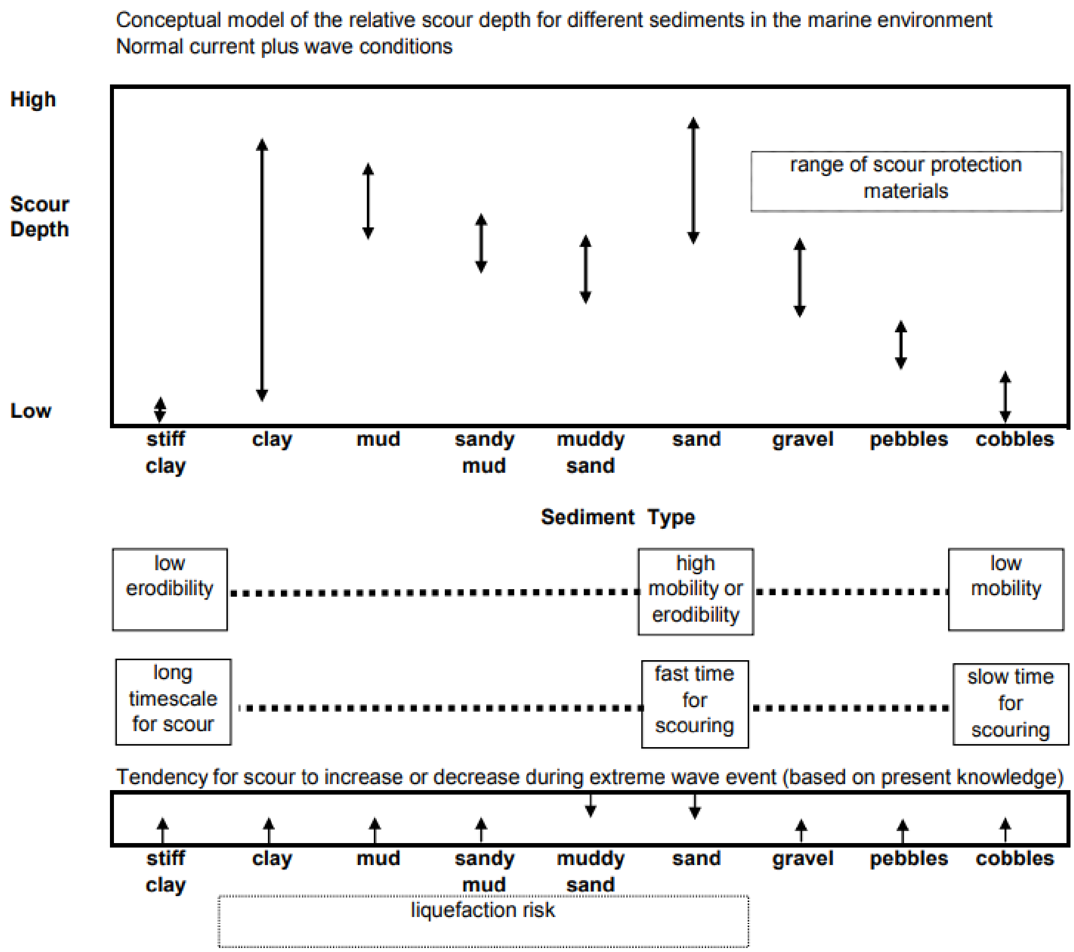
Predicting the location, and effects of scour on offshore windfarms can be complex, especially when mobile seabeds, currents, and wave actions are considered. A realistic prediction can often involve laboratory testing. When a WTG is installed on the seabed, the hydrodynamics of the seabed changes producing an increase in sediment transport and erosion to that localized area. The impact of this may create scouring of the seabed around turbine bases. Despite research over many years, particularly in the offshore oil and gas industry, there is still a high level of uncertainty as to the potential depth of scour in relation to offshore wind turbine foundations and, therefore, uncertainty as to the need for scour protection (Whitehouse et al. 2011).

Scour protection may be required to protect lengths of cable which enter/leave the transition piece of the turbine before they are buried in seabed sediments. Use of scour protection may result in physical impacts on seabed morphology, sediments, fisheries, and navigation (Whitehouse et al. 2011).

Some seabed sediments are more susceptible to scour and for some, the depth of scour will increase with hydraulic forcing associated with storm waves, which may lead to a decrease in scour depth in other sediments (Figure 44). Scour depth in sediments vary in normal wave and current conditions. Clays can have low- to high-scour depths whereas sands can have medium to high depths of scour. Clays take longer to scour whereas sands scour faster if they are more mobile. As indicated in previous sections, significant sediment movement is not anticipated on the pilot areas, unless due to significant storm activity. In such an event, the response of the seabed will depend on the sensitivity of the seabed to increased shearing force on the seabed, and the severity of the event. (Whitehouse et al. 2011). Scour is a progressive process and likely to occur when the seabed is naturally mobile and there is an adequate thickness of sediment for scour to form. Essentially, the long-term variations in currents, waves, and seasonal storm events will control the ways in which scour forms around a structure.

Figure 44. Conceptual Model for Scour Development Around Marine Foundations

Source: modified from Whitehouse (2006)



There are various forms of scour protection which can be used as a remedial measure. These include, but are not limited to, sand/grout/rock bags, concrete mattresses and rock armor placement and are further described below. Rock armor is the most common protection in European windfarms and uses gravel, quarry stone, or blasted rock to cover a particular area of seabed to a specified thickness (Whitehouse et al. 2011).

Rock armor, used as a protection against scouring, is a proven method which has been applied in multiple offshore projects. Once placed, the rock will be able to adapt to changing seabed levels and depressions will be filled in (offshoreWIND.biz 2015). Rock is considered by many as environmentally friendly and having a long lifespan. Scour protection can be extensive with filter layers up to 24 m long and armor layers up to 15–18m long.

Scour protection in the form of sand/grout/rocks can be placed in flexible containers, net bags, or sacks to mold themselves around the base of turbine towers. The sacks can be filled with low-cost heavy materials that withstand erosion and corrosion over the years, although maintenance is often required. The use of chains of mats made from vehicle tires has also been discussed as a long-term stable form of protection at low cost (offshore WIND 2015).

Anti-scour cable protection methods also come in various formats including rock bags, rock placement, concrete mattresses, and cable armoring. These are discussed in below sections. Protection is often required in areas where the risk of damage to the cable is considered too high to be left unprotected. Examples include where seabed cables which have previously been buried and are now exposed, those deliberately laid across the seabed, and those at risk of cable damage or failure from external forces or abrasion.

The impact of scour on the pilot areas is difficult to predict, as the seabed is currently limited in the number of obstacles which may affect the hydrodynamics of the areas. There are charted wrecks within the pilot areas but the survey data obtained does not cover these wrecks and therefore the amount of scour noted around the features cannot be assessed. Limited information obtained from sonar contacts appears to indicate that the minor scour noted around these wrecks is well distributed, rather than noted in isolated areas. Therefore, some scour may be anticipated around the base of the WTGs and OSS within the pilot areas. Modelling with site specific, high-quality metocean data can provide a prediction of the potential for scour ahead of installation and this is normally done as part of the OWF design process.

6.4.9 Inspection Surveys

While integrated geophysical and geotechnical surveys provide data for the development phase of an OWF project, there is a need for continued monitoring to fulfil statutory and maintenance requirements in many European windfarms. It is therefore common for developers and installation contractors to adopt a strategy for inspection surveys upon completion of wind farm installation to fulfill these license conditions or regulatory requirements. However, it is up to the developers or installation contractors to determine if these meet their project needs (Houston 2008).

The objectives of inspection surveys are to assess the condition and burial status of the cables; assess the condition or requirement for any cable protection systems, and to assess the potential of scour impacting the foundation of the WTGs and OSS.

Inspection surveys are generally based on the conditions noted across the wind farm, and the potential impact of scour generally determines the interval between surveys. For example, it is common for seasonal monitoring assessments of European windfarms (summer and winter campaigns) to assess the changes to the seabed for the first three years post installation. Initial scour patterns are likely, simply due to the addition of the WTGs on the seabed; however, should the seabed stabilize out naturally and find equilibrium as anticipated, the monitoring campaign can be reduced to yearly, or even paused indefinitely, with monitoring surveys only undertaken after significant storm activity. In cases where scour patterns are deepening without equilibrium, seasonal monitoring may continue for a further set period to assess the requirements for an additional protection. Inspection surveys can also be focused on site specific areas in cases where issues are considered localized to a certain portion of the wind farm.

Inspection surveys can be undertaken in several ways. Depth of burial of the inter-array and export cables can be assessed using cable tracking equipment or through comparing the differences between the previous bathymetric levels over the cables. The latter is a cheaper way to assess the depth of burial over the cable but can be constrained as the system parameters and navigational accuracies must be the same for each survey.

The OWF market is in an early phase in the U.S. and regulatory requirements for these developments are therefore largely unknown at present. Open communications on the analysis of monitoring surveys can have a positive impact on the fishing community and the coexistence of wind farms and the fishing activities undertaken both in and around them. The analyzed data can be used by fishermen to avoid areas of cable suspensions and scour pits where cables may become exposed, thus reducing the risk to fishing gear, as well as the risk of third-party damage to the cable systems. Monitoring inspection periods could be structured around the results of these inspections and the potential impacts on the fishing community.

6.5 Burial and Protection

6.5.1 Introduction

One of the main topics raised during the information gathering and interviews for this project concerned cable burial and how important it is to the co-existence of fishing and OWFs. Because of this, cable burial conditions across the pilot study areas have been investigated using published information combined with historical data held by OceanIQ.

This part of the report provides insight into historical cable burial records in the area, cable fault causes, and frequency to help understand the existing submarine cable risk profile. Below sections describe burial techniques most commonly used in the industry, which are suitable for the pilot project areas, as well as the burial conditions found across the pilot area.

Additional protection measures can be required for cable crossings and below sections give details on the materials used and a discussion on the impact these have on fishing operations. The report also considers the protection of the turbine foundations and the CPS used to transition from cable burial to the fixed WTG foundation. The measures used in these locations are often linked to seabed scour effects.

6.5.2 Historical Burial and Fault Rates in the Pilot Project Area

There is a rich history of existing telecommunication cables which traverse the pilot project areas in the New York Bight. Telecommunication cables have been laid across the Atlantic to Europe since the 1860's and have gone through several transmission technology changes from the telegraph era, on to coaxial voice lines and in the late 1980's onto the modern FO era. To ensure the historical records used were relevant, only the modern fiber optic cable records were used. These were all buried across the project area, without exception. Unfortunately, not all the burial records for these cables were available. As the burial records for individual cables can be commercially sensitive, the burial statistics do not name individual cables or present positions of burial data points geographically to anonymize the data.

Table 20 shows a list of the fiber optic cables crossing the pilot project areas and whether burial data was available. As many of these cables were not installed by Global Marine Group many burial depth records were not available. Several of these cables are no longer in service, as described in previous sections.

Table 20. Fiber Optic Cables Crossing the Pilot Project Areas (In and Out of Service)

Cable Name	Installation Year	Burial Data Available	Pilot Area Crossed
Globenet Seg 5	2012	Y	Hudson South
TAT 8 Seg D1	1988	N	Hudson South
TAT 14 Seg G	2000	Y	Hudson South
TAT 11 Seg D1	1993	N	Hudson South
TAT 9 Seg F2	1991	N	Hudson South
SEABRAS-1	2017	N	Hudson South
Apollo South	2002	N	Hudson South
Tata (VSNL) Atl South	2001	N	Hudson South
Gemini Bermuda	1997/2007*	N	Hudson South
PTAT Seg E1	1985	Y	Hudson South
CANUS 1	1995	N	Hudson South
TAT 14 Seg K	2000	Y	Hudson North
CANUS 1	1995	N	Hudson North
Tata (VSNL) Atl North	2001	N	Hudson North
Havfrue Seg 1	2020	N	Hudson North
Flag Atl South	2000	Y	Hudson North
TAT 12/13 Seg F/G	1995	N	Hudson North
AC-1 Seg C	1998	N	Hudson North
Apollo North	2002	N	Hudson North
MAC Seg 1	1995	Y	Hudson North
Yellow	1996	Y	Hudson North
Grace Hopper Seg 1	2022	N	Hudson North

* Gemini Bermuda was installed in 1997, recovered and re-laid in 2007. The section crossing Hudson South is the original 1997 cable.

The cables listed in Table 20 were installed between 1985 and 2022 across a 37-year period. Burial depths have been recorded at 54 positions, along seven cables across, or within close proximity to the pilot project areas. These are relatively evenly split across Hudson North and Hudson South. Some basic statistics for these burial data are provided in Table 21.

Table 21. Fiber Optic Cable Burial Data Statistics

Fiber Optic Cable Burial Data Statistics		
Number Cables with Data Available	7	
Number of Burial Records	54	
Mean Burial Depth	0.944 m	3.098 ft
Maximum Burial Depth	1.360 m	4.462 ft
Minimum Burial Depth	0.570 m	1.870 ft
Median Burial Depth	0.976 m	3.202 ft

The historical burial depths achieved do not represent the maximum depth achievable at each location and would have been influenced by the burial tool selection at the time of the installation and the target burial depth for each project. Where data at some cable crossing locations were available, the burial depth was much reduced for cables crossings. These records were omitted in the statistical analysis as they are caused by the physical obstruction of the cable being crossed and not the geological conditions found across the sites or the capabilities of the burial tools.

The historical burial data shows cable burial was consistently achieved with an average depth of approximately 1 m (3 ft). By far the most prevalent burial tool used for telecommunication cables on such projects is a simultaneous lay and bury cable plow. Experience, verified by a NASCA publication in 2019 (NASCA 2019), indicates these projects are likely to have targeted burial depths ranging from 0.6 m (2 ft) to 2.0 m (6.5 ft) at the time of their installations. Earlier cables having shallower depths and later cables having greater depths, reflecting the development of plow technology, more powerful installation vessels to tow the plows, along with a desire to improve the burial depths. In some areas where plowing was not possible, such as very close to a crossing, the burial is most likely to have been carried out by a jetting ROV solution carrying out post-lay burial. The burial data records utilized all come from earlier (pre-2002) cable systems. After the “dot com” bubble burst in 2002 there was a hiatus in the construction of telecommunication cables across the Atlantic and there are four cables that have been installed since 2012. The burial depths achieved for these cables are likely to be greater than those currently recorded, due to the improved capabilities of the plow and vessel combinations used.

Cable faults occur for many reasons. Globally the two most prevalent causes not related to cable and plant (repeaters, joints, branching units etc.) are from fishing snags and anchor strikes. OceanIQ, part of the Global Marine Group, has been involved in the maintenance of cables in the Atlantic continually for over 30 years. They maintain a global cable fault database (GeoCable™), which currently has over 6200 faults dating from 1959 to the current day (2022). AIS data is also utilized to track repair operations by OceanIQ on vessels globally. The faults within the database include both telecommunication cables (98.5%) and power cables (1.5%). There are no historical cable faults within the pilot areas within the database, despite the cables listed in Table 20 comprising a total of 727.6 km of fiber optic cable laying across the pilot study sites. This equates to 0.127 km of cable per km^2 in the pilot project area. The global average for fiber optic cables is 0.004 km of cable per $km,^2$ based on 1.6 M km of fiber optic cables across a global ocean area of 361 $km.^2$ This implies that the pilot areas have a higher-than-average density of cables while having a low fault rate.

This evidence certainly points to the mean burial depth to 1 m (3.2 ft) seen on telecommunication cables across the sites contributing significantly to the security of these cables. Recommended static cable design guidance indicates that all static cables should be buried to a minimum depth of 6 ft below the seabed where technically possible (BOEM 2022b). This would enhance the security of cables in this area even further.

IACs normally connect WTGs in a series of strings—several WTGs connected in series back to the OSS. From the OSS power is transmitted to shore by one or more export cables. The effect of a cable fault on the power production of an OWF is therefore linked to where in the layout the fault lies. A fault in the last IAC at the end of a string, only impacts one WTG, whereas a fault in the first IAC connecting to the OSS will disrupt transmission from the number of WTGs that are linked by that string (typically 5–8). The worst location for a cable fault to occur is one affecting an export cable where a significant percentage, or the entirety of the OWF's power production may be affected.

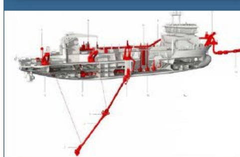
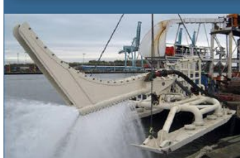
6.5.3 Cable Burial Techniques

NYSERDA's Offshore Wind Submarine Cabling Overview in October 2020 (Tetra Tech Inc.,2020) describes in detail various cable burial techniques used by the cable installation industry and in many cases provides the names of some specific burial tools used by submarine cable installation contractors.

To understand the factors which may determine cable burial in the pilot areas a summary of the techniques and their appropriateness to IAC burial, as well as those less suited to the conditions in the area are discussed below.

As an introduction, Table 22 is a comparison table of burial tools used in the industry (NYSERDA 2020). There are essentially three main methods for installing submarine cables and burying them. The first method is to prepare a cable trench before laying the cable, termed pre-lay burial. The cable is laid into the new trench and afterwards any backfill is performed, as required. The second method is to open a trench at the same time as laying the cable, the cable passes into the trench through the burial tool. Any sediment cover re-consolidates over the top of the cable. This is termed simultaneous lay and burial. The third method is to lay the cable onto the seabed and then perform a separate cable burial exercise with a burial tool. This is called post-lay burial. All these terms are identified alongside each tool in Table 22.

Table 22. Cable Burial Tool Comparison

TOOL TYPE		BURIAL METHODOLOGY	SOIL TYPE	BURIAL DEPTH
	Pre-lay plow	Pre-lay burial/ route and boulder clearance	Can create a trench in soils up to stiff/hard clays	Commonly 1.0 m to 1.7 m depending upon soil type
	Mass flow excavator	Pre- or post-lay burial/de-burial	Various, up to 200 kPa if configured for cutting, 80 kPa as standard	Up to 5.0 m or so is possible depending upon soil types, 2.0 m commonly achieved
	Dredging (TSHD)	Pre-lay burial	Various	Varies depending upon the number of passes etc. *(but up to 5.0 m is achievable but with a wide trench and a large volume of removed material)*
	Injector tool	Simultaneous lay and burial	Various but works well for deep burial in soft soils in shallow water	Up to 10.0 m
	Jetting sled	Simultaneous lay and burial	Cohesive soils up to approximately 100 kPa, sands, silts gravels to approximately 30mm diameter	Commonly up to 2.0 m or 3.0 m (tool specific), a few very large machines can achieve 5.0 m or more
	Cable plow	Simultaneous lay and burial	Soils from approximately 5 kPa through 350 kPa	Up to 3.0 m
	Tracked trencher	Simultaneous or post-lay burial	Cohesive sands up to 100 kPa in jetting mode, soft rock etc up to 600 kPa in chain cutting mode	Tool dependent, up to 3.0 m for jetting, 2.0 m for cutting quite common but ranges up to 5.0 m
	ROV	Post-lay burial	Cohesive soils up to approximately 100 kPa, sands, silts gravels to approximately 30 mm diameter or less	Up to 3.0 m

Of the tools shown in Table 22, it is unlikely that a cable plow or jetting sled would be utilized for the IACs as the distances involved are uneconomic for plow launch and recoveries. There are also significant practical complications in IAC routes when the plow or jet sled vessels must lie a considerable distance ahead of the plow/sled in line with the WTG foundation. All the other tools are feasible options although some are quite specialized and tend to be used in specific situations.

Tracked trenchers, or ROVs working in post-lay burial mode, are the most common cable burial tools for IACs. The seabed within the pilot areas is predominantly sandy, with no slopes expected to exceed the practical limits of tracked trenchers or ROVs. Historical evidence also indicates that burial depths of one to two meters (3.2-6.5 ft) should provide good levels of cable protection and therefore tracked trenchers or ROVs are anticipated to be the most likely tools utilized across OWF's in the pilot study areas.

6.5.4 Cable Burial Conditions

Summarizing the more detailed discussion of the shallow seabed sediment conditions described in previous sections—Hudson North and Hudson South pilot sites are similar with a predominantly sandy seabed featuring localized areas where the sands become gravelly sands and separate localized areas with higher proportions of mud.

The thicknesses of these Holocene Sands vary across the sites and due to the limitations in the 2020 Gardline geophysical data coverage the entire picture across the sites is unknown. Where data is present the minimum thickness of Holocene sands tends to be 1 m and increases in localized areas to a maximum of 17 m (56 ft) in Hudson South and 7 m (23 ft) in Hudson North.

This means that the minimum sand thickness lies within or exceeds the cable burial depth band suggested by NASCA (NASCA 2019), as being successful in protecting telecommunications cables, this being 0.6m (2ft) to 2.0m (6.5ft).

There is a lack of geotechnical seabed strength samples for the pilot project areas and this has meant that it is not possible to comment on the performance of potential burial tools in those soils; however, as described above, historical telecommunication cable burial (mostly by plows) show burial to depths between 0.570 m (1.9 ft) and 1.360 m (4.5 ft) and newer, more powerful advancements mean that deeper burial depths may be achieved.

The seabed characteristics which may affect the success of cable burial found by this study, listed by importance are:

1. Boulders—widely distributed but sparsely and not in densities that prevent detailed route engineering (micro routing) from avoiding them locally.
2. Gravel Sediments—there are some small areas where the gravel fraction in the shallow soils are much higher, particular some parts of the north of Hudson South. This may impede cable burial by water jetting due to difficult in fluidizing gravelly seabeds and swift reconsolidation of the trench profile before the cable has reached its full lowering potential in the trench.
3. Existing Cable Infrastructure—According to the NOAA charted cable database there are 1221.854 km of telecommunications cables, both in and out of service across the sites and 1407.953 km according to the OiQ cable database. Out of service cables are commonly cleared before new cables are laid so may but less problematic, but in service cables will prevent full burial being achieved by the new cable at the crossing locations.
4. UXO—only four charted areas so not widespread. Typically, as new OWF developments proceed a dedicated UXO hazard and risk study will be undertaken by a specialist consultancy and the potential and types of UXO will be assessed in detail.
5. Seabed Slopes—the slope maximum value found across the sites is 8° and this is within the stability parameters of modern cable burial tools.

Successful cable burial relies on selecting the best burial tool for the seabed sediment conditions and this relies on a thorough understanding of the seabed's physical properties to a depth at least equal to the target burial depth. There is a direct relationship between the seabed's geotechnical properties such as hardness, represented by shear strengths and relative densities, and the depth to which a burial tool can achieve. Therefore, a detailed geotechnical marine survey campaign is necessary during the preconstruction phase of an OWF.

These same seabed geotechnical properties will determine the achievable burial speeds, how many burial passes are needed, and the optimum burial tool setups (such as pump pressures, nozzle configurations, jetting sword lengths, etc.).

The purpose of cable burial is to prevent any interaction with the cable from human activities offshore and therefore protect the cable from damage. If the seabed is hard, cable burial can be challenging. Alternatively, if the seabed is soft then burial is easy to achieve. Logically it is also likely the penetration of any equipment from human activities offshore will be similarly affected. Therefore, target burial depths can vary across a site as conditions change. The most common way in which a target burial depth is determined for OSW developments is to undertake a cable burial risk assessment (CBRA). A CBRA will assess the risks to cables in the proposed development area. The Carbon Trust CBRA guidance offers a standardized, repeatable, and qualitative method to improve risk management of subsea cables for OWFs, improve conservative estimates of residual risk, and ultimately reduce the installation and insurance costs for subsea cables.

Mobile bottom-tending gear fishing is at high risk of interaction with cables, if the burial depth is less than the penetration depth of the gear being used. The fishing industry has requested cable burial depths of greater than 6 ft for the scallop fishery and greater than 8 ft for the surfclam/ocean quahog fisheries, which may be deeper than current plans outline.

Scallop dredge gear have penetration depths of 1–15cm (0.4–6 inches) in sand and 1–35cm (0.4–14 inches) in mud (Eigaard 2016) and (Paschen 2000). Hydraulic Dredges used for Atlantic sSurfclam and ocean quahog fishing have penetration depths of 5–40cm (2–16 inches) (Szostek 2017). While these penetration depths alone may not warrant a burial depth of 6 to 8 ft, it is prudent to make an allowance for changes in burial depth over the lifetime of the cables through sediment mobility and scouring affects.

BOEM has recommended cable burial plans to be developed on a case-by-case basis to account for local conditions and to include local fishermen's knowledge to reduce conflicts (BOEM 2014) and more recently recommended cable burial of at least 6 ft where feasible to further reduce conflicts (BOEM 2022b). Fishing vessels may not be able to operate over cables within offshore wind areas if cables are not sufficiently buried because of increased risk of snagging a cable (physical risk) and/or changes in insurance premiums and policies (financial risk).

6.5.5 Additional Cable Protection

Cable burial is the most efficient and cost-effective method of cable protection. However, there are situations when burial to the depth required to protect the cable is not always possible. Some of these situations will occur on the pilot project areas:

- If shallow soil conditions are too challenging for the burial tools selected.
- Should further detailed marine surveys reveal steeper sustained slopes than those found from the data sets reviewed by this report.
- Crossings of other submarine cables.
- Proximity to other seabed structures such as WTG and OSS foundations and the interface with them (J-Tubes or CPS latching apertures).

In the above situations, it is likely that cable protection methods other than burial will be considered. If possible, areas of challenging seabed conditions will be avoided during the cable route planning process, but it is not always possible to do this especially when those seabed conditions are adjacent to the WTGs or OSS positions and form fixed constraints for cable routing.

In those circumstances additional protection materials are often used and the most common types are described in the following text. It is worth noting that recommended static cable design guidance indicates that Lessees should avoid installation techniques that raise the profile of the seabed, such as the ejection of large, previously buried rocks or boulders onto the surface as the ejection of this material may damage fishing gear. The guidance further states that if needed, cable protection measures should reflect the pre-existing conditions at the site. Cable protection measures should be trawl-friendly with tapered or sloped edges (BOEM 2022b).

Concrete mattresses come in different sizes, can be articulated in both directions or just one, and some have features such as fronding (to help retain sediments), or tapered outer edges (to help prevent fishing gear snagging in heavily fished areas). Figure 45 shows an example of some concrete mattresses. These are used to protect cables at the surface when they have little or no burial into the seabed, such as at cable crossing locations. The standard size of a concrete mattress is 6 m x 3 m (19.7 ft x 9.8 ft) with variable thicknesses up to 0.45m (1.5 ft). Further assessment of the risk from scallop/surfclam/ocean quahog gear is suggested as an area of further study to reduce the risk of damage to the cable protection and fishing gear.

Figure 45. Concrete Mattresses with Tapered Edges

Source:SPS

Rock bags come in differing weights and sizes. The advantage of using poly mesh bags allows the bag to be precision-deployed and, if needed, can be recovered later. These can be used to fill in seabed scour around OWF foundations or as cable protection as an alternative to concrete mattresses.

Figure 46. Rock Bag Being Deployed

Source: Pipeshield

Loose rock placement can be achieved using a flexible fall pipe to deliver rock to the seabed in a controlled manner. The rock cannot be removed as easily after deployment but is more efficient for larger areas than numerous rock bags. Rock berms with tapered gradients can be made so that they are trawlable, but this can extend the volume and area of rock required. Rock placement in this manner is the most common method of scour protection around OWF foundations.

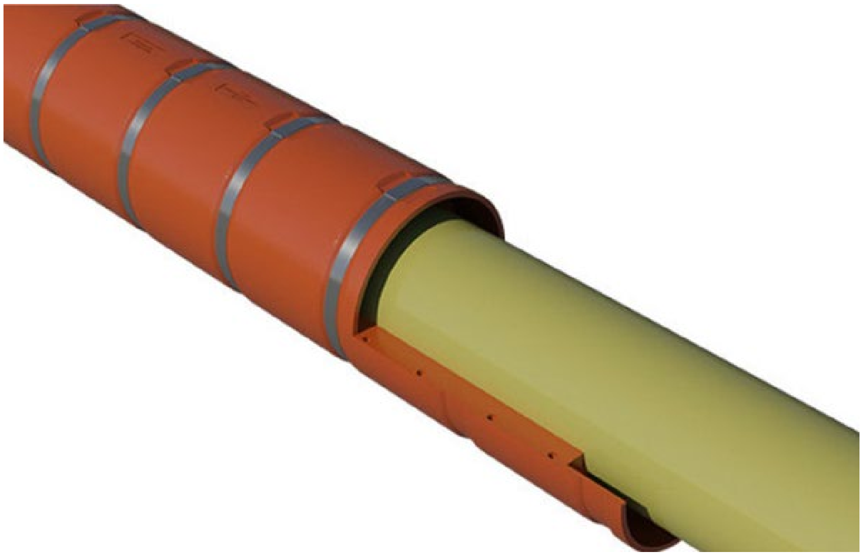
Figure 47. Flexible Fall Pipe Vessel Placing Wind Turbine Generator Scour Protection

Source: Jan de Nul

There are several poly duct cable protection systems on the market. These typically use half shells of polyurethane and metal banding to add a layer of abrasion resistance and impact resistance to protect cables which are in contact with rock or concrete mattresses. These poly duct systems are applied to the cable before deployment from a cabling ship. As the pilot site does not feature any known bedrock areas it is unlikely that they would be used at locations other than at cable crossings.

Figure 48. Power Cable Poly Duct

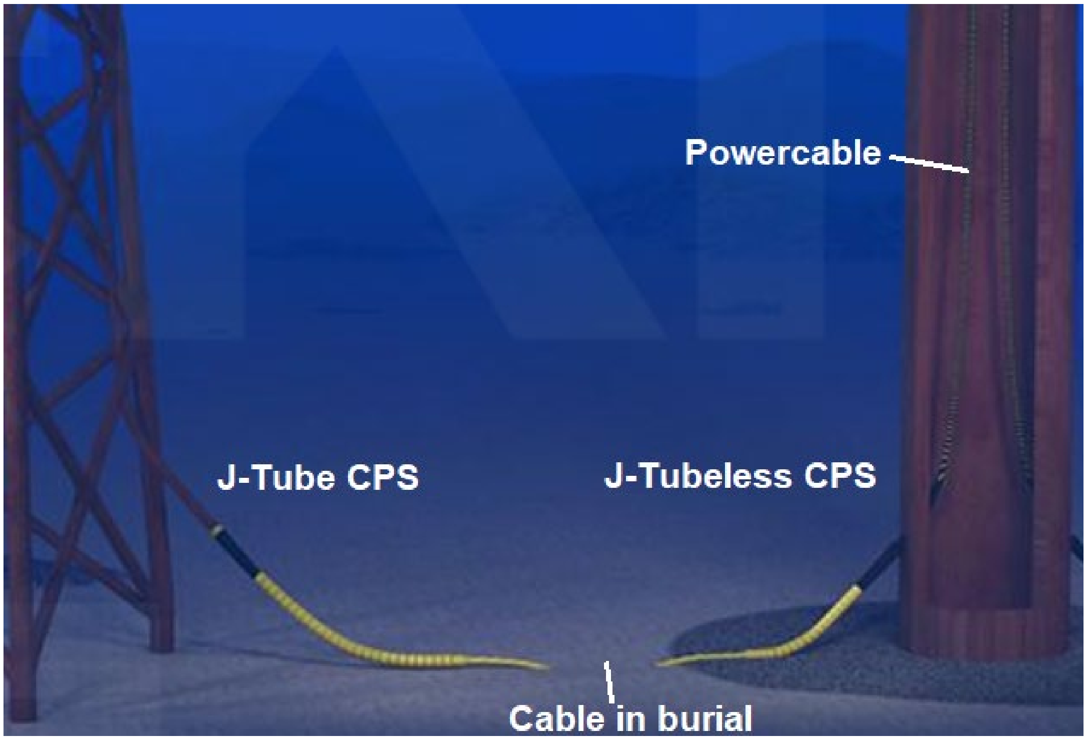
Source: CRP Group



Similar to the poly duct, specialized Cable Protection Systems (CPS) have been designed that protect and secure the cable in the transition from cable burial until the cable is within the WTG or OSS foundation. They can connect to either a J-Tube duct or directly through a piled foundation using a latching mechanism and a J-tubeless solution. CPS design has gone through a considerable amount of evolution as European OWF's have developed. Some CPS designs have been implicated in cable failures (Durakovic 2021)

Figure 49. Cable Protection Systems

Source: Tekmar



Articulated metal piping can be added to the cable to provide additional ballast and a higher level of cable protection using ductile or cast-iron half shells which link together. The application can be limited by water depths because of the considerable additional forces placed on the cable from the products weight which limits the deployable depths. However, they are feasible in the water depths found across the pilot project sites.

Figure 50. Articulated Metal Pipe

Source: Protectorshell

All these materials are used primarily where the cable is at the seabed surface and will represent a snagging hazard to fishing gear. Their requirement is driven therefore by the burial conditions and as described in previous sections. The burial potential across both Hudson North and South appears to be good based on historical burial records, so these methods are not expected to be used extensively across the sites. Regardless of general cable burial conditions, some of these materials will be required at foundations and cable crossings.

6.6 Discussion

This project task investigated the seabed characteristics found across the Hudson North and Hudson South BOEM OSW call areas in the New York Bight. The characteristics presented are those with the greatest potential to influence the turbine siting, layout, and power cable engineering required.

Having assessed the characteristics, a series of engineering practices were presented which could be used to ensure future developments are successful in producing reliable electricity over their design life while trying to limit the impact on scallop and SC/OQ fishing. These are also likely to be the engineering practices used for other bottom tending gear fisheries; however, further evaluation would be necessary to ensure these findings hold true for those additional fisheries.

The work undertaken mostly used publicly available data, supplemented by some analysis of cable information held with OceanIQ's GeoCable™ database, and global cable faults databases on historical cables in the pilot project areas.

An important source of information were the geophysical seabed data sets (NCEI, Alpine 2017 and Gardline 2020). The Alpine 2017 multibeam bathymetry data was utilized in the publicly available 4 m (132 ft) gridded format via the BOEM/NOAA Marine Cadastre web portal. Future OSW developers may benefit from undertaking further analysis using the full resolution (1 m/3.2 ft gridded) bathymetry data. NYSERDA holds copies of this data.

The lack of any shallow geotechnical sampling data across the pilot project sites has limited the predications for cable burial and progress speed.

The main risks to OWF cable infrastructure and the scallop and SC/OQ fishing activities have been summarized with two risk tables. These present the perceived risks, the engineering practices to reduce the risk level, and some comments on the conditions related to each risk found in the pilot project area. See the following for details.

Table 23. Risks to Cables in the Pilot Project Areas

Description of Risk	Engineering Practices to Reduce Risk Level	Comments on Pilot Project Area Environment
Mobile bottom tending gear snagging cables at cable crossings.	Ensure the crossing design considers mobile bottom tending gear activity and uses materials which minimize the chances of snagging fishing gear. Determine the existing crossed cable depth so that if practical the IAC can be buried over the top. Reduce the number of crossings by using the mutualized crossing point concept. Reduce the number of crossings by using appropriate windfarm layout identified strategies. Reduce the number of crossings by clearing OOS cables before the new IAC is installed. Undertake periodic inspection surveys to monitor cable crossing condition and publish to marine stakeholders.	The pilot project area does feature an extensive number and length of existing telecommunication cables and 14 of these are believed to be in service at this time. The probability that OWF's IACs will require cable crossings is high.
Mobile bottom tending gear snagging on exposed cables due to seabed scour.	Obtain data on the local metocean and seabed sediment environment and carry out detailed seabed mobility and scour prediction studies to inform good scour protection engineering. Undertake periodic inspection surveys to monitor scour conditions and publish to marine stakeholders.	Minor seabed scour has been visually identified at between 8 and 11% of the seabed boulders and debris found by the Gardline 2020 survey data. While this does not cover all the pilot sites the shallow soil and seabed current environment is very similar across all the sites. The depth of scour found around the sonar contacts reached a maximum of 3 ft (1 m).
Mobile bottom tending gear snagging on CPS.	CPS design not to extend further than necessary beyond any scour protection and transition to buried cable at earliest opportunity. Investigate latest developments in cable connection technology and ensure CPS system is appropriate to the site conditions.	The information by the study used has not provided an indication on the type and design suited to the pilot sites and will be determined by the developers.

Table 23 continued

Description of Risk	Engineering Practices to Reduce Risk Level	Comments on Pilot Project Area Environment
Cables damaged by UXO.	Undertake a specialized UXO hazard and risk assessment of any OWF development site inside the pilot project area. If appropriate carry out a UXO survey as part of the site development phases. Ensure any UXO exclusion zones are avoided by micro routing around these. Ensure WTG's and OSS's avoid any UXO exclusion zones and provide enough clearance from these so IACs are not forced to cross them in the close approaches to WTG and OSS foundations. Obtain ALARP certification for all IAC routes and OWF foundations.	Only four charted items of UXO are known in the pilot project area, there could well be more lying undiscovered in the pilot project area, relics of the two world wars.
Cables damaged by abrasion.	Avoid areas of harder seabed, seabed debris and wrecks through good micro routing of IACs. Provide WTG's and OSS's with enough clearance from harder seabed, seabed debris and wrecks so IACs are not forced to cross them in the close approaches to WTG and OSS foundations. Prevent cable movement on the seabed surface through cable stabilization measures (where required). Undertake periodic inspection surveys to monitor CPS condition and publish to marine stakeholders.	No hard seabed or bedrock is indicated in any of the pilot project sites. There are items of debris, boulders and eight known wrecks which will pose a risk of abrasion however they are widely distributed and do not occur in dense proximity.
Target cable burial not achieved due to shallow seabed soil conditions.	Avoid areas of harder seabed through good micro routing of IACs. Ensure appropriate cable burial tools are chosen for any OWF developments, capable of reaching CBRA recommended burial depths. Provide additional cable protection materials if the burial depth is insufficient to protect from mobile bottom tending activities and anchor penetration depths.	All indication from historic telecommunications cable burial across the sites are mean burial depth achieved across the site is 0.944 m and there have been no cable faults on over 700 km of fiber optic cables crossing the sites. Shallow soils are predominantly sands and gravelly sands across both Hudson North and Hudson South with good sediment thicknesses of 1 m+, typically suited to jet trenching.

Table 23 continued

Description of Risk	Engineering Practices to Reduce Risk Level	Comments on Pilot Project Area Environment
Target cable burial not achieved due to seabed slopes.	Avoid areas of steep slopes (>10°) through good micro routing of IACs. Consider the use of seabed intervention (removal of sediment) to reduce the slopes to values <10° if steep slopes are discovered on a future OWF development.	The maximum slope values across both Hudson North and Hudson South have not exceeded 5° based on both the comprehensive coarse multibeam data sets and the higher resolution but only partial coverage multibeam survey data sets.
Target cable burial not achieved due to seabed obstructions (boulders/debris).	Avoid areas boulders and debris through good micro routing of IACs. Ensure WTG's and OSS's avoid boulders. Should any boulders be deemed unavoidable and risk impeding cable burial consider removing by boulder picking or plow clearance ploughs.	There were 98 boulders found across the Hudson North and 526 across the Hudson South site by the Gardline 2020 survey. The 2020 survey only covered a very small percentage of the total area. From the wider geological setting it is however reasonable to expect them to extend across both sites. While boulders are widely found, they are also not clustered and don't form any dense boulder fields.
Target cable burial not achieved due to cable crossings.	Reduce the number of crossings by using the mutualized crossing point concept. Clear out of service cables to reduce the number of crossings. Provide additional cable protection materials if the burial depth is insufficient to protect from mobile bottom tending activities and anchor penetration depths. Reduce the number of crossings by using appropriate windfarm layout identified strategies (Task 2).	The pilot project area does feature an extensive number and length of existing. telecommunications cable and 14 of these are believed to be in service at this time. The probability that OWF's IACs will require cable crossings is high.

Table 24. Risks to Fishing Activities in the Pilot Project Areas

Description of Risk	Engineering Practices to Reduce Risk Level	Comments on Pilot Project Area Environment
Trawl gear snagging cables at cable crossings.	Ensure the crossing design considers trawl activity and uses materials which minimize the chances of snagging fishing gear. Determine the existing crossed cable depth so that if practical the IAC can be buried over the top. Reduce the number of crossings by using the mutualized crossing point concept. Reduce the number of crossings by using appropriate windfarm layout identified strategies. Reduce the number of crossings by clearing OOS cables before the new IAC is installed. Undertake periodic inspection surveys to monitor cable crossing condition and publish to marine stakeholders.	The pilot project area does feature an extensive number and length of existing telecommunication cables and 14 of these are believed to be in service at this time. The probability that OWF's IACs will require cable crossings is high. Further assessment of the risk from dredging over concrete mattressing, is suggested as an area of future study to reduce risk and improve access.
Trawl gear snagging on exposed cables due to seabed scour.	Obtain data on the local metocean and seabed sediment environment and carry out detailed seabed mobility and scour prediction studies to inform good scour protection engineering. Undertake periodic inspection surveys to monitor scour conditions and publish to marine stakeholders.	Seabed scour has been visually identified at between 8 and 11% of the seabed boulders and debris found by the Gardline 2020 survey data. While this covers only a small proportion of the pilot sites the shallow soil and seabed current environment is similar across all the sites. The depth of scour found around sonar contacts reached a maximum of 3 ft (1m).
Trawl gear snagging on CPS.	CPS design not to extend further than necessary beyond any scour protection and transition to buried cable at earliest opportunity. Investigate latest developments in cable connection technology and ensure CPS system is appropriate to the site conditions.	The information by the study used has not provided an indication on the type and design suited to the pilot sites and will be determined by the developers Further assessment of the risk from dredging over CPS is suggested as an area of future study to reduce risk and improve access.
Reduction of effective fishing area within array.	Use a windfarm layout and turbine power size to suit the specific development area to maximize access based on strategies identified in earlier in the report.	The existing telecommunications cable infrastructure may offer opportunities to co-locate wider lanes in the array and increase separation of WTGs locally.
Damage to fishing gear due to scour protection (rock).	Investigate and collaborate on scour protection designs at the base of WTGs to explore if they can be made fishing friendly. Ensure scour protection design is appropriate to the site conditions and not over engineered.	Seabed scour has been visually identified at between 8 and 11% of the seabed boulders and debris found by the Gardline 2020 survey data. While this covers only a small proportion of the pilot sites, the shallow soil and seabed current environment is similar across all the sites. The depth of scour found around sonar contacts reached a maximum of 3 ft (1 m).

Use of these engineering practices should reduce the risks to the OWF infrastructure (WTGs, OSSs and power cables). The first three points in each table are common to both and this reflects the common risks for both industries. It is clearly in both the OSW developers and fishing industries interests to reduce the possibility of any interaction between mobile bottom tending fishing gear and OWF seabed infrastructure and cabling.

7 Conclusions

Overall, this project collaboratively developed technical strategies and tools to help minimize the disruption of commercial fishing within OSW arrays in the New York Bight, while also ensuring economical energy generation and safe operation for the developers. To accomplish this goal, the project team worked collaboratively with the commercial fishing industry, OSW developers, and State and federal partners. The major tasks completed for the project included: (1) information gathering on risks to fishing access (i.e., literature review, fishing industry interviews, and data gaps assessment), (2) wind farm scenarios development and analysis, and (3) pilot project assessment, including engineering recommended practices.

For the first project task, information was gathered from a literature review, data assessment, and interviews with the commercial fishing industry to identify key considerations related to potential risks to fishing practices during development of OSW projects and associated impact minimization measures. For the second project task, several possible strategies were analyzed that OSW developers could potentially use to help increase Atlantic sea scallop and SC/OQ fishing access within OSW arrays in the New York Bight. Finally, for the third project task, a pilot project assessment was performed for the Hudson North and Hudson South BOEM call areas in the New York Bight to analyze different cable route engineering, burial, and protection practices could be employed to minimize effects on the fishing industry. The following summarizes some of the key takeaways across the project and potential next steps for future research:

- Information Gathering Task (chapters 2–4)
  - The literature review assessed ~150 literature resources associated with European wind farms and initial OSW development in U.S. waters.
  - The main focus was on operational risks to fishing due to structures and hazards and associated impact minimization measures, including the following:
    - Overall Size, Shape, and Location of Project Area—In general, impact minimization measures include but are not limited to: Siting away from areas of high fish concentration but where not possible, consider co-location needs; considering limiting geographic size of individual and total projects; utilizing state-of-the-art methods for windfarm layout design.

- Turbine Array Layout Impact on Harvesting and Transit of Fishing Vessels—Impact minimization measures include but are not limited to: utilizing fishermen's expertise to develop specific project designs; testing out navigation and gear use within windfarm arrays (e.g., including modifications to gear and training required to meet ability to fish within project area); incorporating fishing vessel transit requirements; executing long-term monitoring programs in combination with targeted research, paired with adaptive management strategies to address observed/detected impacts.
- Inter-Array and Export Power Cables—Impact minimization measures for cabling include, but are not limited to: designing cable routes to maximize the potential for responsible cable burial; optimizing export and IAC layouts that account for existing fishing activity, including minimizing the amount of cable laid; laying power cables using the method that causes the least damage to the seabed; laying HVDC cables with opposing electrical currents alongside each other and with sufficient burial; planning cable location and directionality with delineation of cable locations on charts; considering decommissioning plans, including removal after use and bringing the cable to shore.
- Protective Materials—Impact minimization measures for protective materials include but are not limited to: performing additional research/R&D on materials design to understand fishing and environmental impacts including reef effect; requiring removal of debris from the seabed resulting from OSW construction and operation.

o A broad range of other topics are also of interest to the commercial fishing industry, and would require further study in future projects, including considerations associated with regulatory issues, socioeconomic impacts, insurance rates/liability, and potential species redistribution at OSW farms.

o Semi-structured interviews were conducted to gather data on Atlantic sea scallop and SC/OQ fishermen's operational characteristics to aid in filling these gaps. Interviews gathered qualitative data from sea scallop fishermen (seven respondents) and SC/OQ fishermen (collective industry response) on fishing operations and fishermen's concerns with operating within or around a wind array.

- Based on these interviews, respondents generally preferred larger spacing between turbines, were concerned about towing over cables and cables becoming unburied, and had concerns about hanging up on scour protection, but differences were also observed in the level of concern depending on the respondent and type of risk.

o Based on the risks identified by the fishing community, a data gaps assessment was performed to identify the relevant existing data sets in each fishery and fishing practices utilized in the area of interest to help inform development of mitigation strategies.

- For fishery dependent data, the following sources were assessed: vessel trip reports, vessel monitoring system, dealer data, observer data, study fleet data, automatic identification system, and information derived through documentation of fishermen’s (or others’) ecological knowledge.

- Fishery independent data sources assessed included federal surveys, Northeast Area Monitoring and Assessment Program, and other State-based surveys. Consideration was also given to cooperative research, select data products and aggregations, and confidential fishery data and related projects.
- Gaps in priority data sets were also identified to inform future data collection and modeling efforts.

- Scenarios Development and Analysis (chapter 5)
  - Access scenarios for Atlantic sea scallop and SC/OQ fishing in and around fixed bottom wind farms in the New York Bight were developed based on input from study participants.
  - The cost and performance impacts of the different access scenarios were quantified relative to a baseline scenario in terms of AEP, CapEx, and LCOE.
  - The baseline scenario and five additional scenarios were defined based on: varying the turbine row spacing, incorporating a no-build area for fishing access, and providing more open space for fishing by using fewer, larger turbines spaced further apart (turbine upsizing).
  - The scenarios examined showed that, except for Scenario 6: Turbine Upsizing, increasing turbine or no-build area spacing decreases AEP relative to a baseline scenario optimized for AEP. This is due to increased wake losses and leads to higher LCOE in all but Scenario 6 relative to the baseline scenario.
  - Turbine upsizing from 12 MW to 15 MW turbines (Scenario 6) appears to present multiple advantages for fishermen's access and developers' project costs if turbine positions can be more favorably arranged to help reduce cable crossings and increase the area available to fishing. These trends would likely be amplified if turbine rated power continues to increase beyond 15 MW in the future.

- Pilot Project (chapter 6)
  - With a focus on mobile bottom tending fishing gear, seabed characteristics were investigated within the Hudson North and Hudson South BOEM call areas in the New York Bight and included seabed conditions which could affect the wind turbine foundation, OSS foundation(s), and cable installation and burial.
  - Rather than using historical fishing data, the fishing potential of the sites was assumed to be uniform across all the sites. This prevented any bias in where the route engineering practices would be best employed to maximize fishing access and allows for future variation of fishing effort distribution.
  - The seabed characteristics investigation used numerous publicly available data sets and GIS software to map the seabed sediments and geomorphological features, the presence of natural seabed scouring, marine currents and obstructions such as boulders, wrecks, UXO, and existing cables.
  - Summary tables present the risks found across the pilot project sites to cables and to fishing. Examples of these risks include bottom mobile tending gear snagging on exposed cables, cable burial not being achieved for various reasons, and damage to fishing gear from post lay scour protection.

- A toolbox was developed of scallop and SC/OQ “fishing friendly” engineering approaches which can be adopted by each individual future OSW project's needs. The engineering practices presented could be used to ensure future developments are successful in producing reliable electricity over their design life while trying to limit the impact on scallop and SC/OQ fishing.
- These are also likely to be the engineering practices used for other bottom tending gear fisheries; however, further evaluation would be necessary to ensure these findings hold true for those additional fisheries.

This study has revealed that when offshore wind energy projects utilize feedback and experience from fishermen coupled with scientific data and best management practices for project planning (e.g., layout and installation techniques), there is strong potential for the fishing industry and the offshore wind developers to co-exist and respective risks reduced. Yet, it should not be understated that this takes careful planning so that offshore wind projects are built with environmentally responsibility and cost-effectiveness staying top of mind.

The primary scope of this project focused on the commercial fishing industries for Atlantic sea scallop and SC/OQ and fishing access within future fixed-bottom OSW farms in the New York Bight. However, more study is needed to understand how associated gear types may interact with OSW infrastructure on the seabed, such as potential interactions between clam and scallop dredges and scour protection of cable sections (e.g., concrete mattresses). There is also continued interest in understanding how choice of scour protection and other protective materials may impact fisheries ecology in the region. Environmental and socioeconomic issues were largely beyond the scope of the current study, with open questions for future research related to potential changes to insurance policies, potential redistribution of species and fishing effort, and socioeconomic impacts to fishing communities and businesses.

Future work is needed to focus on other commercial and recreational fishing gear types used in the region to determine their unique requirements and risks associated with fishing access in OSW farms. As well, beyond fixed bottom wind farms, deeper waters are being considered for floating OSW farms, which are attached to the seabed via mooring lines and anchors. Future research is also needed to consider the risks associated with these future floating OSW installations and considerations for both fixed and mobile fishing gear types in the central Atlantic and other regions where wind development is being considered.

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Endnotes

[1] BOEM (2020). State Activities. https://www.boem.gov/renewable-energy/state-activities.

[2] Visit the Whitehouse Website: https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/

[3] Visit the Department of Interior Website: https://www.doi.gov/pressreleases/biden-harris-administration-approves-first-major-offshore-wind-project-us-waters

[4] Visit the K&L Gates Hub Website: https://www.klgates.com/Record-Setting-New-York-Bight-Auction-and-Newly-Announced-Oregon-Lease-Areas-Portend-Rapid-Growth-in-US-Offshore-Wind-Industry-3-16-2022#:~:text=By%20the%20end%20of%20the,dropping%20out%20of%20the%20auction

[5] 33 C.F.R. § 165.9-10, 20.

[6] Visit the BOEM Website: https://www.boem.gov/sites/default/files/documents/environment/environmental-studies/AT%2020-x07.pdf

[7] Visit the BOEM Website: https://www.boem.gov/sites/default/files/uploadedFiles/BOEM-Fishing%20FAQs.pdf

[8] Visit the NOAA Website: https://www.habitat.noaa.gov/application/efhmapper/index.html

[9] Thomas and Ning's paper presents a process using an approach related to continuation optimization methods for reducing multi-modality in the windfarm layout optimization problem, referred to as Wake Expansion Continuation (WEC).

[10] The fishing industry has also called for non-grid patterns for other projects and contends that the least impactful layouts will be project- and location-specific.

[11] This is in large part due to limitations in availability or quality of vessel tracking data for most fisheries operations, as described further in Section 3 below.

[12] Based in the UK, the Carbon Trust serves as a global organization that looks at current and future sustainability challenges and works with business and organisations to develop sustainable strategies to deliver savings.

[13] Visit the Regulations Website: https://www.regulations.gov/docket/BOEM-2022-0033/document

[14] Visit the North American Submarine Cable Association Website: https://www.n-a-s-c-a.org/

[15] Notably, the MARIPARS only evaluated one layout option consisting of turbines arranged in an east-west, north-south grid with 1 nm spacing between turbines in those two directions. It did not examine relative increases or reductions in risk with greater or narrower spacing.

[16] The forthcoming Synthesis of the Science report conducted by RODA, NMFS, and BOEM, et al. will present detailed findings regarding ecological and species impacts and shifts, as they are understood at this time.

[17] Visit the NOAA Fisheries Website: https://www.fisheries.noaa.gov/resource/data/socioeconomic-impacts-atlantic-offshore-wind-development

[18] Visit the BoatUS Foundation Website: https://www.boatus.org/study-guide/navigation/rules/

[19] Visit the NOAA Fisheries Website: https://www.fisheries.noaa.gov/content/greater-atlantic-region-regulations

[20] See Literature Review section report with information on existing cables in the region.

[21] For full context of regulations visit the NOAA Fisheries Website: https://www.fisheries.noaa.gov/content/greater-atlantic-region-regulations

[22] Most other fisheries are also limited access with considerable barriers to entry.

[23] 50 C.F.R. § 229.11.

[24] Atlantic States Marine Fisheries Commission, Economics and Social Sciences. http://www.asmfc.org/fisheries-science/economics-and-social-sciences.

[25] Exec. Order No. 13547 (July 19, 2010).

[26] Visit the NOAA Fisheries Website: https://www.fisheries.noaa.gov/resource/data/fishing-footprints-northeast

[27] Visit the NOAA Fisheries Website: https://www.fisheries.noaa.gov/resource/data/socioeconomic-impacts-atlantic-offshore-wind-development

[28] *See, e.g.*, 50 C.F.R. § 229.11.

29 The Freedom of Information Act exempts from disclosure "trade secrets and commercial or financial information obtained from a person [that is] privileged or confidential." 5 U.S.C. § 552(b)(4).

30 Accessed via PlanetOS. See code on GitHub.

31 FLORIS code and documentation are available on GitHub.

32 Tabular power curve data and documentation are available on GitHub.

33 ORBIT code and documentation are available on GitHub and the model methodology is described in “ORBIT: Offshore Renewables Balance-of-System and Installation Tool” (Nunemaker et al. 2020).

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