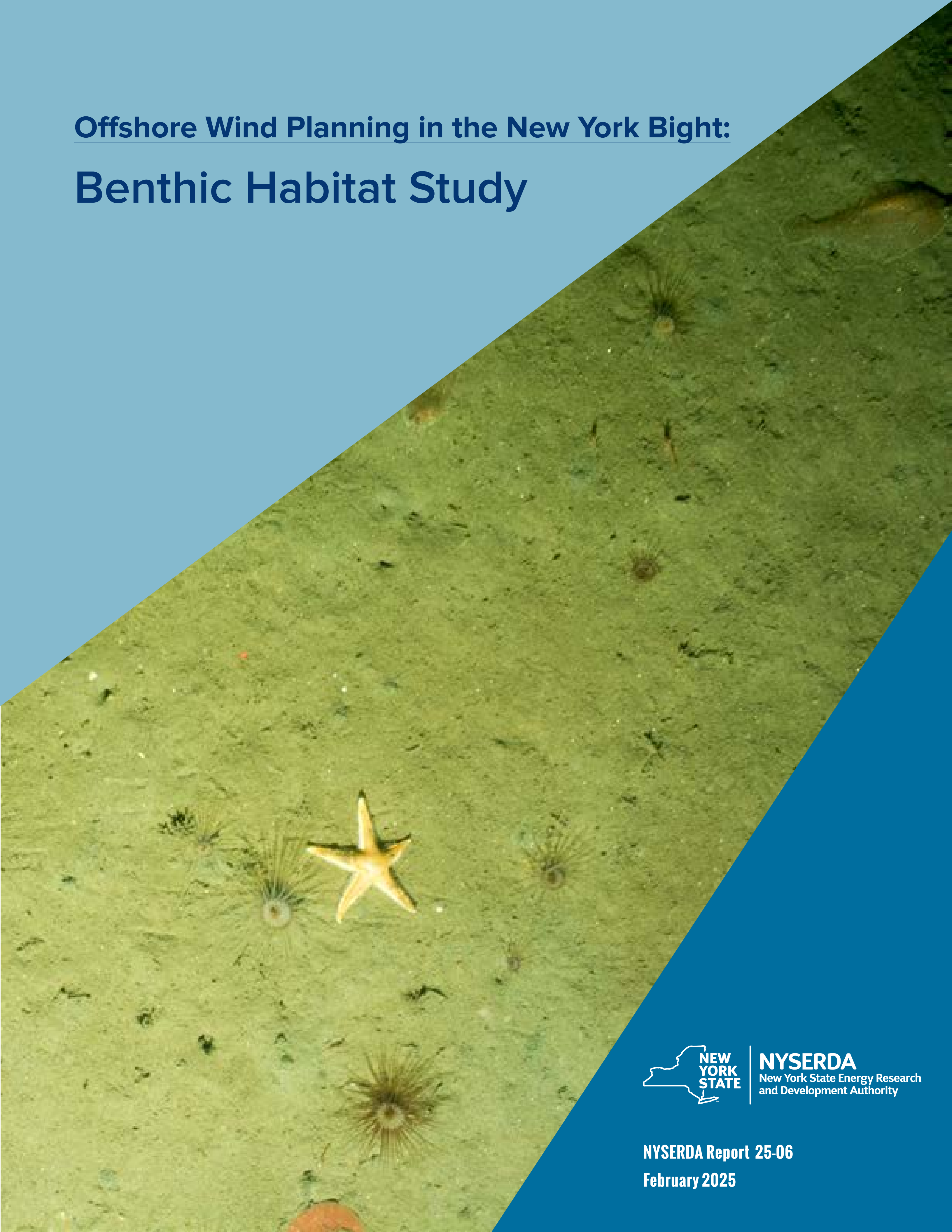
Offshore Wind Planning in the New York Bight:

Benthic Habitat Study



NYSERDA
New York State Energy Research
and Development Authority

NYSERDA Report 25-06
February 2025

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

Cover Image Source: INSPIRE Environmental

Offshore Wind Planning in the New York Bight: Benthic Habitat Study

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Prepared by:

Henningson, Durham & Richardson Architecture & Engineering, P.C.

New York, NY

In Collaboration with:

University of Rhode Island, Graduate School of Oceanography

Kingston, RI

and

INSPIRE Environmental

Newport, RI

NYSERDA Report 25-06 NYSERDA Contract 155561 February 2025

Notice

This report was prepared by Henningson, Durham & Richardson Architecture & Engineering, P.C, the University of Rhode Island Graduate School of Oceanography and INSPIRE Environmental in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter "NYSERDA"). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA's policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

Preferred Citation

New York State Energy Research and Development Authority (NYSERDA). 2025. "Offshore Wind Planning in the New York Bight: Benthic Habitat Study," NYSERDA Report Number 25-06. Prepared by Henningson, Durham & Richardson Architecture & Engineering, P.C., New York, NY. nyserda.ny.gov/publications

Abstract

This study compiles and analyzes existing data on benthic habitats in regional waters greater than 60 meters (m) deep off New York that may be sensitive to offshore wind development. Geospatial data were mapped to assess risk within the Area of Analysis (AoA) to three biological benthic groups (receptors): deep-sea corals, deep-sea sponges, and sea pens, and one physical receptor containing a combined ranking of hard-bottom likelihood. The findings suggest that the AoA is home to many infaunal and epifaunal species, including sensitive assemblages of deep sea corals and deep sea sponges. Significant clustering of biological receptors occurs where hard-bottom substrate is present, along with high currents and significant depth gradients that interact with highly variable topography. However, biological benthic data for selected receptors are not available for large areas of the AoA, with little to no data available for large areas in waters deeper than 2,000 meters. For this reason, the hard bottom likelihood physical receptor was included to assess impacts benthic habitat in areas where biological data are sparse or unknown. The study also evaluated potential impacts to benthic habitats from offshore wind development by phase (pre-construction, construction, post-construction ((operation)) and decommissioning) based on a systematic literature review. Study considerations include establishing environmental and ecological baselines and future monitoring of benthic receptor groups to establish ongoing ecosystem impacts from offshore wind development. Closing data gaps for data poor areas by direct exploration can also add to the understanding of benthic habitat and species in the AoA.

Keywords

Benthic, habitat, deepwater, offshore, wind, stressor, receptor, constraint, risk.

Acknowledgments

We thank the Project Advisory Committee (PAC) and New York State Environmental Technical Working Group (E-TWG) and all Benthic Habitat Study reviewers for volunteering their time toward providing advice on data sources and study review. We also acknowledge the data providers and authors cited whose research and effort contributed to this Benthic Habitat Study.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AC	alternating current
AoA	Area of Analysis
BOEM	Bureau of Ocean Energy Management
Climate Act	Climate Leadership and Community Protection Act
DC	direct current
E-TWG	New York State Environmental Technical Working Group
EEZ	exclusive economic zones
EFH	essential fish habitat
EMF	electromagnetic field
EBK	Empirical Bayesian Kriging
F-TWG	New York State Fisheries Technical Working Group
FAO	Food and Agriculture Organization
HAPC	habitat area of particular concern
HVDC	high-voltage direct current
KDE	kernel density estimate
M	meters
Master Plan	New York State Offshore Wind Master Plan
MBES	multibeam echosounder
MW	Megawatt
NOAA	Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
NYSERDA	New York State Energy Research and Development Authority
OBIS	Ocean Biogeographic Information System
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OSW	Offshore wind development
PAC	Project Advisory Committee
ROSA	Responsible Offshore Science Alliance

RWSC	Regional Wildlife Science Collaborative for Offshore Wind
SLR	systematic literature review
SME	subject matter expert
TNC	The Nature Conservancy
UNGA	UN General Assembly
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
VME	vulnerable marine ecosystem
WEA	Wind Energy Area
WoRMS	World Register of Marine Species

Executive Summary

In 2019, New York's historic Climate Leadership and Community Protection Act (Climate Act) was signed into law, requiring the State to achieve 100% zero-emission electricity by 2040 and to reduce greenhouse gas emissions 85% below 1990 levels by 2050. The law specifically mandates the development of 9,000 megawatts (MW) of offshore wind energy by 2035, building upon its previous goal of 2,400 MW of offshore wind energy by 2030. The New York State Energy Research and Development Authority (NYSERDA) is charged with advancing these goals.

Since the early 2000s, offshore wind development off New York's coast has advanced in relatively shallow areas in the New York Bight, on the Outer Continental Shelf (OCS). As offshore wind (OSW) development continues to mature and offshore wind leases are developed in deeper waters, the size and type of the offshore wind components are likewise expected to grow, and the project footprint will change as the use of floating OSW technology begins to be deployed. This may result in changes in the types of potential effects and interactions seen to date for fixed-bottom offshore wind projects. NYSERDA is conducting studies to investigate the implications of developing floating offshore wind in deeper waters. Findings from the studies will be used to support the identification of areas that present the greatest opportunities and least risk for siting deepwater offshore wind projects, and other workstreams designed to help assure the continued responsible siting and development of offshore wind energy.

Five desktop environmental studies compile and analyze existing data on resources in the Area of Analysis (AoA) that may be sensitive to OSW development. Three zones comprise the AoA: Zone 1 is on the outer continental shelf (60–150 meters deep), Zone 2 is at the shelf break (150–2,000 meters deep), and Zone 3 includes the area beyond the shelf break (2,000–3,000 meters deep).

For this Benthic Study, the most up-to-date, readily available data were used to document the presence of benthic resources and to evaluate risk. Data selected for use in the geospatial sensitivity contained three biological benthic groups (receptors): deep-sea corals (all taxa), deep-sea sponges, and sea pens, and one physical receptor containing a combined ranking of hard bottom likelihood. The distribution and density of each receptor has been mapped within the AoA. Additionally, potential impacts to benthic habitats from OSW (pre-construction, construction, post-construction [operation] and decommissioning) were evaluated based on a systematic literature review.

At least 47 distinct species of corals were identified in the AoA, with significant clustering occurring along the complex topography of the slope in Zone 2. Glass sponges are most abundant in the AoA and demosponges are the most diverse. Corals and sponge density is highest where hardbottom substrate is present, along with high currents and significant depth gradients that interact with highly variable topography. At least 17 species of sea pens are present within the AoA, and their presence is most common in the shelf break in Zone 2. Sea pens along with corals are also present near the head of Hudson Canyon in Zone 1. However, biological benthic data for selected receptors are not available for large areas of the AoA, with little to no data available for large areas of Zone 3.

Study considerations include establishing environmental and ecological baselines for benthic receptor groups and sustained monitoring to establish ongoing ecosystem impacts from OSW. Closing data gaps is also recommended by collecting high-resolution habitat mapping and field verification; enhancing geophysical data collection, including consistent processing of backscatter data and inclusion of sub-surface data; and sharing and standardizing geomorphic and sediment data collected by developers. Distinct features of Zone 2 aligned with high likelihood of hard bottom substrates and higher presence of vulnerable marine ecosystems and their highly sensitive nature to disturbance should be considered as areas to avoid for deepwater OSW.

Additionally, direct exploration is recommended to understand the risks more comprehensively to benthic habitat and biological communities from OSW development, particularly in the case of deepwater development as the associated technologies are in their infancy. Experimental assessment of the response of benthic receptors to major impact-producing factors or direct studies in developed areas is recommended.

1 Introduction

For more than a decade, New York State has been conducting research, analysis, and outreach to evaluate the potential for offshore wind energy. New York State Energy Research and Development Authority (NYSERDA) led the development of the New York State Offshore Wind Master Plan (Master Plan), a comprehensive roadmap and suite of more than 20 studies for the first 2,400 megawatts (MW) of offshore wind energy. The Master Plan encourages the development of offshore wind in a manner that is sensitive to environmental, maritime, economic, and social issues while addressing market barriers and aiming to lower costs. The Master Plan included spatial studies to inform siting of offshore wind energy areas. Now, NYSERDA is undertaking new spatial studies to review the feasible potential for deepwater offshore wind development at or exceeding depths of 60 meters in the New York Bight and to support the future identification of additional lease areas in the region.

Planning processes considering the development of offshore wind in the deepwater areas examined in each of NYSERDA's spatial studies must consider these studies in the context of one another. Decision making must additionally consider different stakeholders and uses and will require further adjusted approaches and offshore wind technologies to ensure the best outcome. Globally, deepwater wind technology is less mature and primarily concentrated on floating designs at the depth ranges being assessed through these spatial studies, while deepwater fixed foundations are at their upper technical limit within the Area of Analysis (AoA). Therefore, floating designs were predominantly considered since most, if not all, of the AoA would likely feature floating offshore wind. NYSERDA, along with other states and federal agencies, is developing research and analysis necessary to take advantage of opportunities afforded by deepwater offshore wind energy by assessing available and emerging technologies and characterizing the cost drivers, benefits, and risks of floating offshore wind. Findings from these studies and available datasets will be used to support the identification of areas that present the greatest opportunities and least risk for siting deepwater offshore wind projects.

Offshore wind energy development is being introduced into a highly dynamic and human-influenced system. These reports seek to better understand the potential interaction of offshore wind development and marine wildlife and habitats; however, it is important to consider these within the broader context of climate change and existing land-based and marine activities. The State will continue to conduct research through its established Technical Working Groups (TWGs) concerning the key subjects of fishing, maritime commerce, the environment, environmental justice, jobs, and the supply chain. These TWGs were designed to inject expert views and the most recent information into decision making.

Taken together, the information assembled in these spatial studies will help empower New York State and its partners to take the informed steps needed to capitalize on the unique opportunity presented by offshore wind energy.

1.1 Spatial Studies to Inform Lease Siting

- Benthic Habitat Study
- Birds and Bats Study
- Deepwater Wind Technologies – Technical Concepts Study
- Environmental Sensitivity Analysis
- Fish and Fisheries Data Aggregation Study
- Marine Mammals and Sea Turtles Study
- Maritime Assessment – Commercial and Recreational Uses Study
- Offshore Wind Resource Assessment Study Zones 1 and 3
- Technology Assessment and Cost Considerations Study

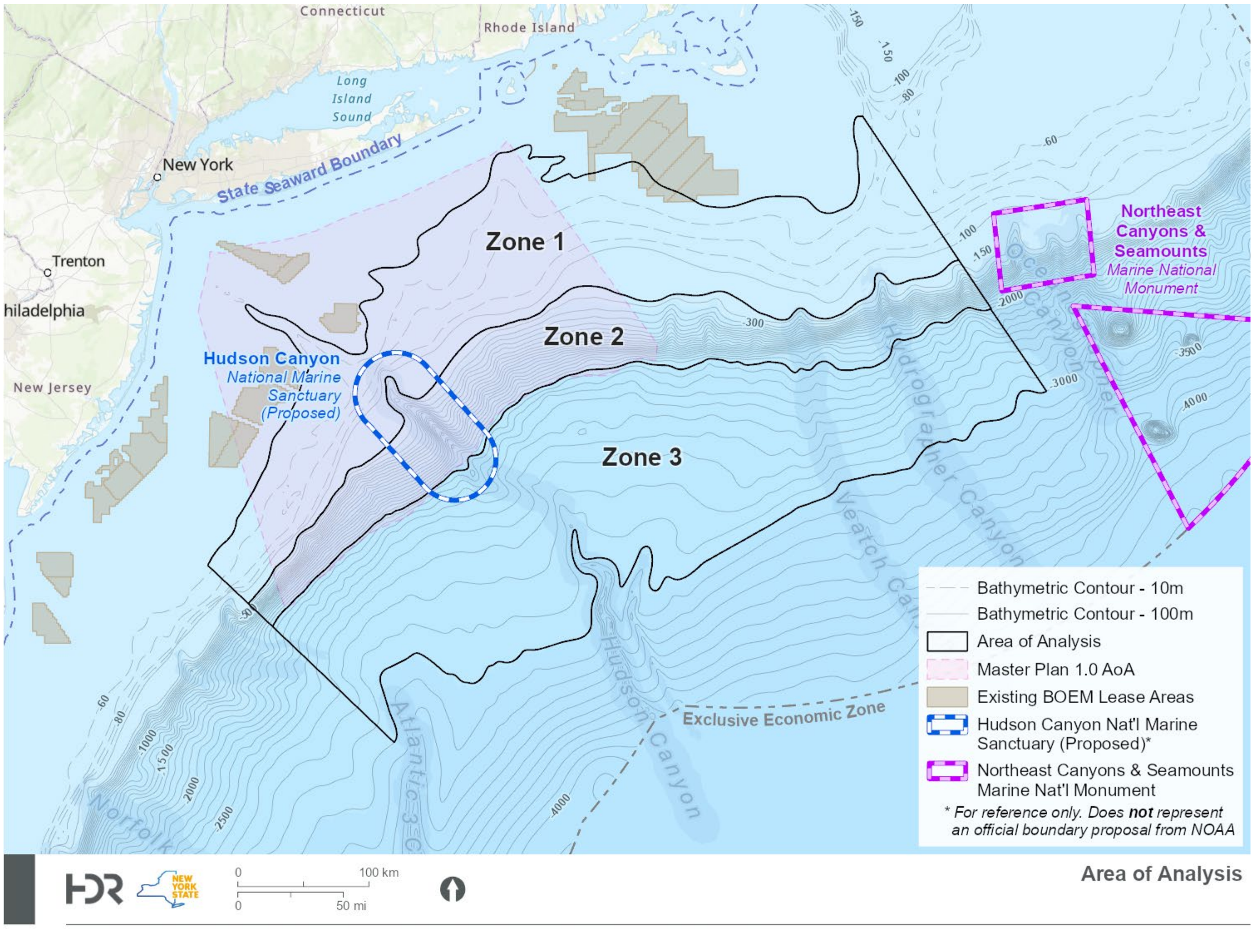
Each of the studies was prepared in support of a larger planning effort and shared with relevant experts and stakeholders for feedback. The State addressed comments and incorporated feedback received into the studies. Feedback from these diverse groups helps to strengthen the studies, and also helps ensure that these work products will have broader applicability and a comprehensive view. Please note that assumptions have been made to estimate offshore wind potential and impacts in various methodologies across the studies. NYSERDA does not necessarily endorse any underlying assumptions in the studies regarding technology and geography including but not limited to turbine location, turbine layout, project capacity, foundation type, and point of interconnection.

The Energy Policy Act of 2005 amended Section 8 of the Outer Continental Shelf Lands Act (OCSLA) to give BOEM the authority to identify OSW sites within the Outer Continental Shelf (OCS) and to issue leases on the OCS for activities that are not otherwise authorized by the OCSLA, including wind development. The State recognizes that all development in the OCS is subject to review processes and decision-making by BOEM and other federal and State agencies. This collection of spatial studies is not intended to replace the BOEM wind energy area identification process and does not commit the State or any other agency or entity to any specific course of action with respect to offshore wind energy development. Rather, the State's intent is to facilitate the principled planning of future offshore development off the New York coast, provide a resource for the various stakeholders, and encourage the achievement of the State's offshore wind energy goals.

1.2 Study Area

The spatial studies will evaluate potential areas for deepwater OSW within a specific geographic area of analysis (AoA) of approximately 35,670 square miles of ocean area, extending from the coast of Cape Cod south to the southern end of the New Jersey (Figure 1). It includes three zones extending outward from the 60-meter depth contour, which ranges between 15 and 50 nautical miles from shore to the 3,000-meter contour, which ranges from 140 to 160 nautical miles from shore.

Figure 1. Area of Analysis



CREDITS: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, USGS, HDR Inc., BOEM, NYSERDA, NOAA Office of National Marine Sanctuaries

The eastern edge of the AoA avoids Nantucket Shoals and portions of Georges Bank, since those areas are well known to be biologically and ecologically important for fish and wildlife, fisheries, and maritime activity. The AoA does include areas such as the Hudson Canyon, which is under consideration to be designated as a National Marine Sanctuary, and thus would not likely be suitable for BOEM site leases.

Due to this designation, more specific analysis and coordination with BOEM in this area is required. While OSW infrastructure will not be built across the entire AoA, the spatial studies analyze this broad expanse to provide a regional context for these resources and ocean uses.

- Zone 1 is closest to shore and includes a portion of the OCS. It extends from the 60-meter contour out to the continental shelf break (60 meters [197 feet] to 150 meters [492 feet] deep). Zone 1 is approximately 12,040 square miles.
- Zone 2 spans the steeply sloped continental shelf break, with unique canyon geology and habitats (150 meters [492 feet] to 2,000 meters [6,561 feet] deep). Zone 2 is approximately 6,830 square miles.
- Zone 3 extends from the continental shelf break out to 3,000 meters (9,842 feet) depth. Zone 3 is approximately 16,800 square miles.

Zone 2, stretching across the steeply sloped continental shelf break with its distinctive canyon geology and unique habitats, is unlikely to host offshore wind turbines, but is still likely to be impacted by offshore wind development activities through maritime traffic and/or cabling and was therefore included in this study. The underwater canyons in this region are distinctive and ecologically significant, making Zone 2 an area of particular interest for scientific research, conservation efforts, and fish and benthic habitats. Another crucial factor prompting this analysis is the presence of electrical cabling in the area, which can have several environmental implications, including electromagnetic fields that might disrupt marine life and the physical disturbance of the seafloor during installation. Lastly, maritime vessel activities throughout the zone could involve shipping traffic, fishing, and other recreational activities related to the sea which can introduce pollutants, noise, and physical disturbances, such as vessel strikes that may have adverse effects on the surrounding environment.

1.3 Study Objectives

This Benthic Habitat Study aims to do the following:

1. Compile and synthesize the best available data on benthic habitat and benthic species of importance within the AoA.
2. Discuss gaps in data and provide recommendations on how to close data gaps.
3. Review and summarize existing literature on the potential impacts of each phase of deepwater OSW on benthic habitat.
4. Provide guidelines on best practices for avoiding, minimizing, and mitigating impacts to benthic habitats from deepwater OSW.
5. Describe areas of greatest risk to benthic habitats from deepwater OSW development.
6. Discuss data gaps and uncertainties, as well as potential recommendations for future actions.

This study focuses on benthic habitats and resources in the AoA. Section 1 describes the study area and study objectives, and the involvement of stakeholders in the development of this study. Section 2 presents the biological and physical benthic data as well as the resource management areas and anthropogenic benthic constraints identified in the AoA. Section 3 discusses the potential stressors associated with each phase of deepwater OSW and how they may affect benthic habitat. As deepwater wind infrastructure has a larger footprint than fixed-bottom wind farms and interact with the marine environment differently, this section provides details on the potential environmental risks posed from deepwater wind infrastructure section 4 discusses the existing guidance for impact avoidance, minimization, and mitigation to benthic receptors and habitat. Finally, section 5 summarizes current knowledge gaps, and future considerations.

This study is one of a series of environmental desktop studies that synthesize available and relevant existing data sets on four key resources groups: marine mammals and sea turtles, birds and bats, fish and fisheries, and benthic habitats. Each of these studies leverages information developed for the New York Offshore Wind Master Plan and expands on the type of habitat and species within the AoA that are found in deep water and identifies potential stressors from different phases of OSW to each resource group, with a focus on deepwater technology. A fifth study builds upon and compiles the results from the four studies into a single environmental sensitivity analysis and presents a series of maps showing areas of greatest risk from OSW.

1.4 Regulatory Framework

The OCSLA (43 United States Code [U.S.C.] §1331 et seq.) defined submerged lands under federal jurisdiction as the OCS and assigned authority for leasing to the Secretary of the Interior. In 2005, the Energy Policy Act (42 U.S.C. §13201 et seq.) amended the OCSLA to clarify uncertainties about OSW and granted development authority to the Secretary of the Interior. The BOEM Office of Renewable Energy Programs facilitates the responsible development of renewable energy resources on the OCS. These regulations provide a framework for issuing leases, easements and rights-of-way for OCS activities that support production and transmission of energy from sources other than oil and natural gas. BOEM is currently in the planning and analysis phase of identifying deepwater WEAs off of New York and New Jersey. This phase is to collect information, reduce potential conflicts of use, and identify areas that are potentially suitable for lease sale. BOEM conducts an environmental assessment once the WEA is established.

The Magnuson-Stevens Fishery Conservation and Management Act’s 1996 Sustainable Fisheries Amendment requires protection of Essential Fish Habitat (EFH) for federally managed marine and anadromous fish. Many benthic habitats described within this study are regulated under EFH. Prior to development, activities that have the potential to adversely affect areas designated as EFH will require consultation with National Oceanic and Atmospheric Administration (NOAA) Fisheries. A more detailed description of the fish species managed under the EFH regulation can be found in the Fish and Fisheries Data Aggregation Study (NYSERDA, 2025).

NOAA has designated much of Zone 2 and Zone 3 as The Frank R. Lautenberg Deep-Sea Coral Protection Area that includes discrete deep-sea coral protection zones and a broad deep-sea coral zone, see section 2.5. NOAA consultation will be required if development in this area is undertaken.

The NOAA Office of National Marine Sanctuaries is in the early stages of designation of a sanctuary for Hudson Canyon. After the site is designated, it will have its own sanctuary-specific regulations and management criteria. However, all sanctuaries prohibit construction on or alteration of the seabed, so it is likely OSW would not be allowed inside the sanctuary boundary once it is delineated. See section 2.5 for the approximate boundary for this proposed Marine Sanctuary.

1.5 Agency and Stakeholder Engagement

NYSERDA is committed to engaging with and incorporating stakeholder feedback in offshore wind planning processes. Stakeholder comments from the Master Plan have been incorporated into this study, as practical. State agency partners were engaged in the development and review of this study, consisting of: New York State Department of State, New York State Office of Parks, Recreation, and Historic Preservation, New York State Department of Transportation, Empire State Development, New York Department of Public Service, New York State Office of General Services, New York State Department of Labor, and New York State Department of Environmental Conservation.

To involve stakeholders in the development and analysis of this study, two stakeholder groups have been consulted. A Project Advisory Committee (PAC), including subject matter experts (SMEs) from State, federal, non-governmental groups and developers have been involved in assisting with the identification of data sources and sensitivity receptors, and have provided comments on the draft study.

Prior to the development of this study, information was shared with the Benthic Habitat PAC and conference calls occurred to discuss technical details of this study as well as data and ranking criteria used the Environmental Sensitivity Analysis (NYSERDA, 2025). Conference call dates for the Benthic Habitats PAC were on May 24 and June 15, 2023.

Additionally, NYSERDA's Environmental Technical Working Group (E-TWG) contributed to a preliminary list of data sources used in the development of this study and provided comments on the draft study. A kickoff call with the E-TWG was held on March 9, 2023. On this call the team was introduced to the E-TWG and the approach for each study was presented.

The State provided a first draft of this study for review to State and federal regulators, TWGs, and other stakeholders on July 28, 2023, and afforded these stakeholders the opportunity to submit written comments on the draft's contents.

Comments received on the draft study included requests for more detail on potential impacts from particular stressors, such as cable protection and armoring, removal and relocation of boulders, high-voltage direct current operations and others. Additional spatial data were suggested as well as additional literature documenting potential stressor impacts or receptor responses. These data and references were incorporated, as practical, throughout the final study. A new section has been included, based on stakeholder feedback that includes the types of technologies expected in each zone and how those potential technologies may affect benthic resources within.

2 Overview of Benthic Data within the Areas of Analysis

2.1 Desktop Study Methods

A detailed desktop data review to obtain spatial data was conducted on regional data portals (e.g., Northeast Ocean Data Portal), from federal and State agency-specific data providers (e.g., National Oceanic and Atmospheric Administration [NOAA], U.S. Geological Survey [USGS], U.S. Coast Guard [USCG], and NYSERDA), and from other known regional data providers (e.g., The Nature Conservancy [TNC], the Ocean Biogeographic Information System [OBIS]). Benthic spatial data were searched throughout and near the AoA across five topical categories, as outlined in Table 1. Readily available data were included in the resultant data source list and database. Appendix A provides a complete list of data sets, sources, and citations indicated in this study and why they have been included. Each noteworthy topical category and distributions within the AoA are discussed within this section.

Table 1. Benthic Spatial Data Search Categories

Category	Examples
Geophysical	Multibeam echosounder bathymetry and backscatter; side-scan sonar; geoforms.
Sediment	Sediment type (grain size, CMECS substrate classification).
Biodiversity/Habitat Suitability	Metrics on presence and/or distribution of sensitive, threatened, and endangered species; designated essential fish habitat and habitat areas of particular concern.
Resource Management Areas	Areas designated to prohibit or restrict fisheries-related seafloor disturbance activities to protect seafloor habitats and demersal species.
Anthropogenic Benthic Constraints	Charted submarine cables; disposal areas; unexploded ordnance; shipwrecks.

2.2 Selection of Benthic Receptors

Organisms that inhabit the benthic habitats of the AoA are typically divided into infaunal species, those living in the sediments (e.g., polychaetes, amphipods, bivalves), and epifaunal species, those living on the seafloor surface (mobile, e.g., sea stars, sand dollars, sandshrimp, crabs, lobsters, isopods, gastropods) or attached to substrates (sessile, e.g., barnacles, anemones, tunicates) (see extensive sampling reports for the larger North East Large Marine Ecosystem – Steimle, 1990; Theroux and Wigley, 1998). Benthic community assemblages and their associated ecological functions vary spatially across the Northwest Atlantic and, specifically, the AoA (Theroux and Wigley 1998), with sediment grain size distribution influencing benthic community distributions, which can be used to infer likely presence of benthic taxa across environments.

While shifts in benthic community assemblages and particular taxa abundances from year-to-year and seasonally have been observed, the benthic habitat and ecological functioning of the benthic community is generally stable within the AoA (Steimle 1990). Specific sensitive taxa found within the region, including deep-sea corals and deep-sea sponges, are generally long-lived and sessile, with their distributions and presence not strongly influenced by seasonality (Packer et al. 2017). Benthic epifaunal assemblages provide important ecosystem functions (Biles et al. 2002; Waldbusser et al. 2004), serving as critical trophic links between plankton and higher-order consumers, including managed and commercially important species. In the deep-sea, benthic assemblages, such as reefs, can enhance local biodiversity and biomass relative to surrounding areas across multiple scales including microbial, macrofaunal, and megafaunal assemblages (Schöttner et al. 2009; Lessard-Pilon et al. 2010; Demopoulos et al. 2014; Pierdomenico et al. 2017).

Benthic organisms, particularly attached epifauna and emergent infauna, add complexity to the seafloor, providing structural biogenic habitat for other species (Bradshaw et al. 2003; Henry et al. 2010). Greater structural complexity in the deep sea is associated with higher abundance in associated species, such as fish (Söffker et al. 2011), and serves as an essential habitat that offers attachment, shelter, feeding and other benefits at depths where food supply and geological substrate complexity generally decline (Buhl-Mortensen et al. 2010). For example, some deep-sea benthic communities provide essential habitat for fish (defined as Essential Fish Habitat or EFH), with research expeditions identifying 16 (Le Guilloux et al. 2009) to 30 (Söffker et al. 2011) unique taxa of deep-sea fish to be associated with benthic communities. In addition, catch size as well as sizes of individual fish within reef communities have been found to be greater than in non-reef areas (Husebø et al. 2002). Associated benthic infaunal assemblages also serve important roles, through nutrient and carbon cycling in the sediments through water filtration, biodeposition, bioirrigation, and bioturbation (Griffiths et al. 2017). Attached epifaunal communities that may be sensitive to impacts from deepwater OSW have been identified as receptors for the sensitivity analysis to be conducted as part of the suite of spatial studies.

Four groups of benthic receptors have been defined in this study, (1) deep-sea corals, also referred to as cold-water corals; (2) deep-sea sponges; (3) sea pens; and (4) hard grounds. Although sea pens are now included under the taxonomic umbrella of Scleralcyonacea (McFadden et al. 2022), they have been retained within this study as a separate receptor category from other deep-sea corals based on distinctive morphological traits and habitat type (soft bottom). These receptor groups are foundational to the physical and biological habitats that underpin communities, sustain elevated local biodiversity, and drive ecosystem function (Ramirez-Llodra et al. 2010; Thurber et al. 2014). As structurally complex habitats, they have high-conservation and management value as loss of structure can have significant and long-lasting impacts (Danovaro et al. 2008; 2020), especially in deeper waters where food supplies are generally limited and organismal growth rates are low (Auster et al. 2011). These habitats are under increased pressure as humans seek to exploit marine habitats for resources, including benthic habitats in deeper waters (Clark et al., 2016; Davies et al., 2007; Danovaro et al. 2017). However, scientific understanding of their distributions, ecology, and ecosystem function remains exceptionally limited, impeding their effective conservation and management (Morato et al. 2018). One mechanism that has become widely used is the concept of vulnerable marine ecosystems (VMEs), proposed by the UN General Assembly (UNGA) in 2006 and by the Food and Agriculture Organization (FAO) in 2009, for the purpose of identifying essential biological habitats that need to be protected against threats from destructive fishing practices (UNGA 2006; FAO 2009). The FAO (2009) defined VMEs using five criteria: (1) uniqueness or rareness, (2) functional significance of the habitat, (3) fragility, (4) life-history of species that makes recovery difficult, and (5) structural complexity. All biological receptors proposed in this review are classified as VME indicator species. While the definition of VME has been applied to ecosystems present on the “high seas,” VMEs are widespread within many exclusive economic zones (EEZ), including the United States. The use of VME criteria has also extended beyond fishing to a variety of other anthropogenic impacts. Many VMEs also provide EFH, although commercially important fish species are covered in Fish and Fisheries Data Aggregation Study (NYSERDA, 2025), EFHs extend to benthic habitats, such as the receptor groups utilized in this study.

2.2.1 Biological Receptor Methods

To determine the distribution of these species groups within the AoA, organism occurrence data was aggregated from the NOAA Deep-sea Coral Research and Technology Program’s (DSCRTP) deep-sea coral and sponge database (NOAA 2016) and the Ocean Biodiversity Information System’s species occurrence data set (OBIS 2023). These two data sets represent a significant aggregation of species occurrences within the region of interest. Specifically, the NOAA deep-sea coral and sponge database is a comprehensive, standardized and quality-controlled resource focused entirely on those species groups with a depth minimum of 50 meters (m). The database integrates linear (trawl and transect) and point (single point observations) from all azooxanthellate corals and all sponge species. OBIS data did not have such species group curation, rather this database aggregates all species, providing the species names are valid and the data record itself meets the minimum required fields. Hence, in the present study, NOAA records are considered as a curated data source and take priority over OBIS records when developing benthic receptor layers. Data sets included historical (pre-1990) records, some of which had reported locational accuracy greater than 1,000 m. However, those with low reported locational accuracy represent less than 1% of the total records.

Records from both data sources with taxonomic accuracy to at least the family level were obtained within a 25 km buffer region around the boundary. This boundary was used to reduce edge effects in statistical analysis and development of the benthic receptor layers, and also to ensure that any occurrences outside of the AoA that may be affected by impacts that can disperse over large distances are noted. These data were filtered to include only benthic functional groups as listed within the World Register of Marine Species (WoRMS). For the OBIS data set, which includes all available phyla, this was performed using the "robis" R package and the "get_worms_fgrp" function (https://github.com/tomjwebb/WoRMS-functional-groups) that matches functional groups to species level unique AphiaIDs from WoRMS. All AphiaIDs with benthic life stages were matched to the AphiaIDs of the OBIS data set. For the NOAA data set, all records of coral, sponge, and sea pens were retained while those identified as any other group were removed. These records were merged to a single data set, with any duplicate records between the two data sources identified. In the event of duplicate records, the record sourced from NOAA was retained over the duplicate OBIS record. It is important to note that these layers are presence only, thus absence of points does not necessarily reflect absence of benthic receptors. Further, these layers are not a direct representation of sampling effort, and it is likely that there are further private or undocumented surveys in the region that are not captured by the data sets.

The combined data set was then further refined to only include benthic receptor species groups (deep-sea corals, deep-sea sponges and sea pens). All cnidarians in the orders Scleralcyonacea, Malalcyonacea, Scleractinia, Antipatharia, and all poriferans in the classes of Demospongiae, Hexactinellida, and Calcarea were retained. Vernacular name categories were assigned to all records based on those that were intrinsic to the NOAA data set, including term names such as "stony coral (branching)," "demosponge," "sea pen," etc. Any records which did not have intrinsic vernacular name categories (e.g., OBIS-sourced records that did not have an exact scientific name match to any records in the NOAA data set) were cross-referenced to the WoRMS database and/or morphological and taxonomic criteria and assigned the best matching existing vernacular name category. A kernel density estimate (KDE) was conducted using a grid size of 10 × 10 km and a bandwidth of 25 km for each specific benthic receptor as well as a combined estimate of receptor presence. Maps and descriptions of occurrence records and occurrence intensity are provided in section 2; however, these occurrences do not necessarily imply absence of receptor species, but rather documented presence without true sampling effort estimates.

2.2.2 Physical Receptor Methods

Because many biological taxa that are most vulnerable to offshore wind development live on stable hard bottom habitats, predicted likelihood of hard bottom was used as the physical habitat receptor for the sensitivity analysis. Three data sets were combined to create a single data layer: (1) a quantitative prediction of mean hard bottom likelihood with coverage of most of the southern portion of Zones 1 and 2 of the AoA (Battista, 2019), and two fill the remaining gaps in the AoA, (2) seabed forms (TNC 2010, updated 2020) in Zone 2 where there is good correspondence to likely hard bottom substrates, and (3) interpolated soft sediment data (TNC 2010, updated 2020) in all other locations. A nominal ranking from least to most likely to have hard bottom substrates was applied to the latter two using best professional judgment.

2.3 Biological Benthic Data

The AoA for the spatial studies contains a substantial number of potentially sensitive benthic receptors, with 12,055 receptor occurrence records collated within the boundary of the AoA. Zone 2 hosts the largest number of occurrences with 10,436 records (Figure 2 and Table 2) with significant clustering along the complex topography of the slope that transects across Zone 2 (Figure 3). The following sections review the biological benthic receptor groups proposed with a focus on providing basic descriptions and an overview of their distribution patterns within the AoA. The deep ocean is widely acknowledged as the least explored and understood of all marine habitats on earth (Ramirez-Llodra et al. 2010). Complete knowledge of species distributions, abundance, biomass, and responses to anthropogenic impacts (ranging from direct human contact to climate change) is lacking, which in turn poses challenges to conserve and manage these species in areas where human impacts overlap (Gros et al. 2022; Clark et al. 2016). Many studies point to the exceptional vulnerability of habitat-provisioning benthic species, where their loss or damage at a habitat scale can significantly impact the local ecosystem, effectively causing high levels of biodiversity loss and reduction in ecosystem function (Huvenne et al. 2016; Pham et al. 2019).

Figure 2. Occurrence Records for All Biological Receptors Found within the Area of Analysis and Surrounding 25 kilometer Buffer

Source: NOAA Deep-Sea Coral Research and Technology Program (NOAA DSCRTP) and Ocean Biodiversity Information Systems (OBIS).

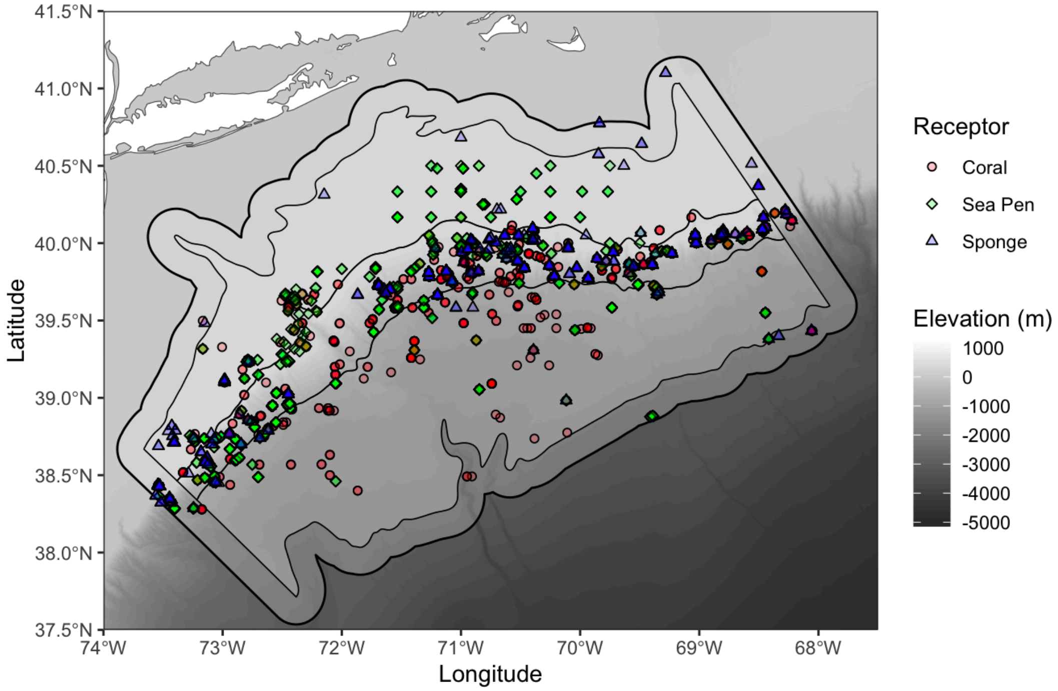


Figure 3. Kernel Density Estimation of Occurrence Data for All Biological Receptors within the Area of Analysis

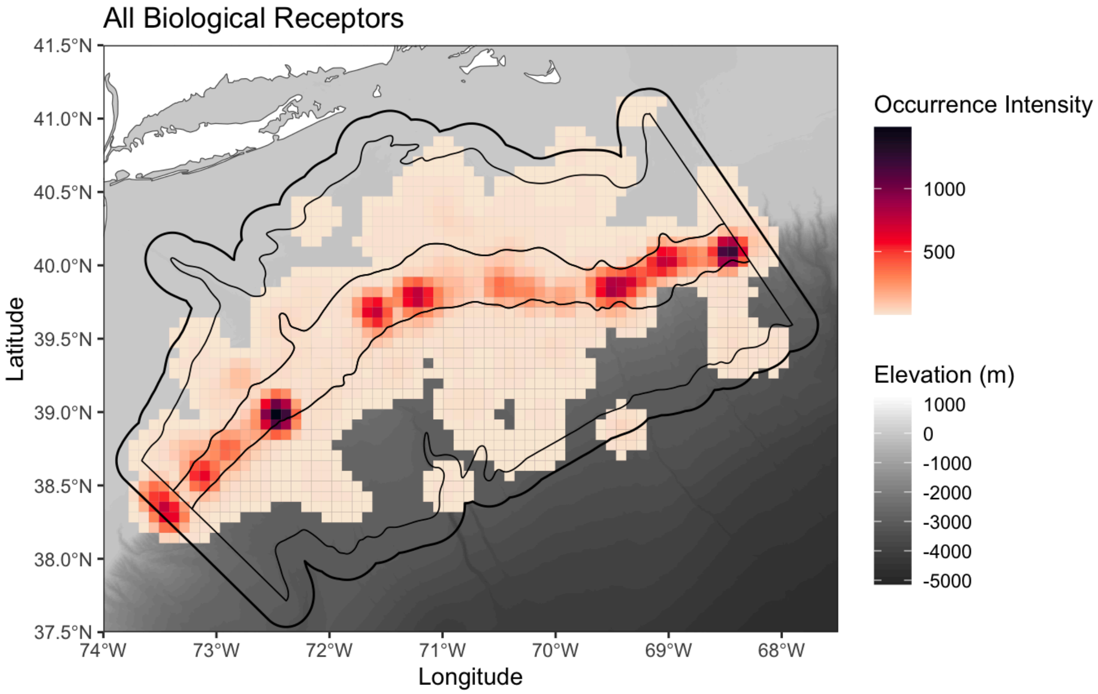


Table 2. Benthic Spatial Data Search Categories

Abundance (Abun) of records is provided along with minimum species richness (SR) estimates, based on the number of distinct species names (this number does not reflect records that had taxonomic accuracy other than species level).

Zone	Corals		Sponges		Sea Pens		All Receptors	
	Abun.	SR	Abun.	SR	Abun.	SR	Abun.	SR
Zone 1	194	4	63	7	294	16	551	27
Zone 2	8,493	36	939	21	1,004	73	10,436	130
Zone 3	597	21	56	3	415	36	1,068	60
All Zones (AoA)	9,284	43	1,058	27	1,713	87	12,055	157
All Zones + 25 km buffer	9,844	44	1,377	30	2,188	92	13,409	166

2.3.1 Deep-Sea Corals

Deep-sea corals are species of Cnidaria*,* primarily from the orders Scleractinia (stony corals), Malalcyonacea and Scleralcyonacea (formerly Alcyonacea: McFadden et al. 2022), and Hexacorals (black corals). Unlike their shallow and mid-depth counterparts, deep-sea corals in the aphotic zone lack zooxanthellae and heterotrophically feed on passing particles for nutrition (Orejas et al. 2016). Food sources consist of predominantly large zooplankton but deep-sea corals are generally opportunistic and may feed on a variety of organic particles (Duineveld et al. 2004; Kiriakoulakis et al. 2004, 2007). However, certain deep-sea coral species may have distributions that extend into mesophotic environments (low-light zones between approx. 50–150 m) and have been found to be apozooxanthellate, i.e., containing zooxanthellae within some depths but not others (Muir and Pichon 2019).

Several studies have demonstrated strong coupling in the delivery of food via physical oceanographic processes, such as tidally driven advection, down-welling and benthic-pelagic coupling (Davies et al. 2009; Maier et al. 2023), largely in areas where there is complex topography and hard substrate (Genin et al. 1986). Most deep-sea coral species are found at depths deeper than 200 m, although they have been observed in shallower depths, such as in Norwegian fjords where specific oceanographic conditions are suitable for growth at depths of < 40 m (Strømgren 1971) and in mesophotic depths described above.

The environmental drivers that govern the distribution of deep-sea corals have been established through observations and habitat suitability modeling and point to generally cool waters (4-12 °C), oceanic salinities (~35 on the practical salinity scale) and saturation in aragonite and calcite ($\Omega > 1$) as critical parameters (Davies and Guinotte et al. 2011; Yesson et al. 2012; 2017a). However, this is now being contested with increasing findings of healthy and abundant deep-sea coral systems outside of these ranges (Baco et al. 2017; Brooke et al. 2013; Hebbeln et al. 2020).

Packer et al. (2007, 2017, 2022) described the presence of four major orders of deep-sea corals along the Northeast U.S. shelf. These orders can be generalized by their vernacular names as (1) black corals (Antipatharia), (2) branching and solitary stony corals (Scleractinia), and (3) octocorals (Octocorallia) which include various gorgonians, soft corals, stoloniferan corals and sea pens (McFadden et al. 2022). Although sea pens are included within the octocorals, the present study considers them separately (section 2.3.3).

Within the AoA, coral records obtained from database searches, represent at least 47 distinct species (Table 2). The majority (n = 8,493) of coral records are located within topographically complex canyon features along the continental shelf slope in AoA, Zone 2, where hard bottom substrate is present, along with high currents and significant depth gradients that interact with highly variable topography (Figure 4 and Figure 5). Additional clusters were observed at the upper shelf of Hudson Canyon in AoA, Zone 1, composed primarily of stony cup coral species and black coral (Figure 4 and Figure 5).

Figure 4. Presence of Deep-Sea Coral Taxa in the Area of Analysis

Source: NOAA and OBIS databases

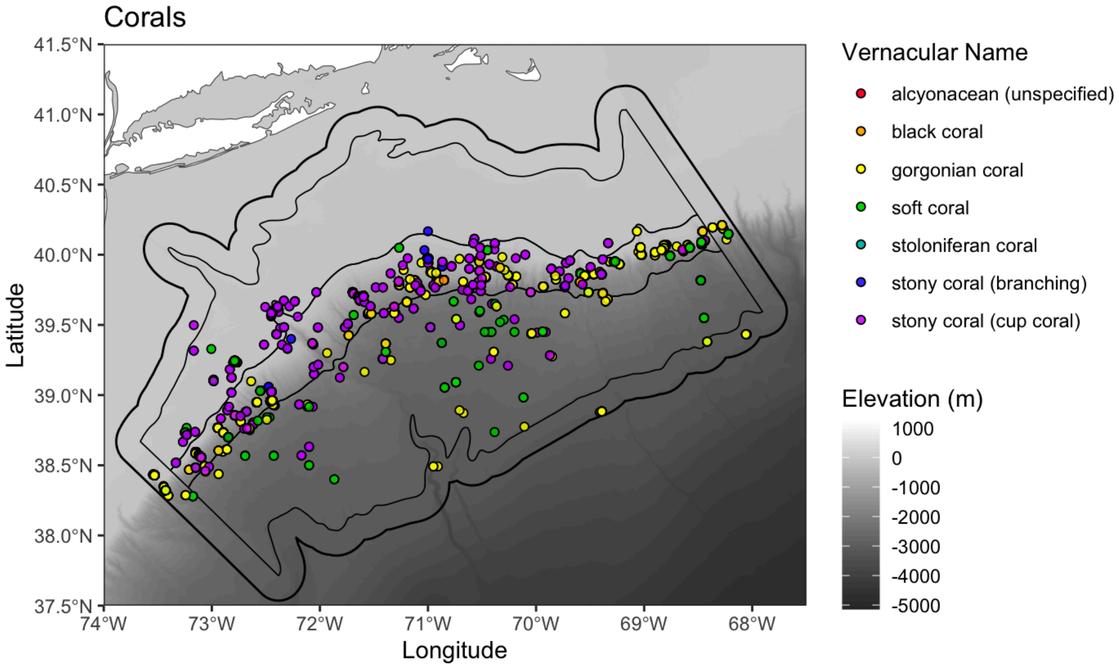
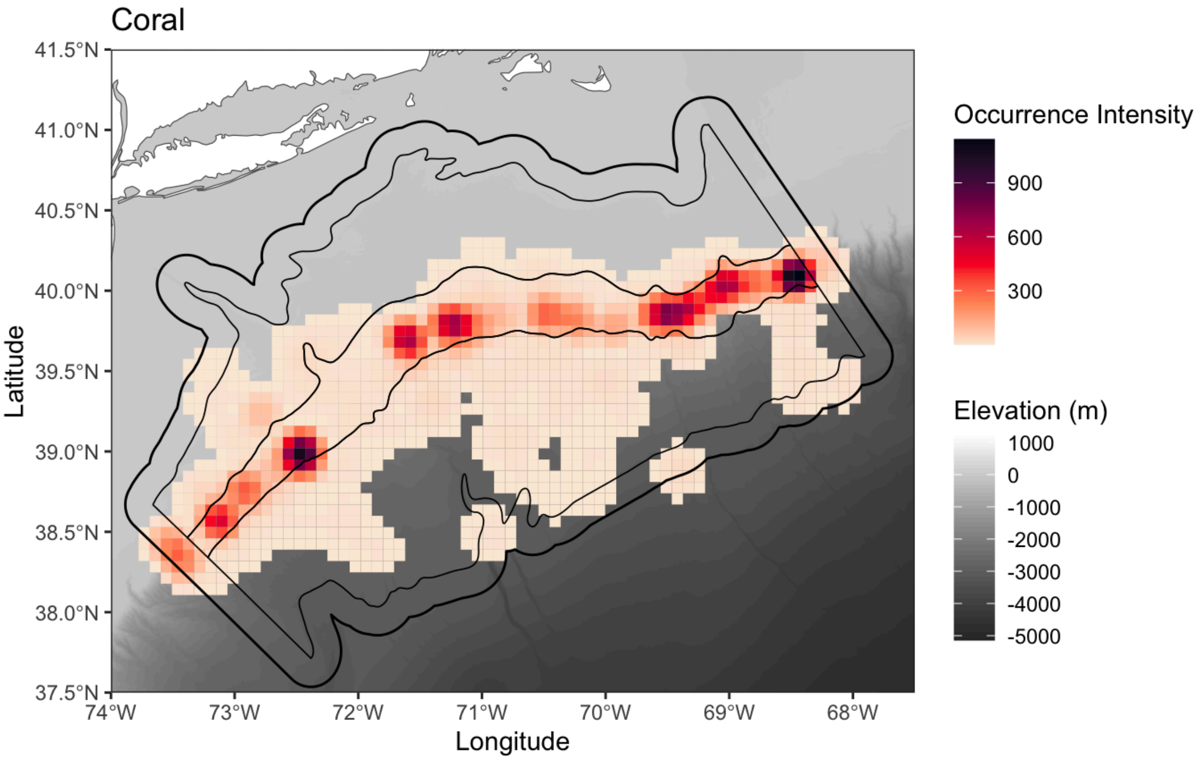


Figure 5. Deep-Sea Coral Occurrence Intensity Calculated Using Kernel Density Estimation



Exceptions to observed distributions within canyons were those occurrences of certain gorgonians (*Acanella* spp.) and species of stony cup corals (*Flabellum* spp.), which can be found within soft sediments. These findings agree with Packer et al., (2007) and Packer et al., (2017), who used a large portion of the same data used in this study. These two sources represent an exceptional series of reviews into the coral habitats of the AoA and the broader New England shelf and slope.

2.3.1.1 Gorgonians and Other Soft Corals

Gorgonians and other soft corals (orders Scleralcyonacea and Malacalcyonacea; McFadden et al. 2022) are the most diverse group of corals in the world. Over 3,000 species are described in this group, most which are found in waters deeper than 50 meters (Cairns 2007). Unlike stony corals, gorgonians and other soft octocoral species build relatively flexible internal skeletons, allowing them to adapt to varying water flow conditions in both mesophotic and deep-sea environments and may benefit their particle capture (Boudina et al. 2021). While these species do not form reefs, they can form single or multi-species assemblages known as “coral gardens” or more recently, “marine animal forests.” These habitats, when in high density, can have significant influence on local biodiversity and ecosystem function and are classified as vulnerable marine ecosystems (Buhl-Mortensen et al. 2010; Edinger et al. 2007).

In the AoA, most coral records (5,642 of 9,248 records) belong to gorgonian (4,574 records) or soft coral families (soft or stoloniferan corals: 682 records; unspecified: 209 records). Gorgonians are also the most diverse group of corals present in the AoA, with nine families represented, including, *Acanella spp*. (bamboo coral; the most abundant coral genus with 831 occurrences), *Acanthogorgia spp*., various plexaurid corals (e.g., *Swiftia spp*. and *Paramuricea spp*.), and corals within the Chrysogorgiidae and Primnoidae families. Common soft corals included *Anthomastus spp.* and *Trachythela rudis*. Most gorgonian and soft corals were largely associated with hard bottom canyon features, except for *Acanella spp*., which could also be found within soft sediment substrata (Figure 4).

2.3.1.2 Black Corals

Black corals (order: Antipatharia) generally inhabit mesophotic and deep-sea regions below 50 meters depth. They are widely known for their use in human and cultural industries, including in jewelry-making and traditional medicine in other regions of the world (Wagner et al. 2012). Despite their name, which is derived from their dark-colored inner skeleton, black corals can display a range of morphological characteristics, including a variety of colors (Cairns 2007).

Black corals possess a rigid, protein-based skeleton composed of chitin, which sets them apart from the calcium carbonate skeletons of stony corals and the more flexible skeletons of soft corals and gorgonians (Goldberg 1976). They are found in both shallow and deep-sea environments worldwide, inhabiting a variety of substrates, including boulder reefs, various hard bottom structure, and seamounts (Yesson et al. 2017a). However, the highest abundances of black corals have been found within deeper depth zones, possibly as a response to competitive exclusion with photosynthetic corals (Wagner et al. 2012). Because of an inability to retract their polyps in the same manner as other cold-water coral groups, most black corals perform poorly in areas with high sediment cover (Daly et al. 2003); however, a few species of black corals (those in the families Schizopathes and Bathypathes) are reported to inhabit muddy or soft sediment ecosystems due to their modified hooked holdfasts (Opresko 2002).

Some species of black corals contain photosynthetic zooxanthellae symbionts, allowing them to derive additional nutrients from sunlight when present, although this is not a primary source of food for Antipatharians (Bo et al. 2011; Wagner et al. 2012). Like other coral groups, black corals provide habitat and shelter for a variety of organisms, including small fish, invertebrates, and other coral-associated species (De Clippele et al. 2019; Love et al. 2007; Roark et al. 2009). Black coral communities also contribute to the overall biodiversity and resilience of marine ecosystems, particularly in deep-sea environments where they may form dense aggregations and forests (Wagner et al. 2012).

In the AoA, 495 records of black coral, primarily in the family Schizopathidae (also present: *Stichopathes spp*. in the Antipathidae family, 9 records) are present throughout the shelf break of Zone 2 and sparsely clustered at the upper portion of Hudson Canyon within Zone 1 (Figure 4). The most common records are *Parantipathes spp*. and *Bathypathes spp*., with 283 and 90 records, respectively.

2.3.1.3 Stony Corals

Cold-water Scleractinia, or stony corals, are a diverse group of corals that inhabit mesophotic and deep-sea ecosystems in all oceans (Freiwald et al. 2004; Roberts et al. 2009). Some species of Scleractinia generate complex calcium carbonate skeletal structures that can create multifunctional habitat for various deep-sea organisms, such as reefs or within coral gardens (Roberts et al. 2006). Communities formed by cold-water Scleractinia are considered biological "hotspots," hosting biodiversity several times greater than surrounding areas (e.g., Buhl-Mortensen and Mortensen 2010; Henry and Roberts 2007). Distinct from their shallow-water counterparts, these corals inhabit a wide range of deep-sea environments, including seamounts, canyons, and continental slopes, often occurring in depths below 200 meters (Davies and Guinotte 2011).

Two major morphological groups exist for deep-sea Scleractinia: branching corals, that is, *Desmophyllum pertusum* (formerly *Lophelia pertusa;* Addamo et al. 2016) and *Solenosmilia variabilis*, which are primary reef-building species, and solitary cup corals, such as *Desmophyllum dianthus* and *Flabellum* spp., which may form habitats on a small scale, including in areas of soft sediment (Brooke et al. 2017). Distribution of deep-sea Scleractinia depends on several physical and environmental parameters, including locally enhanced current speeds, temperature thresholds, hard bottom features, depth, dissolved oxygen concentration, food supply, and others (Auscavitch et al. 2020; Davies & Guinotte 2011). However, knowledge of the patterns that control coral distribution and the extent to which corals exist outside documented tolerances is still evolving. While deep-sea Scleractinia are long-lived, they may be particularly vulnerable to disturbance relative to shallow stony corals due to their slow-growth rate, especially in deeper waters (< 30 millimeters per year) and low-recovery rates to anthropogenic stressors, such as dispersants (Orejas et al. 2007; Weinnig et al. 2020).

Stony corals accounted for 3,147 of the coral occurrence records, subclassified by vernacular names as either "branching" or "cup" corals (Figure 4). The most common coral within the AoA was *Desmophyllum dianthus*, a cosmopolitan cup coral generally associated with hard substrate. Despite their solitary nature, cup corals may grow in dense arrays that provide near-bed structure, even forming pseudo "colonies" in which individual corals grow on top of one another (Försterra et al. 2005). Branching stony corals alternatively form complex colonies with intricate branching structures. *Desmophyllum pertusum* is a branching species despite its shared genus with *D. dianthus*. Of note, however, this shared genus is a result of the reclassification of *Lophelia pertusa* to the *Desmophyllum* genus, which has been accepted by the World Register of Marine Species (WoRMS) based on mitochondrial and microsatellites genetic similarities (Addamo et al. 2016). However, opinions on this transfer vary among coral scientists and molecular taxonomists alike and the former name *Lophelia pertusa* remains widely used within the scientific community. Though a delay in this reclassification is indicated by some until additional molecular evidence is provided, we have opted to utilize *Desmophyllum pertusum* in the present report to align with the data sources used, both of which are based upon taxonomic data from WoRMS (OBIS, NOAA). Although *D. pertusum* is one of the predominant reef-forming corals in the Atlantic, only 10 records of *D. pertusum* were present in the AoA, which likely indicates presence of singular colonies rather than mature *D. pertusum* reefs. However, at least 371 records of *Solenosmilia variabilis*, another branching scleractinian generally associated with deeper regions of the northeastern canyons than *D. pertusum* (Brooke and Ross 2014), were present throughout canyons within Zone 2 of the AoA (Figure 4).

2.3.1.4 Habitat Suitability Models for Deep-Sea Corals

Habitat suitability models, also known as species distribution models, are increasingly used in science, conservation, and management, particularly for the study of species that are incompletely sampled (Vierod et al. 2014; Winship et al. 2020). These models work by quantifying the relationships that species have with environmental predictors and building a geospatial representation of potential habitat for the modelled species (Elith and Graham 2009; Hirzel and Lay 2008; Philips et al. 2006). For species such as deep-sea corals, habitat suitability models have become a primary tool, with assessments ranging from local (e.g., Rengstorf et al. 2013; Rowden et al. 2017), to regional (e.g., Anderson et al. 2016a; 2016b; Guinotte and Davies 2014; Kinlan et al. 2020) and even global scales (e.g., Davies and Guinotte 2011; Yesson et al. 2012; 2017a). However, they are not without their limitations, as models in deep-sea studies are primarily built on presence-records only, with no true absences, and may be built upon incomplete environmental data or poor taxonomic information (Vierod et al. 2014).

In the Northeast USA region, Kinlan et al. (2020) reported on the development of high-resolution (370-meter grid size) regional scale models for deep-sea coral species that cover Zones 1 and 2 of the AoA and a portion of Zone 3 (Figure 6, Figure 7 and Figure 8). Using the widely adopted Maxent statistical approach (Philips et al. 2006), they developed predictions for nine taxonomic groups within subclass Octocorallia (orders Malacalcyonacea and Scleralcyonacea, inclusive of sea pen superfamily Pennatuloidea) and order Scleractinia (Flabellidae and Caryophylliidae). The model did not include black corals (Antipatharia).

Their findings largely reflected reported occurrence distributions from the NOAA and OBIS databases reported above, with canyon habitats being highly suitable for large structure forming species, whereas sea pens were reported in the predominantly soft sediment areas of the shelf and slope. Importantly, this study also conducted limited field verification of generated models, successfully verifying several areas that were predicted to contain corals (Packer et al. 2017).

To generate an expression of habitat suitability for coral benthic receptors, this study used data from Kinlan et al. (2013; 2020) to generate representations of suitable habitat for the AoA for gorgonians and soft corals, stony corals and sea pens (Figure 6, Figure 7 and Figure 8). These outputs are classified into very low, low, low-medium, medium, high, and very high-habitat suitability, and can be interpreted as high and very high representing a strong likelihood of this area supporting deep-sea coral habitat. Areas ranked low-medium and medium may contain suitable habitat, but further detailed investigation would be needed. Low or very low indicates potentially unsuitable habitat where these species are unlikely to be found. The model for gorgonians and soft corals (Figure 6) was the most constrained of all three models, with high and very high-suitable habitat predicted in some canyons; however, much of the AoA Zone 2 was predicted to contain medium suitable habitat. Stony corals were predicted to have high- and very high-suitable habitat within the rugose terrain of the slope, primarily in Zone 2 (Figure 7), with some areas predicted near Hudson Canyon in Zone 1. In contrast, for sea pens (Figure 8), high and very high-suitable habitat was predicted mostly within the shallower areas of Zone 2, with some areas also on the shelf in Zone 1.

Figure 6. Habitat Suitability Model Output for Gorgonians and Soft Corals (formerly Alcyonacea) within the Area of Analysis

Source: Kinlan et al. (2013; 2020)

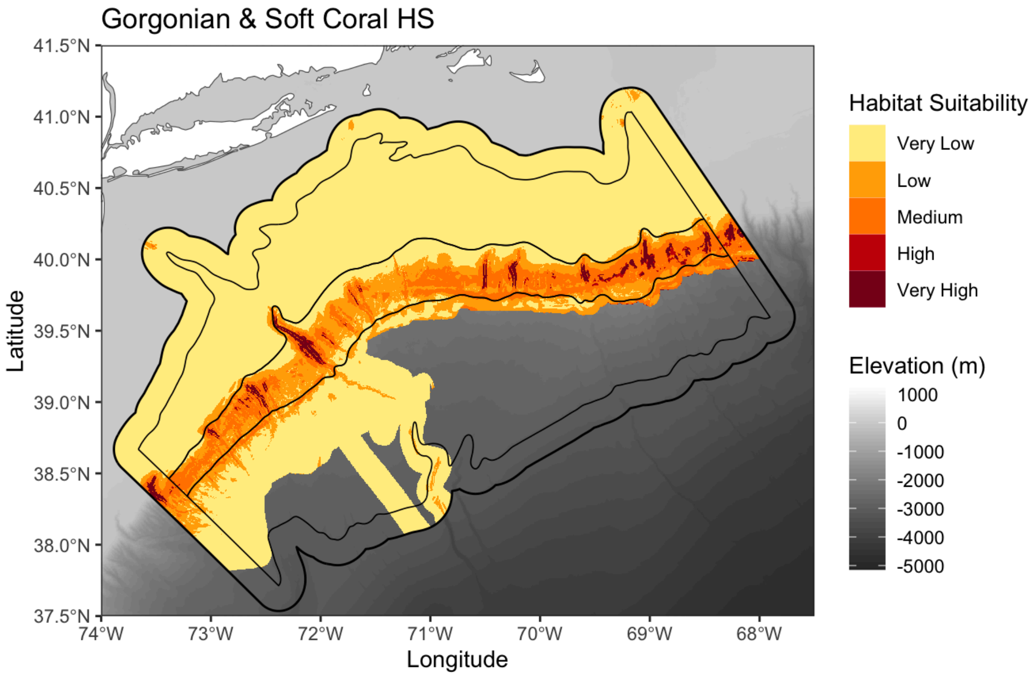


Figure 7. Habitat Suitability Model Output for Deep-Sea Stony Corals within the Area of Analysis

Source: Kinlan et al. (2013; 2020)

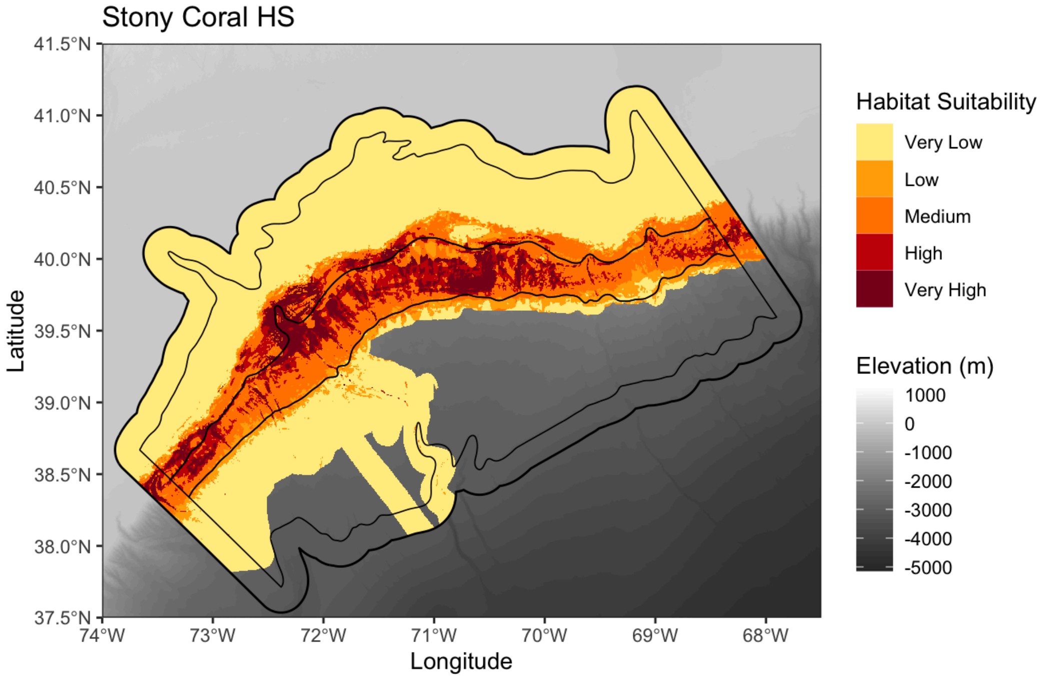
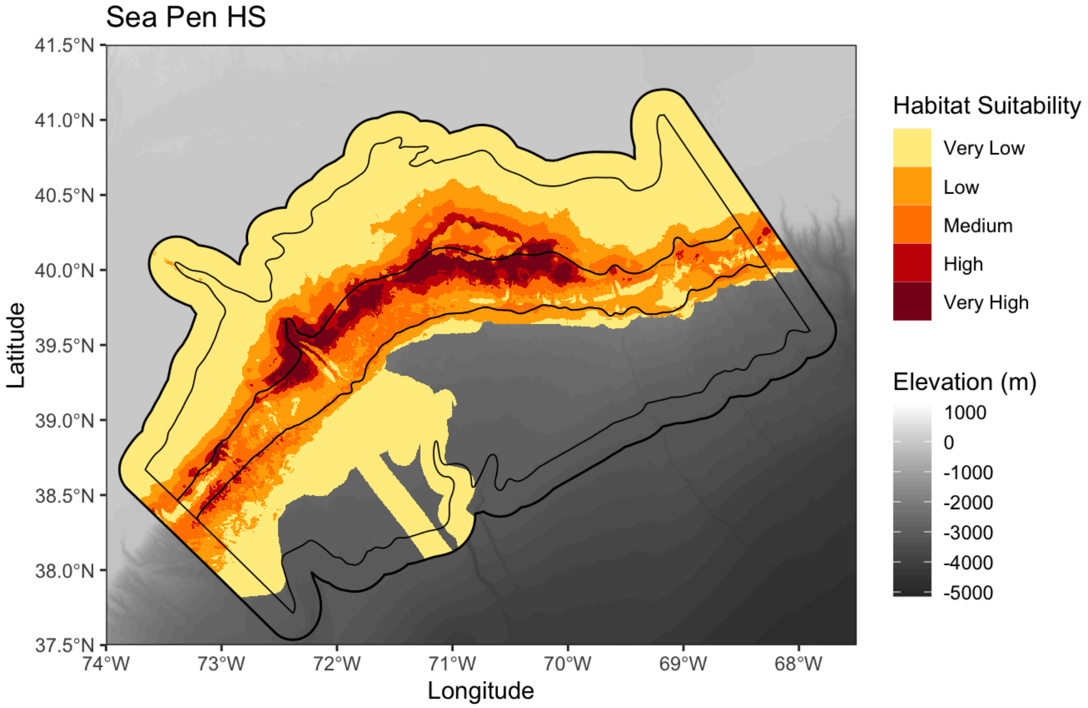


Figure 8. Habitat Suitability Model Output for Sea Pens within the Area of Analysis

Source: Kinlan et al. (2013; 2020).



2.3.2 Sponges

Sponges, phylum Porifera, are considered an important component of deep-sea biogenic reef ecosystems, with research intensity increasing substantially in recent years. These species, while abundant, remain substantially understudied compared to other benthic receptors (Bell et al. 2018; Maldonado et al. 2017). In some areas, dense aggregations of sponges can be formed, comprised of either a single or multiple species, known as sponge grounds (Hogg et al. 2010). In a manner like coral reefs (e.g., Costello et al. 2005), sponges exert strong influence habitat complexity, leading to increased local diversity and habitat provision for other species (Buhl-Mortensen et al. 2010; Hawkes et al. 2019; Meyer et al. 2019). Additionally, sponges have been shown to contribute to nutrient and carbon cycling due to their significant pumping capacity (De Goeij et al. 2013; Maldonado et al. 2019). However, despite appreciation of their emerging functional importance, there remains only limited information about the distribution and potential responses of deep-sea sponge grounds to anthropogenic impacts (Vad et al. 2018). In the deep North Atlantic, sponge grounds are generally dominated by large structure-forming demosponge species from the genus *Geodia* (Class Demospongiae) (Klitgaard and Tendal 2004).

Regional differences in sponge ground composition exist, such as in the Northwest Atlantic where deep-sea sponge grounds can be comprised of mixed assemblages dominated by tetractinellid species (Murillo et al. 2012). However, recent research has identified large sponge grounds dominated by mono-specific aggregations, such as glass sponges (Class Hexactinellida) (Beazley et al. 2018; Beazley et al. 2021).

Sponges within the AoA are classified as demosponges, glass sponges, or calcareous sponges accounting for 1,058 total sponge records (365, 615, and 78 records respectively; Figure 9 and Figure 10). Though glass sponges are most abundant, demosponges are the most diverse, representing at least 17 distinct species (glass sponges: 9 species; calcareous sponges: 3 species). Like most coral records, sponges are also associated with hard bottom features present in the AoA and are similarly aligned with canyon features along the shelf break in Zone 2, except for a few sparsely distributed demosponge occurrence records in soft and hard bottom throughout the AoA. The most commonly reported sponges are the glass sponges Asconema foliatum, and Regadrella spp., with 144 and 106 records, respectively. No occurrence records of sponges were obtained from the two databases explored around the head of Hudson Canyon, whereas many records exist for corals and sea pens. Although the occurrence records from NOAA and OBIS are lacking here, a recent publication indicates the presence of various Porifera species using video transects in the vicinity (Pierdomenico et al. 2017), supported by unpublished data reported by Packer and Dorfman (2012).

Figure 9. Presence of Deep-Sea Sponge Taxa in the Area of Analysis

Source: NOAA and OBIS Databases

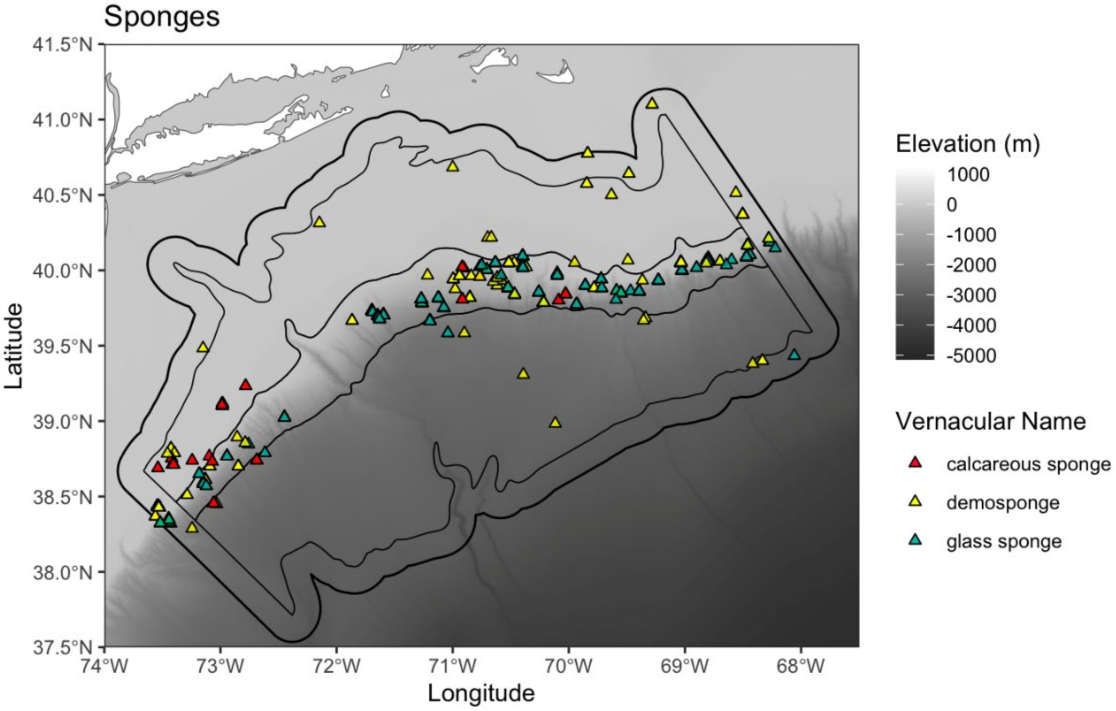
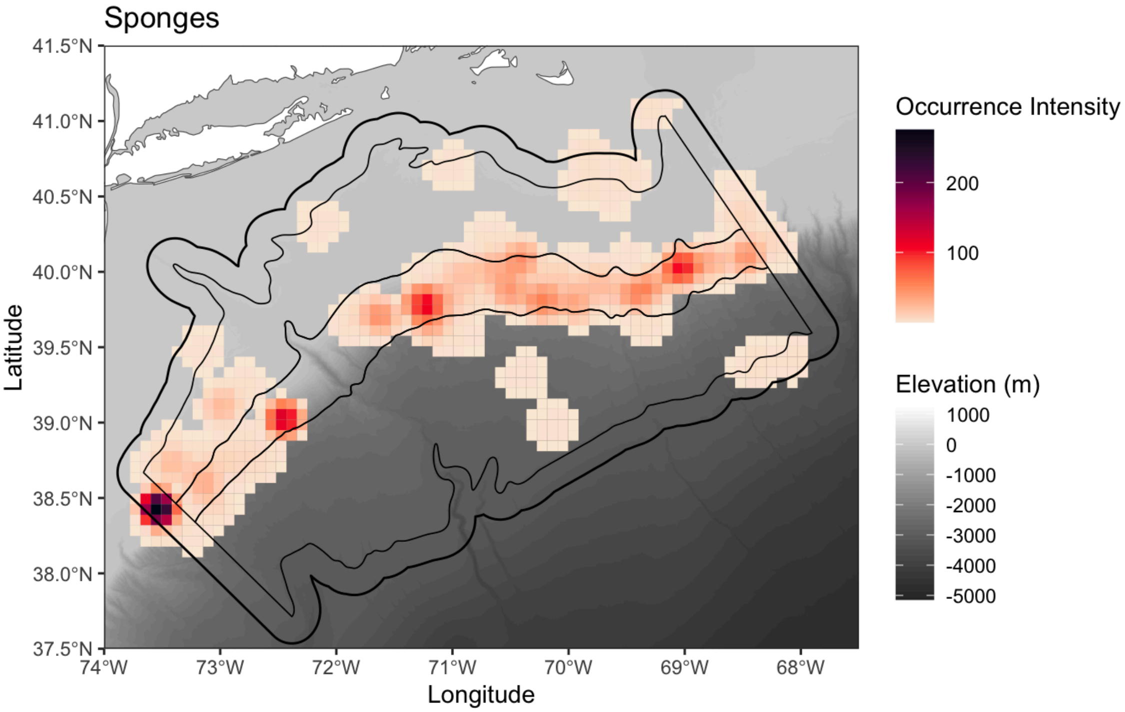


Figure 10. Kernel Density Estimate of Deep-Sea Sponge Occurrence Intensity



2.3.3 Sea Pens

Sea pens, named for their resemblance to plumed quill pens, make up the superfamily Pennatuloidea within the order Scleralcyonacea (formerly separate order Pennatulacea with suborders Sessiliflorae and Subselliflorae) (McFadden et al. 2022). These colonial corals are commonly found across a wide-depth range primarily in soft-sediment habitats, constructing an upright plume structure that is anchored into the substrate via a muscular peduncle (Williams 2011).

In some regions, sea pens aggregate within soft-sediment plains to form large “fields” of sea pen communities, which in turn constitute added habitat framework for various macrofauna in an otherwise uniform deep-sea plain (Miatta & Snelgrove 2022). Relatively little is known about the drivers of deep-sea sea pen distribution and biology, and it is in recent years that focus has turned to sea pens considering their potential role as critical habitat-formers in soft-sediment communities, their ability to create biodiversity hotspots, and their potential as macrofaunal community indicators (Packer et al. 2017; Miatta & Snelgrove 2022). Multiyear surveys revealed a high prevalence of fish larvae, like redfish (*Sebastes spp.)*, varying among five different species of sea pens (Baillon et al. 2012).

At least 17 distinct species, from 1,713 records of sea pens, were present in the AoA (Figure 11). Of these species, *Protoptilum* spp. were most common with 522 records, followed by *Kophobelemnon* spp. with 410 records. Sea pens appeared to be sparsely distributed within all AoA zones, but were most common along the deep areas of the lower shelf break and within canyons of Zone 2, with a subset of records clustered along the upper mouth of Hudson Canyon formed by *Stylatula elegans* and widely dispersed records in soft sediment within the central-east region of Zone 1 (Figure 12).

Figure 11. Presence of Sea Pen Taxa in the Area of Analysis

Source: NOAA and OBIS databases

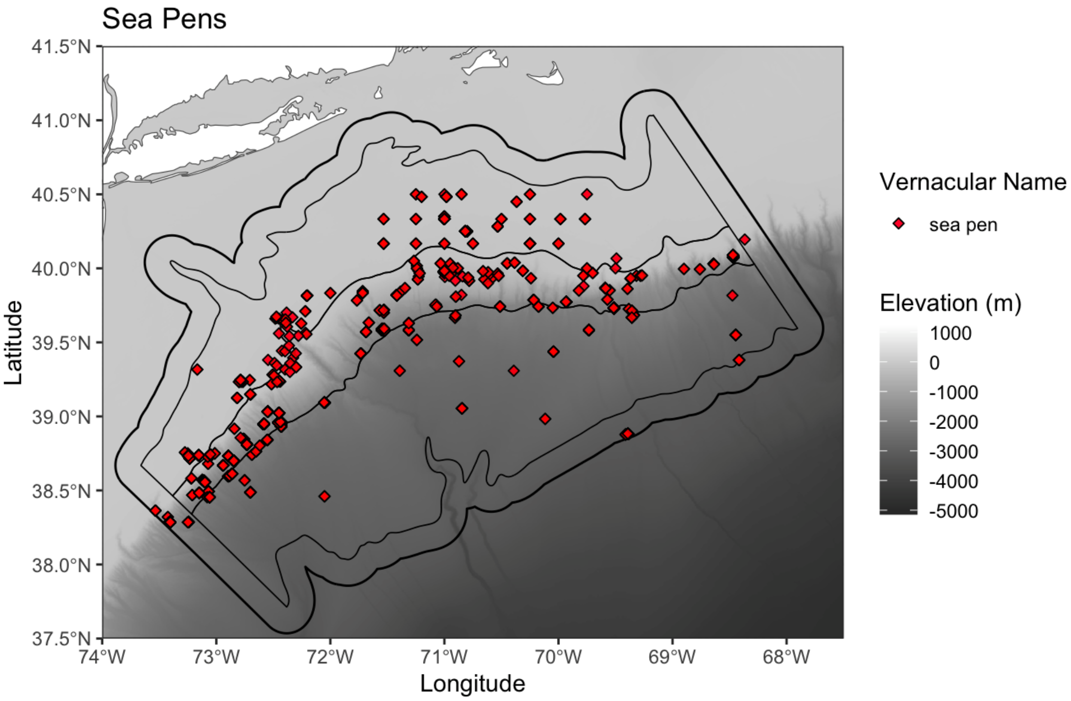
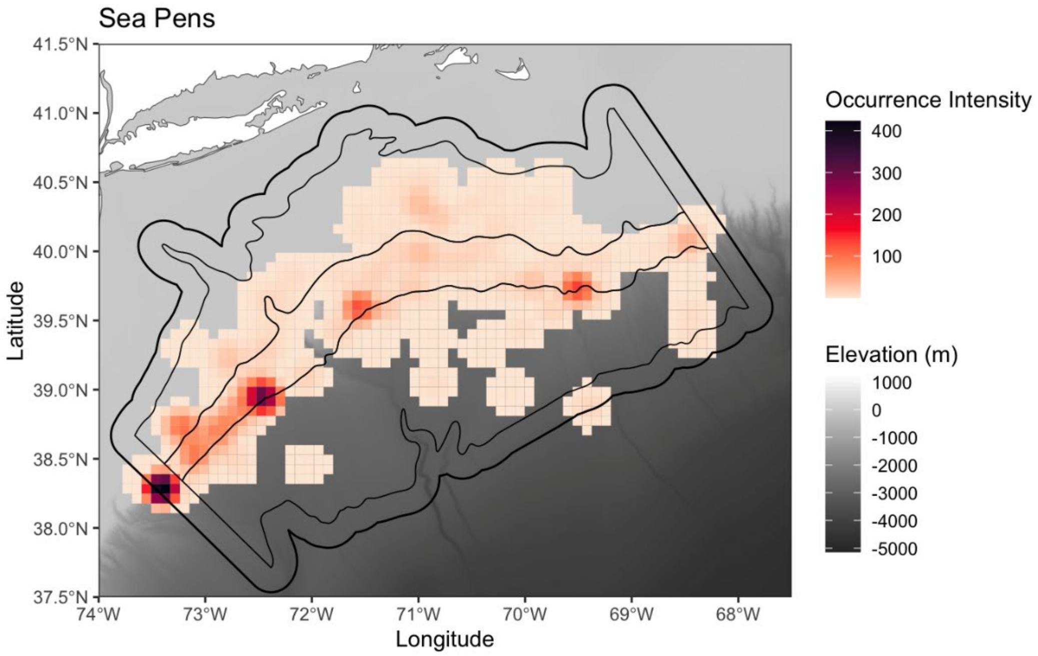


Figure 12. Kernel Density Estimate of Sea Pen Occurrence Intensity



2.4 Physical Habitat Data

It is important to document the physical attributes of the seafloor that compose benthic habitats within the AoA prior to identification of potential lease areas and construction activities. The physical environment includes sediment characteristics, including stability and topography of the seafloor. Together, physical characteristics predict the occurrence of species within the AoA.

2.4.1 Geophysical

Geophysical data available within the AoA consists primarily of bathymetric data (Figure 13), with sources from federal data collections by the NOAA Office of Coast Survey, USGS, and further collections by academic institutions with robust ocean mapping programs (University of New Hampshire, Woods Hole Oceanographic Institution). One of these data sources (Butman et al. 2017) also provided backscatter reflectivity at the Hudson Canyon (Figure 14), a prominent canyon within the canyon complex found in Zone 2 of the AoA.

Figure 13. Bathymetric Data with Complete Coverage in Zones 1 and 2 and the Nearshore Portion of Zone 3 of the Area of Analysis

Source: TNC 2010, updated 2020

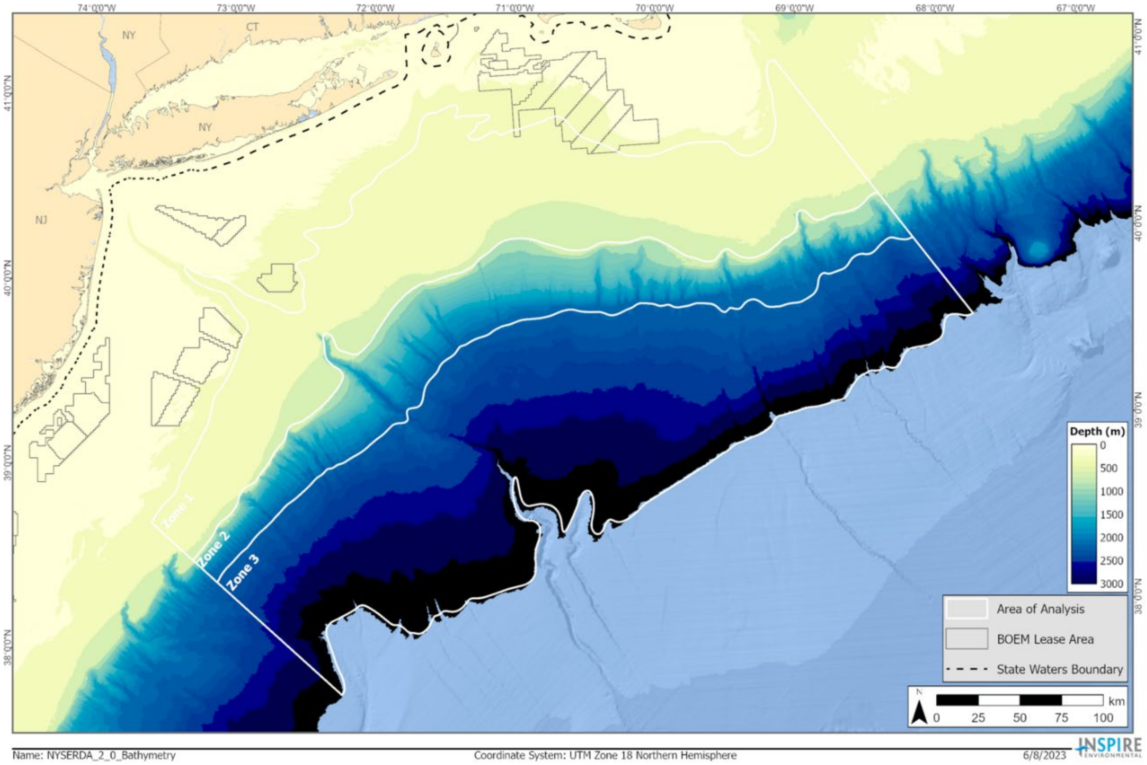
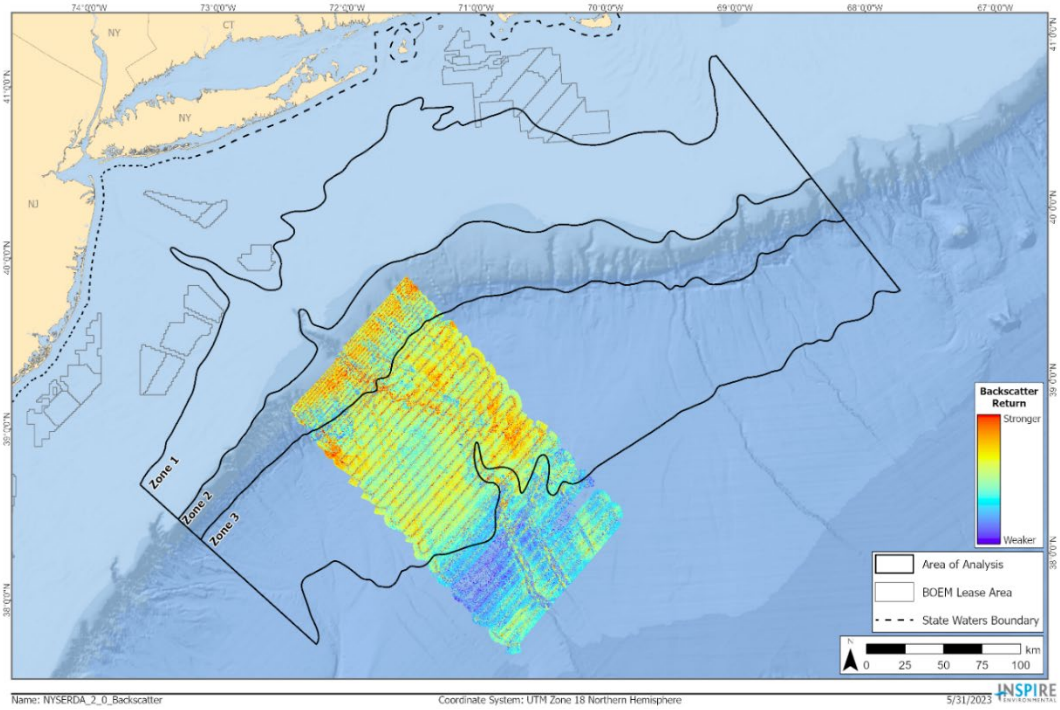


Figure 14. Backscatter Data in the Vicinity of Hudson Canyon with Coverage in Zones 2 and 3 of the Area of Analysis

Source: USGS; Butman et al., 2017



As described in section 1.2 of this study, the zonation of the AoA moves from the OCS in Zone 1 to the shelf break in Zone 2, to the area beyond the shelf break in Zone 3. Prominent differences in the overall depth and large-scale bathymetric features of the seafloor are evidence in regional bathymetric data (Figure 13). Hydrodynamics, sediment type, and large- and small-scale geomorphology are all influenced by these patterns in water depth and seafloor topographic relief. Therefore, widespread bathymetric data are essential to support assessments of the seafloor and foundational as predictive information regarding sediment types and benthic biological communities likely to be present. A synthesis of regional scale bathymetry provides nearly complete coverage for the AoA (Figure 13).

Bathymetric and backscatter data are collected from the same instrument, a multibeam echosounder (MBES); however, the settings on the echosounder can only be optimized for one of these data types. Most surveys prioritize optimization of bathymetric data collection as these data provide direct information about the depth of the seafloor and can be interpreted, compared, and combined with bathymetric data collected across different surveys and equipment (Brown et al. 2011). In comparison, backscatter reflectivity data are relative in nature and referred to in terms of low, medium, and high reflectance rather than absolute decibel values. Nominally softer, fine-grained sediments absorb more of the acoustic signal and a weaker signal is returned to the MBES. Although backscatter data provide valuable information about sediment grain size, decibel values reflect not only sediment grain size, but also compaction, water content, and texture (Lurton and Lamarche 2015). In addition to seafloor composition and texture, backscatter decibel values are also influenced by water temperature and salinity, sensor settings, seafloor rugosity, and MBES operating frequency, among others (Lurton and Lamarche 2015; Brown et al. 2019). Therefore, differences in backscatter decibel values can occur when data have been collected over a very large survey area under dynamic conditions, with different instruments, and in different years. This scenario is common and does not nullify the data; rather, expert-approved methods account for these variables by optimizing sensor-specific data processing and visualization for interpretation (Lurton and Lamarche 2015; Schimel et al. 2018). Backscatter data products vary based on processing (Lucieer et al. 2017) and data display procedures.

Backscatter data collected in Zones 2 and 3 of the AoA in the vicinity of Hudson Canyon reveal a mixture of low- to high-backscatter returns, along with sampling artifacts that clearly show survey vessel swath lines (Figure 14). Higher backscatter returns were interpreted, along with bathymetry, as the geomorphological features of canyon walls, floor, and floor-filled (Figure 15). At broad scales, differences in backscatter return are related to depth, with higher returns in shallower depths; this pattern is evident in the differences between areas in Zone 3 interpreted as upper rise and outside of Zone 3 interpreted as lower rise (Figure 14 and Figure 15).

2.4.2 Geomorphology

Data on geomorphology describes geologic formations found at various scales on the seafloor. Geomorphology has a strong influence on sediment distribution, and therefore, distribution of benthic biological communities. Geomorphology can also influence the distribution and settling of food supply; for example, steep canyon features can funnel food supply from the shelf and support high-benthic biomass. Two geomorphology data sets are available for the AoA. The authors of this study used geophysical data reported in Butman et al. 2017 to create a model of geomorphology in the vicinity of Hudson Canyon, with coverage in Zones 2 and 3 (Figure 15). TNC provided comprehensive geomorphological data across the AoA in their North American Ecoregional Assessment (TNC 2010, data updated 2020). Seabed form categories were derived from performing spatial neighborhood statistics on bathymetric data at both fine and broad scales and categorizing the results into named features, such as valley and mid flat (Figure 16). In the AoA, Zone 1, is primarily a low flat, consistent with its position on the continental shelf. Geomorphology present in regular patterns highlights the canyon topography along the shelf break in Zone 2 and these patterns continue to the edge of Zone 3 (Figure 16).

Figure 15. Geomorphological Data in the Vicinity of Hudson Canyon with Coverage in Zones 2 and 3 of the Area of Analysis

Source: USGS; Butman et al., 2017

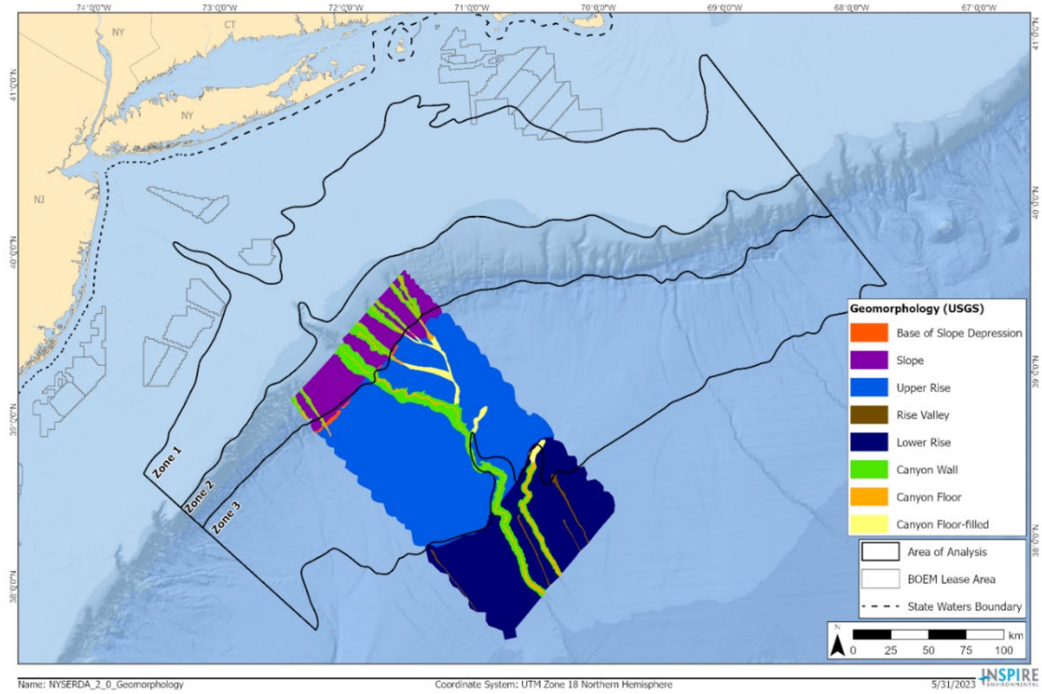
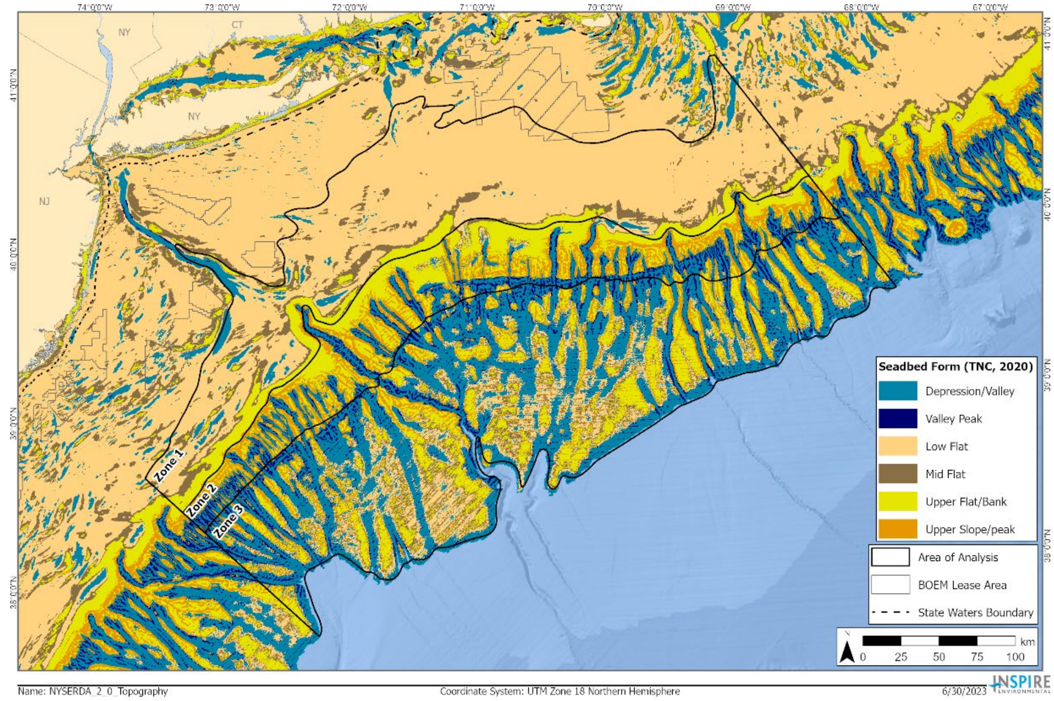


Figure 16. Topographic Seabed Forms with Nearly Full Coverage of the Area of Analysis

Source: TNC 2010, 2020 update

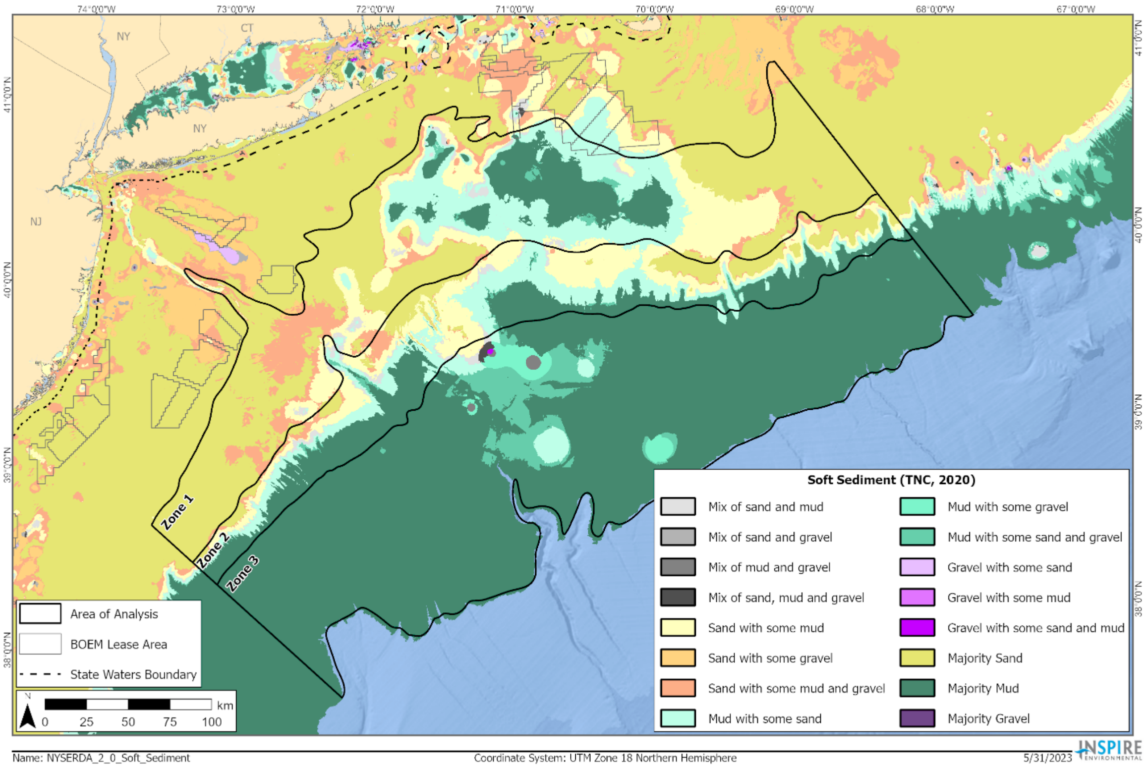


2.4.3 Sediment

Distribution of sediment types on the surface of the seafloor is influenced by bathymetry, hydrodynamics, and sediment supply. Multiple governmental and publicly available data sets on sediment type are available with some degree of overlap with the AoA (appendix A). Notable sources include the USGS usSEABED database and TNC's North American Ecoregional Assessment interpolated soft sediment data set, which uses the usSEABED data as the primary input and was recently updated (2020) using empirical Bayesian Kriging (EBK) regression (Figure 17). The outer continental shelf is primarily sandy with patchy distributions of gravel and mud in some locations, the continental slope marks a transition from predominant sand to predominant mud, and offshore of the slope, muds dominant the deep abyssal plain (Figure 17). Patchy areas of gravel are generally associated with the Hudson Canyon and Hudson Shelf Valley and areas with higher rugosity, particularly along the continental slope (Figure 17). Because this interpolated data set uses results from grab samples at point locations, it underrepresents presence of hard bottom substrates (e.g., continuous cobble and/or boulder, bedrock). Hard bottom substrates are associated with the canyons present along the continental slope, as discussed below.

Figure 17. Soft Sediment Interpolated Data with Nearly Full Coverage of the Area of Analysis

Source: TNC 2010, 2020 update



USGS created a model of substrate and sediment properties (Battista 2019) for much of the New York Bight with coverage of most of the southern portion of Zones 1 and 2 of the AoA (Figure 18 and Figure 19). Benthic data collected in support of New York's Offshore Wind Master Plan were utilized to update this model. Although multiple parameters were assessed, median grain size and hard bottom likelihood were selected as primary results for benthic assessment of the AoA (Figure 18 and Figure 19). Similar to patterns revealed in the TNC soft sediment data, larger median grain sizes are associated with canyon and slope features (Figure 18). The relief and rugosity of the continental slope and relative hardness of the seafloor is revealed in detail in the predicted likelihood of hard bottom, with numerous linear canyons characterizing Zone 2 (Figure 19).

Figure 18. Predicted Median Grain Size Data Available for the Southern Portions of Zones 1 and 2 of the Area of Analysis

Source: USGS; Battista, 2019

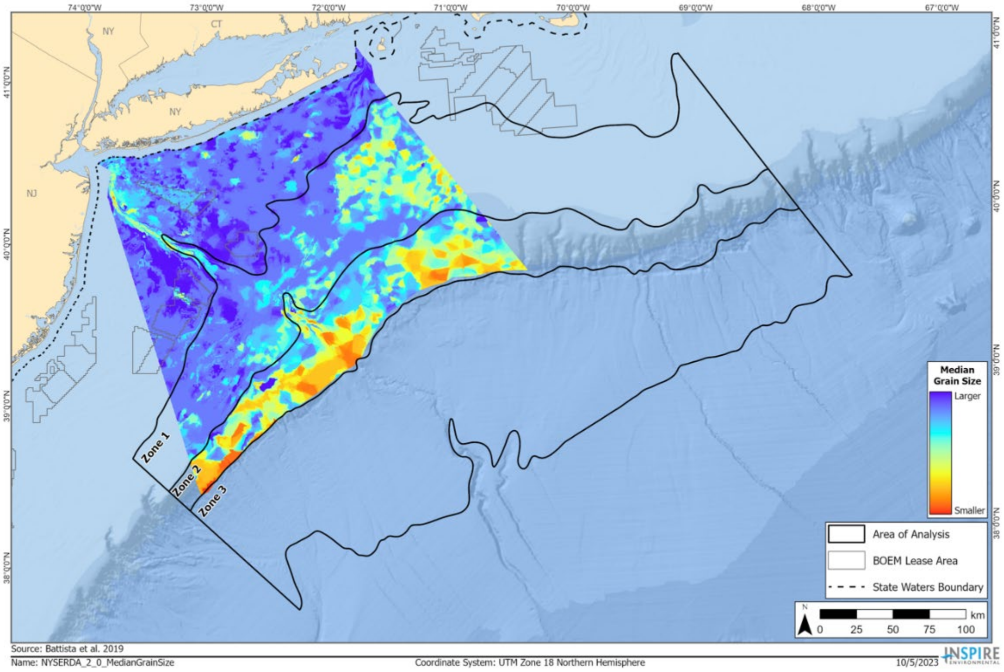
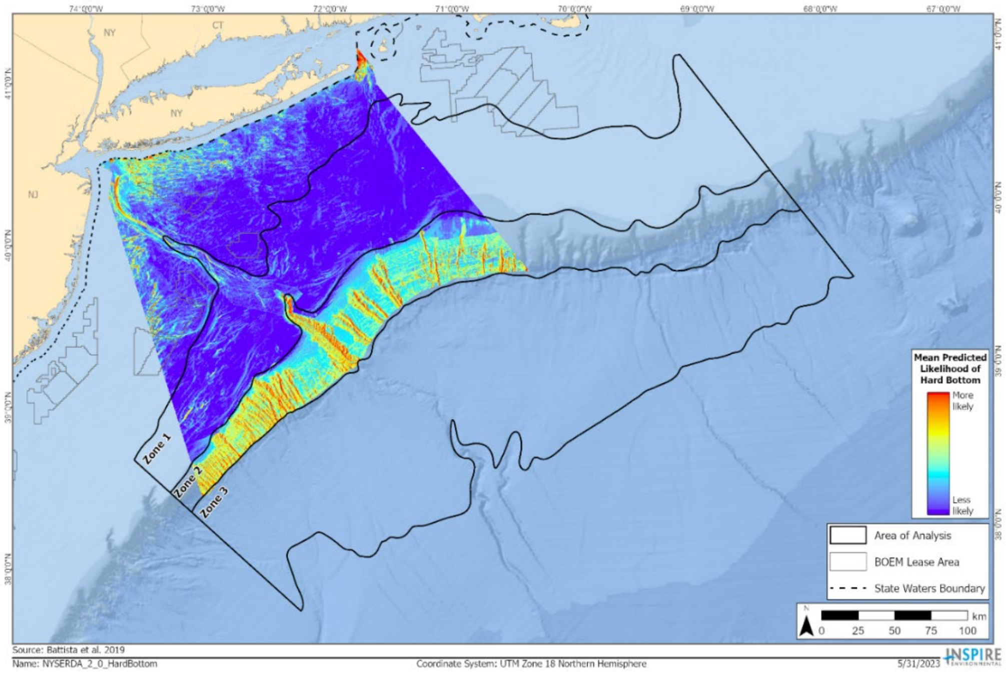


Figure 19. Predicted Hard Bottom Likelihood Data Available for the Southern Portions of Zones 1 and 2 of the Area of Analysis

Source: USGS; Battista, 2019

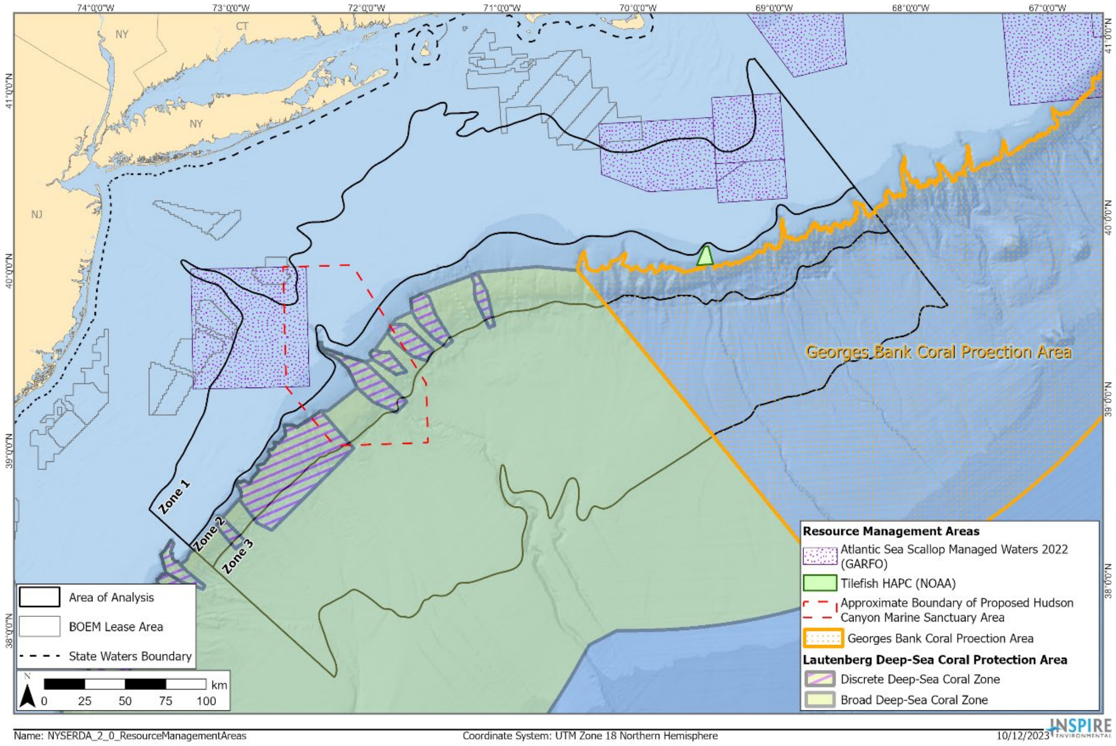


Source: Battista et al. 2019
Name: NYSERDA_2_0_HardBottom
Coordinate System: UTM Zone 18 Northern Hemisphere
5/31/2023

2.5 Resource Management Areas

Several types of areas within the AoA have been designated to protect resources and preclude certain activities. The Frank R. Lautenberg Deep-Sea Coral Protection Area includes discrete deep-sea coral protection zones (15 canyon features) located mostly in Zone 2 with some small areas of overlap in Zone 3 and a broad protection zone that encompasses much of the southwestern portions of Zones 2 and 3 (Figure 20). A complementary deep-sea coral protection zone, the Georges Bank Deep-Sea Coral Protection Area, abuts the Lautenberg Deep-Sea Coral Protection Area to the northeast (Figure 20). Within these areas, fishing gear that touches the seafloor, such as that used in bottom-trawling, is prohibited. NOAA Fisheries designates portions of the Atlantic for scallop fishing access on a rotational basis, to support both scallop populations and the scallop fishing industry. When a rotational area is open, a specific number of fishing trips are permitted per fishing year; when closed no fishing activity is permitted. Several of these managed areas overlap with Zone 1, both by Hudson Canyon and at the northern extent of the AoA (Figure 20). A designated habitat area of particular concern (HAPC) for tilefish aligns with Veatch Canyon. A tilefish gear restriction area is also in place in this location (Figure 20). The NOAA Office of National Marine Sanctuaries is in the early stages of a process to designate a sanctuary for Hudson Canyon. At this stage, a broad area has been identified (Figure 20) and more specific geographical bounds would accompany the designation.

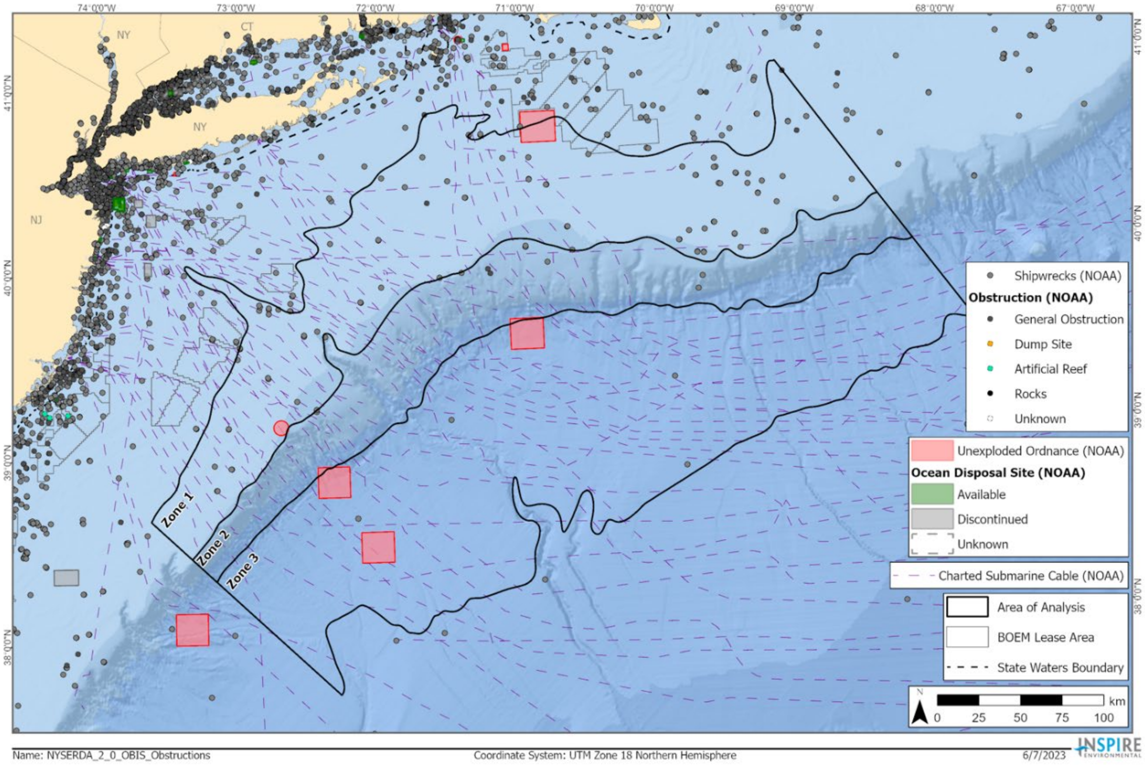
Figure 20. Areas Designated or Proposed for Resource Management and Protection Purposes



2.6 Anthropogenic Benthic Constraints

Multiple types of anthropogenic objects are present on the seafloor that present potential constraints to siting offshore renewable energy infrastructure (appendix A). These include discrete features, such as shipwrecks, clustered features, such as artificial reefs, and linear features—most notably existing networks of submarine cables (Figure 21). In addition, areas of the seafloor have been mapped that identify areas with known unexploded ordnance and active and discontinued disposal sites (Figure 21). These areas would need to be avoided by new project development or given additional consideration and assessment should development be proposed that overlaps these areas. Shipwrecks are sparse in Zones 2 and 3 and more prevalent but still relatively scattered and sparse within Zone 1 (Figure 21). Submarine cable are spatially prevalent and cross all zones of the AoA; notably, the northern portion of Zone 1 is relatively free of cable (Figure 21). Three unexploded ordnance (UXO) areas are located in Zone 3 and one smaller area is located in Zone 1 (Figure 21). Disposal sites and artificial reefs are not located within the AoA but are present closer to shore where cables may make landfall (Figure 21).

Figure 21. Potential Obstructions and Areas with Designated Restrictions and/or Uses

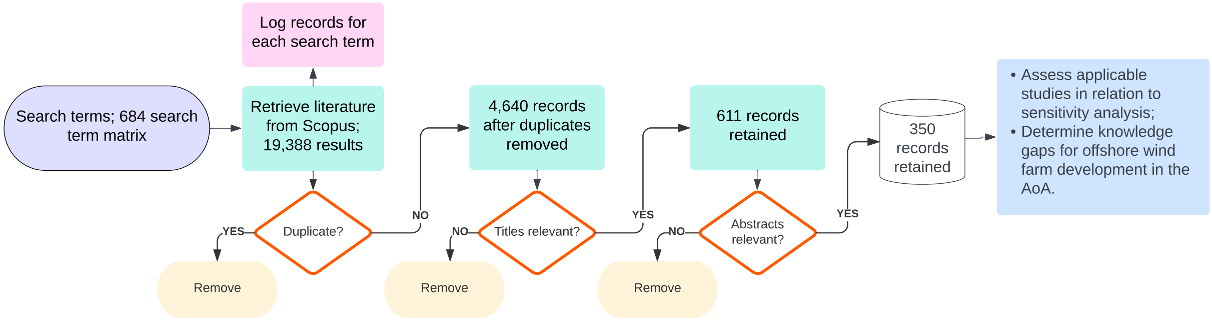


3 Stressors Associated with Deepwater Offshore Wind Development

3.1 Literature Review

To establish the literature basis for the review of potential impacts of OSW on benthic habitats, a systematic literature review (SLR) was conducted (Figure 22). A SLR is a repeatable approach that includes a rigorous search for published and unpublished work on a subject to allow for the synthesis of qualitative and quantitative information (Siddaway et al. 2019). SLRs have been used in prior studies for OSW energy, for example, to investigate spatial trends and best practices for OSW energy development (Peters et al. 2020) and the impact of offshore marine energy development on marine species (Kulkari & Edwards 2022). The resulting literature serves as the foundational knowledge base to inform sections 3 through 6 of this study.

Figure 22. Flow Chart of the Process of Systematic Literature Review to Explore the Impact of Offshore Wind Farms on Benthic Habitat Receptor Groups



Three groups of key words were used to create a set of search terms (Table 3) these were “receptor,” “stressor” and “constraint.” Receptor is specific to this study and includes all the benthic receptors that have been identified in section 2 (i.e., deep-sea coral, deep-sea sponge, sea pens and hard ground). Stressor indicates anticipated impact-producing factors that are derived from prior studies into the impact of OSW technologies on benthic habitats. BOEM defines impact-producing factors as “activities that directly or indirectly affect physical, biological, economic, or cultural resources” (BOEM 2019). Finally, constraint terms were used to limit responses to relevant literature on known anthropogenic disturbances to the selected benthic receptors (e.g., oil and gas exploration and development, cable laying, fishing impacts). Detailed results from the literature search can be found in B.

Table 3. Search Terms Used in the Systematic Literature Review for this Study

Constraint Terms	Receptors	Stressors
"offshore wind energy" OR "floating wind energy" OR "wind energy" OR "offshore wind farm" OR "OWF" "oil" OR "gas" "deep-sea mining" "bottom impact fishery" OR "bottom trawl" "long line" OR "long lining" "anchor" OR "anchorage" OR "anchoring" "cable" OR "cable laying" "shipwreck" OR "wreck" "unexploded ordnance" OR "UXO" OR "detonation"	"deep-sea coral" OR "cold-water coral" "deep-sea sponge" "hard ground" OR "hard bottom" "sea pen" OR "sea pens" OR "seapen" OR "seapens"	"sedimentation" OR "sediment plume" OR "turbidity" "physical impact" OR "physical damage" "food supply" OR "organic enrichment" OR "particle supply" "artificial structure" OR "artificial reef" OR "structure removal" "scour" OR "erosion" OR "scour protection" "hypoxia" "hydrodynamics" OR "flow" OR "upwelling" OR "downwelling" OR "currents" "thermal stress" OR "temperature" "electrical stress" OR "electromagnetic frequency" OR "EMF" OR "electromagnetic field" "invasive species" OR "non-native species" OR "alien" "noise" OR "sound" "artificial lighting" "habitat conversion" OR "habitat degradation" OR "boulder removal" "dredging" OR "trenching" "pile driving" "pollution" OR "anti-foulant" "entanglement" OR "secondary entanglement" "activity displacement" OR "displacement" "cumulative impact" OR "multiple stressor"

3.2 Phases of Construction

Potential stressors for all environmental resources assessed in the Environmental Sensitivity Analysis (NYSERDA, 2025) are shown in Table 4. As this study is focused on deepwater OSW, the stressors identified similarly focus on the potential impacts from deepwater OSW. The scale and severity of stressor impacts from OSW on benthic receptors is in part driven by the phase of the project (Table 4). Using the SLR findings, supplemented with expert contributions during PAC and E-TWG meetings conducted during the study period, an assessment was developed of how impact-producing factors and the differing stages of deepwater OSW may influence the benthic receptor groups in section 3 (i.e., deep-sea corals, deep-sea sponges, sea pens and hard grounds).

The following sections will touch on the potential impacts on all stressors listed in Table 4, based on the results of the literature search but will focus on those stressors that are of primary concern to benthic species and habitats, including bottom disturbance, and changes in water quality and atmospheric/oceanographic dynamics.

Table 4. Stressors Outlined during Different Phases of Offshore Wind Energy Development

Pre-Construction	Construction	Post-Construction (Operation)	Decommissioning
Noise	Noise	Noise	Noise
Bottom Disturbance	Vessel Traffic	Bottom Disturbance	Vessel traffic
Vessel Traffic	Bottom Disturbance	Scouring around Seafloor Structures	Changes in Water Quality
UXO Detonation	Artificial Lighting	New Structures	Artificial Lighting
	Changes in Water Quality	EMF	
		Vessel traffic	
		Artificial Lighting	
		Changes to Atmospheric/ Oceanographic Dynamics	
		Changes in Water Quality	

1. The **pre-construction** phase of OSW may present risk to benthic receptors as a result of contact mediated bottom disturbance due to increased survey activity. These activities may include bottom contact gear during fisheries surveys, grab or sediment sampling, geotechnical sampling, and survey vehicle contact (i.e., remotely operated vehicles and uncrewed autonomous vehicles). Additionally, if vessels are anchoring during survey, there may be increased risk of bottom contact. Seismic and acoustic surveys are expected to represent minimal risk to benthic receptors; however, there is emerging evidence that anthropogenic noise can disrupt natural soundscapes that larvae may use to locate habitats to settle. No research study has explored the influence of acoustic and seismic surveys on these deep benthic receptors.
2. The **construction** phase of OSW represents the period when potential impacts to benthic receptors are predicted to be most severe. During construction, a risk to these benthic receptors is from acute direct bottom contact disturbance that can result during the transport and placement of floating or fixed wind platforms through anchoring and establishment of mooring lines, as well as from vessel anchors. Any form of construction work that includes a bottom contact component would also cause harm if conducted in the immediate vicinity of benthic receptors, particularly from pile driving, drilling, trenching, or seabed preparation, such as sand wave leveling or boulder relocation which can lead to habitat conversion. Acute effects from locally increased sedimentation from the establishment of new structures, as well as from drilling effluent, pile driving, and cable laying would cause disturbance to benthic receptors in the region as sediment plumes can inhibit species health and function and may have greater impacts during early life stages. Chronic sound caused by construction activities may impact larval recruitment and settlement at healthy reef sites due to the masking of reef soundscapes.

3. During the **post-construction** (operation and maintenance) phase, OSW farms can result in long-term alteration of the surrounding ecosystem (i.e., habitat conversion) through modulation of biological, atmospheric, and current dynamics. It is likely that this phase, which is largely operational, represents a less acute but more chronic impact over earlier development phases. Anthropogenic structures including protective materials can serve as artificial reefs within the marine environment, allowing for the recruitment of hard substrate associated sessile and motile organisms, potentially including non-native species, which may use windfarm structures as islands to "hop" to new coastal environments. The presence of artificial lights at night on OSW platforms may alter biological responses of organisms, including zooplankton that exhibit diel vertical migration driven by negative phototaxis. Alterations of these migration patterns and associated grazing have the potential to alter the nutrient profile of zooplankton for filter-feeding benthic receptors. The reduction of wind speeds in the wake of wind farms may result in alteration of ocean mixing dynamics, which were associated with decreased oxygen concentration in bathymetric depressions. However, the resulting secondary impacts of this alteration to mixing is dependent on site-specific bathymetry and oceanographic baselines. OSW platforms also represent a potential risk for the accidental release of oil required for their operation and maintenance. The accidental release and settlement of oil from these platforms can result in contact with sessile benthic organisms, with responses ranging from reduced growth and tissue necrosis to the inability of larval life stages to settle. Insufficient evidence exists to ascribe potential effects of electromagnetic fields from power cables on benthic receptors proposed in this study; however, possible impacts cannot be ruled out.
4. **Decommissioning** shares a similar impact profile to that of the construction phase, particularly if infrastructure is removed. Structure removal represents a potential risk, especially if vulnerable receptor communities are in the area or have colonized the structure themselves, as observed for deep-sea corals on some deep shipwrecks and oil/gas rigs. It is likely that the structure removal would result in additional bottom contact activity and sedimentation events that can impact benthic receptors' respiratory rates, feeding behavior, and larval mortality. The noise generated during the removal of structures may additionally impact larval recruitment and settlement.

3.3 Stressors and Their Impact on Benthic Receptors

As this study focuses on deepwater OSW, the stressors identified in Table 4 similarly focus on the potential impacts from deepwater OSW on benthic species and habitats. Due to prohibitive costs associated with installing fixed OSW structures in waters deeper than 50 m (NREL 2022), floating structures are far more likely to be considered for all zones within the AoA (minimum: 60 m in Zone 1; Figure 1). For this reason, floating turbine platform designs and their associated mooring systems are the primary focus of this analysis. However, fixed structures, such as offshore high-voltage direct current (HVDC) substations, may still be considered within the shallowest zones of the AoA, so stressors associated with fixed platforms are also included within this discussion where appropriate. A summary of stressors related to the feasibility of different OSW technologies within the AoA zones and the relative distribution of benthic receptors is provided in section 3.4. Each stressor listed in Table 4 is discussed in the following sections with specific reference to individual benthic receptors. For stressors that have unknown or inferred impacts to benthic receptors due to a lack of empirical studies, relevant literature and broader physical-ecological principles are discussed to provide the best available information linking potential stressors to benthic receptors. The sections have been generally discussed in order of potential risk they pose to the benthic receptors in this study. Cumulative and/or synergistic effects are particularly lacking and are discussed as knowledge gaps in section 5.

3.3.1 Bottom Disturbance

As sessile organisms, the primary risk to the proposed benthic receptors is direct contact of installed structures and equipment within the seafloor (Halpern et al. 2007) during the placement of anchors, mooring systems, export and inter-array cables, and fixed structures (e.g., for substations within shallower depth zones). Additional impacts in the form of habitat disturbance might occur during the pre-construction phase due to seabed preparation techniques, including sand-wave leveling or boulder/debris relocation prior to installation of mooring systems, although no studies have examined the direct impacts of these procedures on benthic fauna. While specific cases of the impacts of anchoring and other bottom-mediated disturbance from OSW energy developments on these communities are not currently available, parallels can be drawn between the impacts of long-line and bottom contact fishing as examples of direct damage on these groups and others (e.g., Hiddink et al. 2006; Jørgensen et al. 2016; Morrison et al. 2020; Yesson et al. 2017b).

Direct contact to benthic receptors has long-term and habitat-wide implications that may persist for periods of up to a decade or more (Huvenne et al. 2016; Morrison et al. 2020; Williams et al. 2010). This is due to the fragility, structure-forming nature, limited recruitment, and slow grow rates of receptors, such as deep-sea coral, deep-sea sponges, and sea pens (Althaus et al. 2009; Hall-Spencer et al. 2002; Neves et al. 2015). Fish associations in cold-water coral reefs with differing structural complexity (containing living and dead coral framework) were found to exhibit certain patterns (Söffker et al. 2011). The patterns that were discovered revealed that, in comparison to flatter reef areas, reef sections with higher levels of coral framework included much more fish. This included certain fish species that seemed to only congregate in high-structure locations. The authors noted significant trawl damage and abandoned fishing gear in the reef sites, which caused breakage of coral framework and reduction in 3-dimensional habitat space. This suggests that direct damage to habitat forming structures in the deep sea could have significant impacts by decreasing the amount of structural habitat available, leading to a reduction in the contribution of this system as an EFH. The majority of research for monitoring and detection of bottom impact from deep-sea fishing damage has been conducted on deep-sea corals. Clark et al. (2016) reviewed multiple studies that reported significant damage, and in some cases, widespread loss of deep-sea coral fauna due to trawling as well as impacts from resuspension of sediments and negative impacts on habitat quality and ecosystem function. In severe cases, fishing gear seabed disturbance have the equivalent impact on marine ecosystems as forest clearcutting has had in terrestrial environments (Watling and Norse 1998).

Only a few studies have been conducted on the resilience and recovery of deep-sea sponges to bottom contact (e.g., Viera et al. 2020). For example, Malecha and Heifetz (2017) found that at 200 meters, the effects of a single trawl across large deep-sea sponges were still evident after 13 years. This estimate is supported from observations by Rooper et al. (2011), who used sponge bycatch data to estimate recovery for large sponges (to 80% of pre-impact biomass) to be between 13 and 36 years. In contrast, in shallower water, hard ground sponge communities (20 meters water depth), recovery rates may be far faster, with experimental damage from trawling no longer detectable after 1 year (Van Dolah et al. 1987). A recent review of the impacts of offshore oil and gas exploration and development determined that impacts that have bottom contact and resuspension are likely to have significant impact on deep-sea sponge communities (Vad et al. 2018). It could be posited that while sea pens are found in soft sediments, they have a degree of structural flexibility and, in contrast to other deep-sea corals, may have a degree of resilience to bottom impact. However, several studies have shown that this is not the case, and when coupled with relatively slow growth rates, direct impact will have lasting impacts on sea pen communities (Neves et al. 2015; Pierdomenico et al. 2018). The long timescales suggested for the recovery of deep benthic receptors must be kept in mind, as any damage because of OSW energy development and operation may persist throughout the operational life of the platform, with further potential for contact mediated damage to recovering reef sites during decommissioning further extending recovery periods.

Anchor gear from large vessels, including anchor and chain, and jack-up barges (should they be utilized in floating wind installation) have also been highlighted as a significant cause of bottom disturbance (Broad et al. 2020; Davis et al. 2016), with impacts to benthic receptors comparable to damage that can occur from bottom trawling (Abadie et al. 2016). Of the primary anchor types for floating wind platforms, installation of drag embedment anchors, which involves dragging an anchor across the seafloor until the anchor is sufficiently buried/embedded within sediment, poses the greatest potential risk to benthic receptors because they require the largest seafloor footprint and because they are suited to use with catenary moorings that directly contact the seafloor, expanding this footprint. The process of installation for drag embedment anchors can confer direct physical damage to sediment-dwelling organisms in the drag path as well as sediment disturbance and/or resuspension (discussed further in section 3.3.2) (Milazzo et al. 2004; Maxwell et al. 2022).

Pre-construction surveys represent a moderate risk to benthic receptors resulting from anchor mediated contact, but specific sampling technologies, including, for example, fish surveys that utilize a trawl methodology, represent a large risk of bottom disturbance to benthic receptors during surveys. Appropriate efforts should be taken to mitigate potential contact. Impacts from vessel anchors are expected to be most severe during construction and decommissioning phases due to an anticipated larger number of vessels and extended period of anchoring during these phases. Bottom disturbance from vessel anchoring is anticipated to be minimal during the post-construction/operational phase, due to the ability of vessels to tie off to OSW energy platforms, reducing the requirement for bottom anchoring by vessels.

Cable arrays between wind turbines and onshore power stations also represent a sizable physical benthic footprint in addition to anchor and mooring systems with distances between turbines of up to approximately 1 mile, and distances to shore that may exceed several hundred miles. Power cables from turbines may be free hanging under their own weight, in a catenary style, increasing potential for damage to benthic receptors from direct contact with cables during wave and tidal motions (Rentschler et al. 2020). Inter-array power cables, laid between OSW platforms and substations, also represent a risk for direct contact mediated bottom disturbance during their installation, increasing potential for damage to benthic receptors from direct contact with cables during wave motion (Rentschler et al. 2020). These inter-array cables may also be weighted or buried between turbines, reducing potential for movement-based contact but increasing the overall footprint. While these approaches may limit movement of power cables, they can also increase the immediate impacts around cables by disturbing soft sediments during installation which can increase sediment suspension and turbidity, or by placing concrete mattresses over hardground sites, smothering of benthic habitats.

For laid cables, different methods of installation vary in the severity of bottom disturbance they incur, with methods, such as trenching causing significant impact along the entire length of the cable route (Bennum et al. 2021; Dresser 2021). Even short duration pre-construction and construction activities which require alteration or removal of existing sea floor features (e.g., sand wave leveling, boulder removal) or installation of new structures on the sea floor (e.g., riprap scour protection) can result in permanent habitat conversion. Boulders or other non-contiguous exposed rocky features that are naturally distributed along the seafloor can be important “islands” of hard bottom for sessile organisms to colonize in otherwise soft sediment areas of the deep-sea (Vertino et al. 2010). Seabed preparation that requires the removal of these features prior to installation of anchors (or other seafloor structures) thus results in significant local impacts to hard bottom, to the biological receptors that rely on them, and to the provisioning of EFH by these receptors.

3.3.2 Changes in Water Quality

Changes in water quality can occur in marine settings due to leaching of chemical or lubricant dispersants from installed infrastructure and construction vessels. The operation and maintenance of OSW energy platforms require oil for lubrication of gearboxes and other components, with total volumes per platform of up to approximately 200 gallons (Gunter 2014). Therefore, an associated risk of these platforms is the accidental release of oil because of gearbox failure or structural damage to the platform during construction, operation, and decommissioning. Survey studies following the Deepwater Horizon oil spill in the Gulf of Mexico have provided an assessment of the long-term impacts of direct contact with oil and chemical dispersants on deep-sea corals (Beyer et al. 2016; Fisher et al. 2014). Following contact with discharged oil, deep-sea corals within the Gulf of Mexico exhibited necrosis of exposed tissues, branch loss, increased mucous production, and decreased growth rates (Girard et al. 2019; White et al. 2012). However, it is important to note that the volume and duration of pollution from this ecological disaster were orders of magnitude greater than what would be expected from accidental OSW discharge, and so the studies following Deepwater Horizon are of limited relevance here.

While the impacts of *in situ* oil spills are less studied within deep-sea sponges and sea pens, limited field and laboratory studies have provided insight into how these receptors may respond (e.g., Vad et al. 2018). Exposures of sponge larvae to a range of hydrocarbon concentrations during lab studies have shown that while larvae may have a high tolerance to hydrocarbons regarding mortality, there is significant reduction to larval settlement rates and metamorphosis (Luter et al. 2019), which may hinder recovery rates of damaged sponge grounds under additional impacts, such as bottom disturbance. Further, for deep-sea sponge communities, changes in communities have been detected up to 1,000 meters away from drilling activities and the release of drilling muds during oil and gas extraction (Ellis et al. 2012), with reductions in filter-feeding communities and transitions to deposit feeders (Trannum et al. 2010).

Underwater marine structures are often coated with anti-fouling measures, including the use of a growing number of biocidal agents within marine coatings, to reduce the impacts of biofouling, such as pitting subsurface structures and increased weight, which may alter the function of structures (Bejarano et al. 2022). The diffusion of these biocidal agents into the water column represents a potentially localized risk to benthic receptors, but the severity of impact cannot be assessed with any confidence due to the large number of commercially available biocidal coatings (Bejarano et al. 2022), and lack of published research on lethal concentrations of these coatings on benthic receptors.

Bottom disturbances to the seafloor, particularly during pre-construction seabed preparation, installation of anchors, cables, and substations, during operational scouring processes, and during decommissioning can cause resuspension of fine sediments to the water column, resulting in either acute or chronic events, which may persist for days to decades depending on the size of sediment particles and the geophysical context of the area (Aleynik et al. 2017; Martín et al. 2008). Some OSW projects have even produced “turbid wakes” (sediment plumes downstream of windfarms) spanning several kilometers that were observable by satellites (Vanhellemont and Ruddick 2014). As filter feeders, changes to water quality for deep-sea coral and sponges can have impacts on the effectiveness of feeding strategies, alter respiration rates, and even cause mortality (e.g., Brooke et al. 2009). For example, in experimental manipulations, an approximately 60% reduction in respiration rates were observed in deep-sea sponges after one day of exposure to elevated suspended sediment conditions, which ultimately may impact their growth, reproduction, and survivorship (Mobilia et al. 2021). Sponges have also been shown to have a range of tolerance to sedimentation levels, with higher resilience to acute sedimentation events, including several physiological response mechanisms linked to sediment clearance, including increased production of “mucus,” and sloughing off external tissue. However, these may come with metabolic tradeoffs (Strehlow et al. 2017) that could result in a decline in sponge ground health from chronic sediment plumes during construction and decommissioning phases (e.g., Mobilia et al. 2021).

Assessment of the impacts of sedimentation events during the construction phase of oil and gas activities, has shown that healthy adult *Desmophyllum pertusum* (formerly *Lophelia pertusa*) were able to maintain growth rates within chronic sedimentation plumes, but with an approximately 50% reduction in growth rates during high-sediment load (17–19 milligrams per liter [mg l^{-1}]) compared to low (3.3–3.6 mg l^{-1}) (Larsson et al. 2013). However, both Brooke et al. (2009) and Allers et al. (2013) found that smothering from sedimentation will result in mortality. Beyond the concentration of sediments, sediment composition was also shown to impact deep-sea coral growth. Comparisons of coral exposed to natural benthic sediments to drill cuttings also showed a reduction of coral growth rates when exposed to drill cuttings, which contains drilling fluids and weighing agents, such as barite, across both high- and low-sediment loads (Larsson et al. 2013). Additionally, coral larvae, which can persist within the water column for up to three weeks before settlement, were shown to have much higher sensitivity to drill cutting sediments, with approximately 33% mortality following five days of exposure, suggesting that the timing of drill cuttings and other sedimentation events should account for periods of coral spawning and settlement (Larsson et al. 2013). The impacts to water quality from sedimentation are likely to be more severe where structures are sited within fine sediment substrates which are more readily entrained into the water column and remain suspended for longer than large grain sediments. For this reason, sedimentation risks are expected to be relatively high in Zone 3 of the AoA, where these sediment types (mud, clay) are most prevalent. If significant amounts of sediment impact sites that have complex morphologies (for example both live and dead hard coral can provide habitat), habitat complexity could reduce, with resulting impacts to biodiversity and associated species abundances. However, particles (including pollutants) entrained within the water column may be transported up to thousands of kilometers via density-driven turbidity currents that can retain high concentrations of suspended particulates and which are prevalent at continental shelf features like deep-sea canyons (Wells and Dorrell 2021). Therefore, increased turbidity and/or the introduction of harmful particles into local waters may generate non-localized impacts dependent on the prevailing hydrodynamics and density structure of a potential OSW site.

OSW-derived water column turbidity may also reduce light penetration to low-light benthos present in Zone 1 of the AoA. Some species of deep-sea corals and sea pens are apozooxanthellate (containing zooxanthellae at certain depths) with distributions that overlap with deeper mesophotic zones (Williams 2011; Muir and Pichon 2019). Shading from suspended anthropogenic particulates can shift the burden of energy supply for these species towards heterotrophic feeding, which may be insufficient for organisms adapted to local light levels (Kahng et al. 2010; Smith et al. 2019). While the majority of benthic receptor occurrence records in Zone 1 comprised azooxanthellate species, some apozooxanthellate corals (*Madracis* spp.) and sea pens (*Virgularia* spp.) were present within the AoA.

The conversion of power generated from offshore windfarms from high-voltage alternating current (HVAC) to high-voltage direct current (HVDC) to minimize energy loss over long distance transfer to shore results in the generation of heat by offshore substations. To ensure continual operation of offshore substations the heat generated during the conversion from HVAC to HVDC must be dissipated, most commonly using an open loop cooling system with seawater as the heat sink (Middleton et al. 2022). Seawater is pumped from the water column into the substation’s cooling system with intakes potentially as deep as 30 feet from the seafloor. This water is passed through a series of filters at the intake to prevent uptake of particles greater than 500 microns. This pumped seawater may also be treated with biocidal agents, such as sodium hypochlorite (10–200 ppm), generated through electrochlorination of seawater, to prevent biofouling of the cooling system. The filtered and treated water is then pumped into the substation's heat exchanger where it is heated and subsequently discharged back into the water column. The amount of seawater heated within the heat exchanger and the temperature it will be heated to before being pumped back into the water column is not currently subject to regulation (Middleton et al. 2022).

It has been proposed that the heat from substation effluent pumped back into the ocean will dissipate within the surrounding water column, returning to ambient temperature without impacting the surrounding environment. It is important to note that local-scale dynamics may result in areas of locally increased temperature surrounding the effluent pipe (Middleton et al. 2022). The intensity of this localized warming will be site specific and determined by local bathymetry and hydrodynamics. Sessile receptors, such as deep-sea corals and sponges, in proximity to effluent may be impacted by the increased temperature and biocidal agents. While these organisms are capable of surviving under fluctuating temperature ranges, continual increased temperatures have been shown to impact survival particularly when coupled with other stressors (Strand et al. 2017; Weinnig et al. 2020). While the impacts of continual exposure to biocidal agents, such as sodium hypochlorite on deep-sea corals and sponges remains largely unstudied, it has been shown that some warm water corals are susceptible to concentrations as low as 20 ppm of sodium hypochlorite, with observable tissue damage within 72 hours of exposure (Altvater et al. 2017). To mitigate the risk of increased temperatures and biocidal agents on reef sites, placement of the offshore substation cooling loop outlets should be positioned away from hardground reef sites, or in regions with fast currents to prevent localized heating of the area.

Of additional concern is the impact that open-loop cooling systems may have on coral and sponge larvae during periods of spawning. While the intakes for open-loop cooling systems often contain filters to exclude particles greater than 500 µm, this does not prevent potential risk of entrainment of larval life stages. Sponge species larval life stages range in size from 50 µm–5 mm (Maldonado 2006), with deep-sea corals exhibiting similar larvae lengths ranging from 100 µm–5 mm (Rakka et al. 2021). Within the smaller size class (less than 500 µm) these larvae are susceptible to being entrained into the open-loop cooling system where they will be exposed to biocidal agents and increased thermal stress. Those larvae of the greater than 500 µm may be excluded from by the intake's filter but will become impinged and at risk of physical damage. While many systems implement a backflow system to wash filters the viability of larvae impinged on filters for extended durations remains unknown. To fully assess how these factors impact larval survival rates, more research is needed to fully assess the resilience of coral and sponge larvae to acute thermal stress and biocidal agents, like sodium hypochlorite, such as what would be experienced after entrainment in the open-loop cooling systems. The use of closed-loop cooling systems, which are being developed for offshore substations, would help to mitigate these potential entrainment impacts on benthic receptors, if feasible. While still using surrounding seawater as a heatsink, closed-loop systems do not require the uptake or discharge of seawater within the substation, mitigating the risk of localized warming near outlet pipes in benthic habitats, while also removing the risk of entrainment of coral and sponge larval life stages into the cooling system.

If open-loop cooling systems are to be used within the AoA, consideration should be given to their placement to minimize their proximity to currents that may transport coral and sponge larvae. The risk of entrainment of coral and sponge larvae within open loop cooling systems is greatest in Zone 2 where current dynamics near the shelf break may play a major role in larvae dispersion within the AoA (section 3.3.4). The risk from this stressor is lower in Zone 1 and Zone 3 but remains near coral or sponge ground sites.

3.3.3 New Structures and Scouring Around Sea Floor Structures

OSW projects require large-scale introduction of structures that will unavoidably impact benthic communities. On the seafloor, introduced structures primarily include anchor systems, scour protection material (boulders or other material placed around anchors), export cables and cable protection (e.g., concrete mattresses), and fixed structures (e.g., fixed HVDC substation platforms). The placement of new structures would impart a direct bottom contact impact if placed in the general area of, and/or directly upon benthic receptor species, as discussed in section 3.3.1.

A potential effect imparted by new structures is hydrodynamic scouring of the seafloor, resulting in erosion of preexisting sediments and in faunal communities, and the potential conversion to hard bottom grounds. Scouring around seafloor structures may also be a source of sediment resuspension and entrainment (Bonaldo et al 2014; Maxwell et al. 2022), which might then affect water quality and light availability for photosynthesizing coral species found at mesophotic depths (approx. 50–150 m, dependent on light attenuation) (discussed in section 3.3.2). Most anchor systems (e.g., suction anchors, drag embedded anchors) require soft substrate such as clay or mud and thus these anchor structures and/or their associated mooring systems (especially catenary moorings that can contact the seafloor) present sediment scour risk to soft bottom benthic habitats. Scouring is expected to have the greatest impact on sea pens and certain specialist coral species that rely on soft bottom regions that may be lost or altered as a result of scouring. Minimal direct impact would be expected for deep-sea corals and sponges that require hard bottom substrate. However, indirect impacts may occur to hard bottom communities via the export of scoured sediments onto hard bottom areas, discussed further in section 3.3.2. The selection of an anchor type depends heavily on the substrate where OSW is sited.

While all zones of the AoA contain areas of soft substrate, Zones 1 and 3 are comprised mostly of sand and mud, respectively (Figure 17), such that these zones present greater risk of scour. However, the impacts of scour are intensified for structures placed in smaller grain-sized sediments (e.g., mud), which scour deeper and wider than larger grain sizes (Kells et al. 2001), potentially placing Zone 3 at relatively higher risk of scour potential. Near-bed current velocity is also an important factor that can increase the effects of scouring around structures (Bonaldo et al. 2014) that may in turn be driven by local hydrographic features of a site, regardless of zone. Although scour protection structures such as boulder riprap or concrete blocks are commonly placed around anchors and other seafloor structures to mitigate these effects (section 5.3), scour protection materials themselves will permanently convert soft bottom habitats to hard bottom and may exacerbate changes in faunal communities discussed below.

Along with seabed structures listed above, mid-water and surface structures including turbine platforms, suspended or “lazy wave” inter-array cables, and mooring systems can also impact benthic receptors by creating artificial habitat that may alter natural biodiversity and assemblages. For all introduced structures, changes to existing benthic communities can occur via colonization of organisms on the surfaces of structures. For example, upon introduction to the marine environment, new structures immediately undergo colonization by microbial species, and the subsequent formation of biofilms that serve as the foundation for successive colonization by epibenthic species (Dang and Lovell 2016). This colonization of anthropogenic structures, including pylons, anchors, and power cable structures, can act as an artificial reef supporting distinct assemblages of organisms throughout the water column, including mussels, macroalgae and anemones, and associated sessile macrofauna, which can serve to increase biomass at the new structures site by 4,000-fold (Rumes et al. 2013).

Enhanced biomass resulting from artificial reef effects, particularly the attraction or production of economically important fish species, can also create indirect impacts by drawing traffic from fishing vessels and create potential for increased disturbance to areas where structures are placed. OSW energy developments outside of the U.S. are generally protected by no-take zones; however, this is not currently the case in the U.S. and future regulation is unclear within floating OSW developments. The effects of enhanced biomass can extend beyond the windfarm footprint (Langhamer 2012). Potential displacement of fishing activity, particularly bottom trawling and long-lining, away from existing fishing grounds to new areas that include sensitive benthic habitats, may also serve to increase contact mediated bottom disturbance for previously unimpacted benthic receptors (Davies et al. 2007; McConnaughey et al. 2020), further discussed in section 3.3.1.

As part of the increased settlement of these structures, they may also serve as locations for the introduction of opportunistic and non-native species that may outcompete local species, allowing them to "hop" between these locations and increasing the spread of invasive species into new ecosystems (e.g., Glasby et al. 2007; Meyer et al. 2017; Sammarco et al. 2004). Slow growing benthic cold-water corals and sponges are likely to be outcompeted in the colonization of new structures due to their slow growth rates, which may serve to alter habitat structure and dynamics on and around OSW energy development platforms. While it is difficult to predict where introduced structures may create additional connectivity points that allow for the spread of non-native species, areas where hard bottom has not been historically present and/or areas hydrodynamically connected (allowing pelagic larval export) to existing habitats may be at particular risk (Adams et al. 2013). The AoA encompasses a cross-shelf portion of the Mid-Atlantic Bight, which is characterized predominantly by the Shelfbreak Jet current, flowing southwest alongshore at the shelf break, as well as influences from cross-shelf upwelling at the shelf slope (e.g., within canyon features) and an offshore recirculating gyre in the slope waters between the Shelfbreak Jet and Gulf Stream countercurrent (Gawarkiewicz et al. 2012; Forsyth et al. 2020). As a function of these features, transport within the Shelfbreak Jet can disperse larvae in both the alongshore direction as far south as Cape Hatteras, NC, and the cross-shelf direction, primarily towards the offshore recirculating area where they may become re-entrained in the Gulf Stream (Garkiewicz et al. 2007). As such, siting of OSW structures in Zone 2 may present a higher risk than other regions within the AoA due to the increased likelihood of non-native larvae becoming entrained into the Shelfbreak Jet. Zone 1 may also present a high risk for the export of coastal organisms into deeper areas due to the presence of structures in shallower waters. Coastal velocities are generally slower than alongshore currents at shelf breaks and thus limit potential dispersal distances within inshore regions; moving from inner coastal waters toward the shelf break where alongshore velocities are significantly faster, even short distances can increase the potential dispersal distance for planktonic larval exponentially (Largier 2003). By introducing structures into an area of Zone 1 that would connect otherwise-retained inshore larvae to the dispersive Shelfbreak Jet current, stepping-stone impacts become region-wide. However, dispersal pathways for native and non-native species from introduced structures remain poorly understood, particularly for dynamic settings such as the AoA, and more information is needed to understand the impacts of this potential stressor.

Conversely, several studies have also noted the growth of native habitat-building deep-sea species, including corals and sponges, on oil and gas infrastructure, and shipwrecks (Bell and Smith 1999; Gass and Roberts 2006; Macreadie et al. 2011). The removal of these anthropogenic structures during decommissioning can also disturb species that have colonized during the lifespan of the windfarm platform, negating potential positive impacts of increased biomass at these sites, and potentially collapsing newly established habitats that have formed during the lifetime of the platform (Macreadie et al. 2011). The growth of these habitats on such infrastructure could enhance EFH if left for a significant amount of time, similar to shipwrecks that create hard structures in the deep-sea (Larcom et al. 2014), but the removal of these structures in decommissioning would likely negate any benefit to EFH.

3.3.4 Changes to Atmospheric/Oceanographic Dynamics

As discussed in section 3.3.3, the AoA is hydrodynamically influenced by the Shelfbreak Jet current and other oceanographic features that drive the circulation of different water masses with distinct chemical and physical properties. Interruption to these natural oceanographic dynamics can disrupt wholesale water column processes that benthic communities rely on, with resulting implications for benthic community distribution, growth, and health. While localized subsurface impacts might be influenced by the draft of a turbine platform (e.g., narrow drafted barge platforms versus large-drafted spar buoys), wind-driven and coupled atmospheric-oceanographic effects are a concern for all OSW turbine configurations and could be compounded by the arrangement of multiple windfarms. The installation of OSW farms reduces wind speed by up to 43% in regions spanning up to 65 km in the wake of turbines relative to the surrounding area (Christiansen and Hasager 2006; Platis et al. 2020). Reductions at this scale have been shown to also introduce wind stress curl at the surface and generate regions of increased downwelling and upwelling within the wake of the platform, which can serve to alter surface stratification and transport of biologically important nutrients (Floeter et al. 2022; Raghukumar et al. 2023). The exact impacts and their severity resulting from the modification of upwelling and downwelling dynamics on benthic habitats would be determined by site-specific dynamics, including site bathymetry and atmospheric dynamics.

Both numerical modelling studies and empirical case studies indicate that OSW structures can alter upwelling and surface mixing regimes within localized areas. Raghukumar et al. (2023) modeled the spatial structure and net transport of cross-shelf upwelling to the California Shelf after the addition of 877 deep OSW turbines. While net upwelling volume transport and nutrient delivery were not greatly diminished at a broad coastal scale, smaller spatial areas between 20 and 80 km from shore did experience significant changes in transport and the overall structure of upwelling within the region shifted to a non-natural state. The North Sea, a region that has furthered research on hydrodynamic impacts due to the implementation of many OSW projects in recent years, experienced changes to water stratification within the wind-wake of OSW platforms. These changes were defined by a shallowing of the surface mixed layer, bringing higher nutrient water from below the thermocline into the photic zone, with the potential for generating increased primary production at scales of approximately 10–35 km (Floeter et al. 2022). This anthropogenic excess of organic carbon may be a concern because of the potential to generate localized oxygen minimum zones, driven by increased carbon fixation (and thus oxygen consumption) as this material sinks into the water column. Another modeling study of atmospheric and current dynamics in the wake of North Sea windfarms predicted a reduction of oxygen concentrations within bathymetric depressions where exchange is limited with surrounding water. The increased flux of organic material from the surface due to predicted increases in primary production were modeled to increase oxygen consumption, which predicted a local decrease of oxygen concentration to 0.97 mL L^{-1} within these seabed features (Daewel et al. 2022). This deoxygenation of bathymetric depressions is likely further compounded by predicted deoxygenation (0.03–0.05 mL L^{-1}) of the world's ocean due to increased thermal stratification caused by climate change, which is predicted to impact water depths of 100 to 1,000 meters most severely (Sweetman et al. 2017).

However, tolerance to hypoxic conditions is variable between benthic organisms. The deep-sea coral species, D. pertusum, has been shown to persist under varying oxygen concentrations (2–3.7 mL L^{-1}), with small reefs in the Atlantic observed in regions with dissolved oxygen as low as 1.1–1.4 mL L^{-1} (Hebbeln et al. 2020). Despite this range of tolerance to chronic hypoxic conditions, laboratory studies have shown that D. pertusum is limited in its ability to cope with 40 to 50% reduction of ambient dissolved oxygen concentrations, highlighting its potential susceptibility to acute hypoxic events (Dodds et al. 2007; Lunden et al. 2014). Some deep-sea sponges also exhibit tolerance to low oxygen conditions with several species tolerant to dissolved oxygen as low as 0.68 to 2.22 mL L^{-1}, with lethality at < 0.57 mL L^{-1} (Micaroni et al. 2022). Even after loss of living colonies, the dead coral framework of stony coral can continue to provide similar habitat complexity as live corals to support fish and invertebrate biodiversity (Emslie et al. 2014), so it is unclear as to how oxygen availability to benthic receptors will affect EFH over varying time scales. In the long-term, if oceanographic conditions change significantly to alter dissolved oxygen levels for benthic organisms in this region, there could be a reduction in the amount of new EFH creation and critical habitats could take time to recover due to slow growth rates (Orejas et al. 2007; Weinnig et al. 2020).

3.3.5 Noise

OSW energy development can increase noise within the marine environment, either via acute short-term activities such as structure installation and construction vessel traffic or via long-term chronic noise incurred by regular operation of wind energy platforms. Though information is particularly lacking for the benthic receptor species in this study, anthropogenic noise is a poorly understood and potentially underestimated threat to all coral communities with impacts on physiology, behavior, and distribution that could lead to permanent changes that decrease survival and alter ecosystems (Ferrier-Pagès et al. 2021).

It has been suggested that both natural abiotic and biotic sounds may be important cues for marine organisms in areas with distinctive soundscapes (Simpson et al. 2004; Montgomery et al. 2006). Coral reef ecosystems in general have been shown to be "noisy" due to associated species generating sounds across a wide spectrum of acoustic frequencies, with healthy and damaged reef sites having distinct associated soundscapes (Ferrier-Pagès et al. 2021). Ciliated coral larvae have been shown to utilize low frequency (25–1000 Hz) reef sounds between 5 and 10 decibel (dB) to direct settlement of larvae to healthy reef sites (Vermeij et al. 2010; Lillis et al. 2018).

While there has been no evidence assessing anthropogenic noise on mature corals, studies have shown that it can cause significant negative impacts in other invertebrates such as physical damage to statocysts (sensory receptor systems) in cnidarians and cephalopods, and behavioral stress responses including altered feeding patterns in some gastropod species (Weilgart 2018). Low-frequency noise pollution (relevant to wind farm noise production) impaired invertebrate behavior (*Corophium volutator*; burrowing) relevant to ecosystem functions (e.g., biogeochemical cycling, organic matter remineralization) (Wang et al. 2022). Both acute and chronic noise can reduce important nutrient cycling in the benthos by causing lobsters and clams to repress burrowing and feeding behaviors, which, in turn, reduces critical bioirrigation and bioturbation of upper sediment layers (Solan et al. 2016). With respect to habitat value, anthropogenic noise may also reduce the suitability of benthic receptors as EFH; biomass and abundance of fish species have been shown to be significantly lower in marine habitats affected by anthropogenic noise (Weilgart 2018).

Anthropogenic noise from OSW is expected to be attributed to several development activities including, increased vessel traffic, high-resolution geophysical (HRG) surveys, pile driving, and trenching. Some of the noisiest activities include seafloor installations from impact pile driving for pile anchors or fixed platforms, as well as trenching to install long-distance export cables. Underwater noise measurements performed during installation of two monopiles as part of the Coastal Virginia Offshore Wind (CVOW) Pilot Project (WaterProof 2020) indicated that peak sound pressure levels from unattenuated impact piling reached 190 dB at a distance of 750 m. In most instances, floating OSW turbines do not require pile driving unless necessitated by the anchor type selection (such as pile anchors), which is dictated by the seabed sediment composition (Maxwell et al. 2022). Installation of the other types of anchors (i.e., drag-embedment, suction caisson, or gravity anchors) does not result in high-noise levels such as those emitted by pile driving (Diaz et al. 2016). Sound pressure levels generated from vibratory pile driving can be up to 15% lower than the sound emitted from impact pile driving (Matuschek and Betke 2009).

While pile anchors may be deployed in various substrate types, they are the preferred system for hard bottom habitats and unpreferred in sandy substrates (as opposed to drag embedment or suction anchors; see Deepwater Wind Technologies–Technical Concepts Study (NYSERDA, 2025)). Due to the presence of hard bottom features along the shelf break, Zone 2 may be best suited to pile anchoring for floating wind platforms and thus noise from impact pile driving would potentially be most impactful within this zone (Figure 19), and less likely to occur in sandy expanses of Zone 1 (Figure 17). However, installation of suction and drag embedment anchors within soft sediment of Zones 1 and 3 may also require at least moderate noise and should not be discounted. Other sources of noise include geophysical surveys including multibeam echosounders and seismic survey techniques, trenching, and vessel traffic (Madsen et al. 2006). Echo sounders emit a short pulse of sound and "listen" to reflected energy from the seabed. While this technology can operate across a wide range of system parameters (Mooney et al. 2020), deep-water multibeam systems operate with multiple beams of sound at frequencies below 20 kHz (Scientific Committee on Antarctic Research 2002). Nedwell et al. (2003) found trenching noise to be highly variable and dependent on the physical properties of the particular area of the seabed; they estimated sound pressure to be 178 dB at 1 m. Popper et al. (2014) estimate that sound levels from vessel traffic can range from less than 150 dB to over 190 dB depending on the size and type of vessel, vessel speed, load, condition, age, and engine type.

Chronic noise from regular turbine operation, while generally lower in frequency, may also significantly change ocean soundscapes as a result of mechanical sounds and intense platform vibrations (Mooney et al. 2020). Floating OSW turbines also require the use of mooring devices, which can contribute to an additional source of noise around the structures (Risch et al. 2023). Risch et al. (2023) reported that a study found these noises, described as impulsive “snaps” due to the steel cables, chains, or wire ropes, to potentially exceed 160 dB at a distance of 150 m. Chronic noise impacts within the AoA are likely to be localized to the area in which turbine platforms and/or seafloor structures are placed and thus the severity of impact is likely to be roughly equal within all zones of the AoA.

The majority of marine anthropogenic noise pollution overlaps natural reef frequencies, but can be considerably louder (e.g., pile driving up to 190 dB) (Slabbekoorn et al. 2010; Bolle et al. 2016; WaterProof 2020). As a result, anthropogenic noise from both construction and operation activities may mask natural cues that are required for the orientation and settlement of deep-sea coral and other reef species within OSW farm sites (Slabbekoorn et al. 2010; Lecchini et al. 2018). For this reason, impact risks of noise pollution could be most severe during periods of coral spawning and larval settlement, but specific targeted research is needed to fully understand this potential impact.

3.3.6 Unexploded Ordnance Detonation

There is a lack of existing literature focused on the impacts of unexploded ordnance (UXO) detonation on any life stage of the benthic receptors (deep-sea corals, deep-sea sponges and sea pens). Therefore, there is only speculation about the exact impacts of UXO detonation on these habitat forming groups beyond likely direct damage to these groups from close proximity to any detonation, which would have a similar impact to bottom disturbance activities and noise. Such detonation would also impact the ecosystem services that benthic receptors provide (e.g., EFH) (see section 3.3.1).

3.3.7 Artificial Lighting

OSW structures will require significant artificial light in the marine environment across all phases of development, including long-term safety lighting on turbine platforms at the surface, vessel lights during construction and operation, and sub-surface lights during pre-construction surveys (e.g., from remotely operated vehicles). While impacts to deep-sea coral species, sponges, and sea pens have not been assessed, artificial light has been found to cause significant impacts to shallow water coral species. Disruption to light-cued diel cycles by artificial light at night can alter feeding behavior and disrupt metabolic functions for shallow corals (Levy et al. 2006; Mardones et al. 2023). Additionally, anthropogenic light can directly impact coral photosystems and alter skeletal morphology (Kramer et al. 2023). If morphology is affected in a significant way it will likely have effects on the ability of benthic receptors to act as EFH, which largely depends on habitat complexity (Söffker et al. 2011; Emslie et al. 2014). Reproductive success for shallow corals is also influenced by artificial light at night, which can reduce larval settlement success and cause oxidative stress that prompts unsynchronized gamete release (Tamir et al. 2020; Ayalon et al. 2021). Though some impacts may not directly correlate to deeper species, mesophotic species that photosynthesize (e.g., apozooxanthellate corals or sea pens) and/or species which have pelagic larvae attuned to light cues may be similarly affected. Direct surface light impacts for mesophotic species would only be a concern for Zone 1 where natural light may penetrate to the seafloor and biological rhythms could therefore potentially be disrupted by artificial light.

However, indirect impacts from light may still affect benthic receptors in all zones; artificial light at night has been shown to modulate behaviors of organisms within the water column, including timing of diel vertical migration of zooplankton species (Davies et al. 2020). Zooplankton, which can migrate to depths of up to 400 m in a negatively phototactic response (Forward 1988), can serve as important food sources to benthic filter feeders, through direct export of carbon via fecal pellets at depth or direct consumption of the plankton themselves (Boyd et al. 2019). Artificial lights, particularly at night, could influence the extent of zooplankton vertical migration, which may decrease their nutritional density, having potential impacts to food supply dynamics for deep-sea corals and sponges (Davies et al. 2010; Mienis et al. 2012). The spatial distribution of vertically migrating zooplankton is highly variable, dependent on the movement of different water masses and community composition (Ashjian et al. 1998), but total plankton biomass may be seasonally enhanced inshore of the shelf break front (Hirzel et al. 2023). This area corresponds to the boundary between Zones 1 and 2 of the AoA, with implications that this region could be especially impacted by artificial light at night; however, these impacts are not spatially limited and should be considered for all areas within the AoA.

Artificial light around oil and gas platforms in the Gulf of Mexico has also been shown to influence fish abundance and communities in different ways seasonally and daily with more fish seen overall at lit platforms than unlit (Barker and Cowan 2018). However, studies do not appear conclusive regarding the influence of artificial light on fish communities as Bolton et al. (2017) found fewer fish under artificial light conditions than unlit nights. The impact of artificial light in OSW development on benthic receptors and habitat providing services (i.e., EFH) is largely unknown and requires further research. The potential impacts of artificial light are present during all stages of OSW energy development, representing a potentially chronic impact to benthic receptors, but the magnitude of this impact and the sensitivity of benthic receptors would require observation and monitoring.

3.3.8 Electromagnetic Fields

Submarine power cables which conduct electrical current from OSW turbines to shore (export cables) as well as between turbine structures (inter-array cables) require the use of extensive three-phase alternating current (AC) as well as high-voltage direct current (HVDC) spanning hundreds of kilometers of submerged space. Electric current passing through a cable induces electric fields of up to 1000 µV m-1 and generates intense magnetic fields of approximately 3200 µT, more than 70 times greater than naturally occurring magnetic fields (Taormina et al. 2018). The strength of these fields, together referred to as electromagnetic fields (EMF), are extremely localized to the surface of a cable, with EMFs decaying exponentially within the surrounding 10 m (Taormina et al. 2018). Cable armoring and/or burial in soft substrates is frequently used with submarine cables and further reduces the strength of EMFs (discussed further in section 4.8). Because many marine species rely on geomagnetic field cues for orientation, disruption of natural magnetic fields by artificial EMFs is a concern (Taormina et al. 2018; Bochert and Zettler 2004).

No peer-reviewed scientific literature is currently available on the likely impacts of EMF on the benthic receptors analyzed in this study. Thus, any direct impacts from EMF on benthic receptors is not well understood and the impacts on benthic receptors as EFH in relation to this stressor remains unknown. However, studies on EMF effects on other benthic species show varying impacts. Prolonged exposure to strong magnetic fields showed no significant effects on survivorship for multiple benthic species, including blue mussels (*Mytilus edulis*), multiple crustaceans, and flounder (*Placthicthys flesus*), nor on reproductive health for *M. edulis* (Bochert and Zettler 2004). However, behavioral studies showed subtle but significant changes in American lobster (*Homarus americanus*) behavior and orientation, along with stronger behavioral changes in electromagnetically sensitive benthic elasmobranchs (e.g., little skate, *Leucoraja erinacea*) (Hutchison et al. 2018). Especially little is known about these potential effects on larval stages of the benthic receptors discussed in this report. However, EMFs have been shown to reduce swimming speeds in larval fish under experimental conditions (Cresci et al. 2022). Because no studies have examined EMF effects on cold-water corals, sea pens, or sponges, potential impacts cannot be ruled out and it is recommended that this data gap is filled by future studies.

Despite the lack of information on benthic impacts, EMFs are likely to be strongest for cables that are not adequately armored or buried within the AoA. Where cables are installed at the seafloor, burial within areas of soft sediment such as Zone 1 (sand) or Zone 3 (mud) is feasible. Cables laid across hard bottom areas within Zone 2 may require protective concrete mattressing, which could similarly reduce the potential impacts from EMFs. Suspended cables, which may or may not be armored, are often used for inter-array power connections would be feasible in all zones of the AoA but may be more likely within the deepest Zone 3.

3.3.9 Vessel Traffic

Increased vessel traffic presents a risk to benthic communities as a result of direct bottom impacts on sensitive benthic habitats during the placement of anchors. This impact is further discussed within the bottom disturbance stressor description (section 3.3.1). Vessel traffic may also impact benthic communities via anthropogenic noise (section 3.3.5) and incidental fluid/debris spills (section 3.3.2). These stressors above could impact the benthic community and the ecosystem services, like EFH, that benthic receptors provide. Vessel traffic is likely to be most impactful in the specific area(s) where OSW structures are installed, which will depend on the specific deployment plan generated by developers. Anchoring of construction vessels may occur in any zone; however, damage from anchors to hard bottom receptors is most likely to occur in Zone 2 where the majority of hard bottom is present (Figure 17). Anchoring in soft sediments and the impacts of sediment disturbance and short-term scouring around vessel anchors is most likely to occur in Zones 1 and 3, where the majority of sediments are fine-grained muds but would be dependent on depth and vessel technologies such as dynamic positioning (Figure 19).

3.4 Distribution Summary of Feasible Technology Impacts within the Area of Analysis

The siting and selection of feasible technology for OSW deployment and, therefore, the extent of various potential impacts in an area, will depend on several environmental factors such as depth, substrate type, slope, distance to shore, and other considerations. A detailed discussion of the physical and environmental constraints for various OSW technology types is provided in the Deepwater Wind Technologies–Technical Concepts Study (NYSERDA, 2025), hereafter referenced as the Technical Concepts Study. This section discusses where the possible configurations of OSW technology may be most likely based on substrate type, depth, and seabed features found within the AoA (note: “next generation” designs are not considered here) and where these may have the greatest impacts on the benthic receptors according to their distribution (section 2). An overview of the constraints for OSW technologies is provided first, followed by zone-specific discussion.

3.4.1 OSW Design Constraints

The entirety of the AoA is better suited to floating turbine platforms than fixed structure arrays, which can be cost-prohibitive at depths greater than 50 m. However, some individual fixed structures such as HVDC converter substations may still be considered within the shallowest depths of the AoA. Floating platform designs and their mooring systems are generally dependent on the anchoring systems used, which, in turn, are constrained to various substrate types and low-grade or flat slope seabed forms.

3.4.1.1 Anchoring Systems

Three major anchor systems are discussed in the Technical Concepts Study: suction, drag embedment, and pile anchors. Suction anchors are stabilized by suction of sediment within caissons and are suited to soft substrates, with mud or clay-like sediments preferred over sand. Suction anchors may be used with any of the major mooring systems and floating platform types but are frequently used with tension-leg platforms (TLPs) or spar buoy platforms. Along with pile anchors, suction anchors can be installed at precise locations and have a relatively small spatial footprint on the seafloor.

Drag embedment anchors, meanwhile, involve the dragging of an anchor along the seafloor until the anchor is stably embedded into the seafloor and thus are also primarily constrained to use in soft substrates. Due to the installation process, final position of drag anchors cannot be precisely sited and have the largest seafloor footprint of all anchors. They are often used with catenary (slack) moorings but may also be used with semi-taught mooring systems.

TLP systems are not feasible with drag anchors. Installation of pile anchors involves repeated pile driving of the anchor into the seabed via vibratory or impact hammer and may be used in any substrate type, including hard bottom (sand is least preferred). Like suction anchors, pile anchors are precisely sited, have a relatively small seafloor footprint, and may be used with any of the major mooring and platform types.

For all anchor types, potential impacts of concern for benthic receptors include bottom disturbance during installation (including sediment disturbance) and introduction of new structures that permanently alter habitat. Scouring around anchors is of greatest concern for fine-grain sediments such as mud or clay (Kells et al. 2001). Because drag embedment anchors are buried in the seafloor, sediment scour is of least concern for this anchor type; however, scour is still a concern for the catenary mooring chains that can lie on the seafloor and are often used with drag anchors. Scour protection measures are often employed with OSW anchors and may consist of relocated boulders or man-made materials. Though scour impacts can be mitigated in this way (section 4.1), these protections can increase the amount of introduced hard bottom surfaces that contribute to artificial reef effects.

3.4.1.2 Mooring Systems

Mooring systems used with floating OSW include catenary lines, taut/TLP moorings, and semi-taut moorings. Catenary lines are slack chains (4 times longer than depth) that may partially lie on the seafloor and thus increase the seafloor footprint of an OSW configuration. TLP moorings involve near-vertical taut lines, which connect anchors with floating platforms to stabilize vertical motion from waves and have the smallest seafloor footprint. Semi-taut moorings combine elements of both catenary and taut moorings, such that lines retain some slack at an angle to the seafloor and flexibly accommodate wave action. For catenary and (to an extent) semi-taut mooring lines, direct contact with chains to the seafloor can contribute to bottom disturbance and scour/sediment resuspension. For all mooring systems, chains and scour protection materials may be colonized and thus contribute to artificial reef effects.

3.4.1.3 Floating Platforms

Four primary floating turbine platforms are currently used in OSW projects: barge, semi-submersible, spar, and tension-leg platforms. The barge, semi-submersible, and spar platform designs may be used with catenary or semi-taught mooring systems, while the tension-leg is the turbine platform associated with TLP systems. Selection of a turbine platform can depend on the depth of the site; spar platforms have the deepest draft (120 m), so are limited to deeper offshore regions, while barge platforms have draft requirements of just 20 m and may be selected for shallower zones. Configurations of the four platform designs may vary, but in all cases, the amount of submerged surface area and surface footprint can contribute to the extent of impacts incurred by a platform. Alteration of oceanographic/atmospheric dynamics will be related to the size of the obstacle at the surface, and the amount of submerged surface area will contribute to the potential space that can be colonized, contributing to artificial reef effects. TLP systems that are under greater force may also contribute greater noise pollution due to tension-related vibrations.

Other components of OSW include inter-array and export cables that conduct electrical current between platforms (inter-array) and between an OSW farm and shore (export). Inter-array cables are often suspended in the water column via subsurface floats (e.g., “lazy wave” umbilical or dynamic riser designs), and most often conduct three-phase alternating current (AC). Export cables, conducting HVDC may also have suspended components, but are significantly larger and heavier than inter-array cables at approximately 240 tons per mile (Dresser 2021). Export cables are frequently lain over long distances along the seafloor, requiring burial trenching (especially in soft bottom) or protective materials laid over top. While cables can be laid over hard substrates, sloping hard bottom features like shelf breaks and canyons limit their feasibility. Cables are usually wrapped in an external material such as cast-iron sheaths that protect the internal conductors and limits the emission of EMFs. Cables may also be protected by placement of rocks, concrete mattresses, or filter bags, all of which can greatly expand the seafloor footprint of export cables laid over long distances. Impacts from cables include bottom disturbance during installation, introduction of new hard bottom structures (especially from protective materials), and the leaking of EMFs and small amounts of heat into surrounding waters (even when sheathed/buried).

Terminal cables from an OSW windfarm may be connected to export cables via an offshore substation that converts multiple AC terminal input cables to an HVDC cable for export to shore. An offshore substation may be fixed, floating, or fully subsurface (“subsea”). Fixed platforms frequently comprise jacket structures that have their foundations pile driven in the seafloor; however, substations are considerably smaller than turbine platforms. The conversion of electrical current can generate significant heat, and many substations include pumping systems that utilizes seawater to cool the converter. In addition to many of the same impacts as OSW platforms and mooring systems, entrainment of pelagic fauna into the cooling system and generation of localized heating may be an added source of impact.

3.4.2 Zone 1 Summary

Zone 1 is the shallowest (60–150 m) and nearest-to-shore region of the AoA, primarily consisting of low flats, with some mid flat and depression seabed forms, particularly in the vicinity of the mouth of the Hudson Canyon (Figure 16). Interpolated sediment modeling predicts the majority of Zone 1 to be sandy substrate, with some intermixed mud and gravel around the mouth of Hudson Canyon in the west, and some larger areas of mud and/or mud with gravel in the east-central region of the zone (Figure 17). This zone also includes portions of Atlantic Sea Scallop managed waters (GARFO) and upper portions of the proposed National Marine Sanctuary of the Hudson Canyon (Figure 20). Biological benthic receptors in Zone 1 are moderately distributed with some clustering of sea pens that aligns with the region of muddy substrate in the central east and of corals at the boundary of Zones 1 and 2 around the mouth of Hudson Canyon; distribution of sponges is generally sparse throughout Zone 1 (section 2.3). Coverage of occurrence records for Zone 1 is fair, with well-distributed coverage of data layers throughout, providing moderate confidence for this region.

Due to the high cover of sand, drag embedment anchors may be the most likely anchor system used in Zone 1, although all major anchor systems are feasible. Because of their large footprint and frequent use with catenary moorings, bottom disturbance, sediment scour and resuspension, and introduction of new structure effects may be of particular concern within this zone. Export HVDC cabling is almost certain to be present in this zone, so there is a high likelihood of EMFs, as well as potential impacts from HVDC converter station(s). Zone 1 is a potential stepping-stone region for non-native species export between coastal waters and shelf break currents that would aid in long-distance dispersal. Portions of Zone 1 benthos lie within the mesophotic (low light) zone, which could allow artificial light from surface platforms to disrupt natural light-driven diel cycles of benthic receptor species. Particularly vulnerable receptors for Zone 1 include sea pens in mudded areas, which may be impacted by OSW-driven sediment changes. However, occurrence records with moderate data confidence indicate that Zone 1 may have relatively low direct impact on other receptors that are less common (non-local impacts notwithstanding).

3.4.3 Zone 2 Summary

Zone 2 of the AoA encompasses the majority of the continental shelf break features between 150 and 200 m, including canyon walls and inter-canyon slopes. The canyon depression and valley features in conjunction with the steepness of the shelf drop-off make Zone 2 the most bathymetrically complex zone of the AoA. In addition to having the highest likelihood of hard bottom (within canyons), Zone 2 marks the transition of mostly sandy substrates at the outer shelf to mostly mud at the shelf basin and into the deeper zone of the AoA, including a mixed zone in the mid-upper shelf slope (Figure 17 and Figure 19). Several canyon features within Zone 2 are designated as discrete deep-sea coral protection areas within the broader Frank R. Lautenberg deep sea coral zone, including a multi-canyon coral protection area in the southwest (Figure 20). This zone also includes the majority of the proposed National Marine Sanctuary of the Hudson Canyon (Figure 20). Aligned with the presence of hard bottom as a benthic receptor, Zone 2 hosts the densest distribution of occurrence records as well as the greatest area of highly suitable habitat for all biological benthic receptors (section 2.3). Confidence of occurrence data is high for this zone based on the distribution of occurrence records.

The high density of biological receptors and the presence of hard bottom make Zone 2 particularly vulnerable to the impacts from all structure configurations and all phases of construction discussed in the previous sections. However, Zone 2 is unlikely to be suitable for a number of OSW technologies, due to the complex topography and slope grade along the shelf. Active sediment transport and hydrodynamic forces (such as upwelling) across and within canyon features may impact seabed-installed infrastructure, including drag and suction anchor systems, laid cables, or fixed foundations. Furthermore, canyon features may propagate turbidity currents that can transport potential pollutants or excess sediments, making this zone more vulnerable to potential water quality impacts. If hard bottom substrate is preferred for installation of OSW anchoring, pile-driven anchors could feasibly be used within the hard bottom areas that are unique to Zone 2, but pile driving would contribute to increased noise during installation relative to other anchor types in the soft bottom regions of Zones 1 and 3. Zone 2 is nearest to the Shelfbreak Jet current, making the area hydrodynamically active and, therefore, may allow long-distance dispersal of non-native larvae that could colonize artificial structures placed within the current. Disruption of water column flow regimes could also be of concern in Zone 2, where surface productivity is expected to be relatively high because of dynamic currents along the shelf break; however, these patterns are not temporally consistent (Ma and Smith 2022).

3.4.4 Zone 3 Summary

Zone 3 is the deepest zone of the AoA (2,000–3,000 m), extending from the foot of the continental shelf slope offshore. Zone 3 is predicted to consist of majority fine-grain sediment (majority mud) and includes outflow channels downslope of canyon features present in Zone 2. Zone 3 also encompasses the George's Bank coral protection area, the Frank R. Lautenberg broad deep-sea coral protection area, as well as the deepest portions of some of the discrete coral protection zones at the base of the shelf slope, and the deepest portion of the proposed National Marine Sanctuary around Hudson Canyon (Figure 20). Biological receptor occurrence points are the least dense within Zone 3; however, data within this zone are especially lacking and confidence levels for all biological receptor data (including habitat suitability) is accordingly low or zero. Still, occurrence records within Zone 3 show moderate distribution of some coral species (largely scleractinian cup corals and bamboo coral Acanella spp. that may colonize soft substrates) (Figure 4), sparse presence of sea pens (Figure 11), and rare presence of demosponges (Figure 9).

Depth is a major constraint for OSW deployments in Zone 3, such that length of moorings would require anywhere from 2,000 (for TLP moorings, equivalent to water depth) to 12,000 m (for catenary lines, four times water depth) of line and likely require larger/heavier anchoring systems, incurring the largest water column footprint from introduced structures within this zone. The surface area of the submerged footprint could in turn cause subsurface hydrodynamic regimes to be especially altered within the water column. Because the seafloor of Zone 3 predominantly comprises mud, all major anchor systems are feasible. However, the sediments in the region are likely to be especially susceptible to scouring around seafloor structures and resuspension/sedimentation impacts due to their fine grain size. Because of the limited occurrence data available, estimating the severity of impact as a function of receptor density is not possible at this time for this zone.

4 Existing Guidance for Avoiding, Minimizing, and Mitigating Impacts

Impacts imposed on the proposed benthic receptors from OSW energy development as described in section 3 may be mitigated with appropriate environmental impact assessment, planning and selection of appropriate installation methods throughout the lifetime of a project. Several of the best practices described in this section may incur tradeoffs in the form of alternative impacts to benthic communities, so each option should be carefully weighed with respect to the overall project and specific habitats where installation is being considered. Case study reports and published literature have been reviewed to present a summary of these best practices. BOEM will likely require any lessee or developer in the AoA to implement pre and post construction monitoring, to better understand the local project impacts, as they have done on other OSW projects in New York (BOEM 2021a; BOEM 2023b). The guidance included in this section may be used for general planning purposes and is not an exhaustive list. Conservation recommendations for future development will likely be significantly refined based on project specific impacts and operations.

In addition to stressor-specific or multiple-stressor mitigation tactics described below, general best practices should be implemented throughout the OSW energy development lifespan and may need to be adjusted for each activity. Strict adherence should be applied to mitigation protocols, including those for waste management, construction, and regulatory procedures. Post-construction maintenance and monitoring should be planned and the groundwork laid well in advance of the pre-construction phase. Monitoring is of particular importance and should include detailed and comprehensive baseline surveys of potential areas for implementation within the AoA, including biological assemblages, substrate type, water quality, hydrodynamic patterns, and physical-ecological tolerances for receptor species, as outlined for other OSW projects in the Mid-Atlantic Region (Ocean Wind 1 and South Fork Wind Farm) (BOEM 2021a; BOEM 2023b).

Commitment to monitoring of pre-construction benthic conditions and changes post-construction should be planned upfront, with schedule and metrics outlined for the lifespan of the OSW, as well as considerations for post-decommission time periods (Allen et al. 2020; BOEM 2021a; BOEM 2023b). This commitment also includes implementing response and intervention protocols in the event of adverse benthic changes, such as introduction of invasive species or severe benthic habitat destruction. In some cases, these protocols may include the potential for impact offset measures, such as habitat restoration (including deep-sea habitats, an emerging area of active research), additional protection policies, or ecological offset payments (Van Dover et al. 2014; Bennum et al. 2021; Montseny et al. 2021; Danovaro 2021).

4.1 Bottom Disturbance

As discussed in section 3, the greatest potential impact to benthic receptors is damage to biotic structures and or/habitat from direct contact as a result of structure/cable installation, anchoring, and/or chain contact with the seafloor. To avoid or minimize these impacts, siting of structures and any bottom-impact activity well-away from critical habitats and specific benthic receptors is a key consideration. For oil and gas rigs that can cause benthic impacts similar to those described for OSW, guidelines from the U.S. Department of Interior restricted placement of structures near sensitive benthic communities at depths deeper than 300 meters (within the Gulf of Mexico). These guidelines indicate a minimum distance buffer of 2,000 feet for the discharge of mud and cuttings, with an additional 1,000 feet buffer if the platforms are anchored. Additionally, a 250-foot buffer must be maintained for any other potential benthic disturbances including those caused by chains, lines, and placement of pipelines (DOI 2010). Further regulatory framework from federal agencies is needed to establish whether these or other buffering guidelines are appropriate for OSW structures. Sensitive species/habitats at a minimum are defined by the benthic receptors listed herein (deep-sea corals, deep-sea sponges, sea pens, and hard bottom), but consideration may also be given to other species/habitats which meet one or more of the following criteria:

- Species/habitats that form structurally complex features, including abiotic structures (e.g., boulder fields, sediment ripples, mega ripples).
- Rare or endemic species.
- Species/habitats particularly sensitive or not adapted to frequent disturbances (e.g., slow growing/long-lived species).
- Species listed as threatened or endangered (International Union for Conservation of Nature red list and/or Convention on International Trade in Endangered Species of Wild Fauna and Flora).
- Species/habitats of particular economic value or that provide key ecosystem services.
- Habitats that host high levels of biodiversity (i.e., “hotspots”).
- Habitats under special designations such as EFH, Habitat Areas of Particular Concern (HAPCs), deep-sea coral protection areas (e.g., Frank R. Lautenberg or Georges Bank discrete coral protection zones), or other designations.

Prior to all construction, post-construction (operations), and decommissioning activities that involve seabed preparation, cable burial, and scour protection, construction companies must provide notification to the Bureau of Safety and Environmental Enforcement (BSEE), as required by BOEM in the Ocean Wind 1 ROD and the South Fork Farm ROD (BOEM 2021a; BOEM 2023). Anchoring plans should be prepared for all activities that occur within the 500 meters of seabed habitat and complex habitats determined by environmental assessments and pre-construction surveys (BOEM 2021a; BOEM 2023). The submission of micrositing plans is required for the intended routing of inter-array cables and other cables that may impact raised areas of the seabed such as ridges and areas identified with complex habitat. The siting plans must also account for proposed boulder relocations (BOEM 2021a; BOEM 2023).

If siting cables, foundations, and/or anchors away from benthic receptors (or other species/habitats listed above) is not an option, direct bottom disturbance in areas containing sensitive benthic communities should be minimized or mitigated through use of alternative structures, installation procedures, and routing. Best practices to minimize benthic disturbance from installation of submerged power cable corridors include laying cables over the shortest possible distance between points while avoiding critical habitats, minimize the numbers of cable crossings between structures, and bundle multiple cable lines together where practical (for instance, when multiple OSW energy developments are present in a region) (OSPAR 2012). For particularly sensitive soft-sediment habitats, alternative approaches of cable burial versus a lain-down technique should be considered for tradeoffs between acute sedimentation and/or direct bottom disturbance and potential for long-term electromagnetic field emissions (although these have not yet been studied in the proposed benthic receptors). One approach to mitigate trenching and sedimentation impacts for cable burial is to use a horizontal directional drilling technique, whereby burial corridors are created below the benthic surface by tunneling; however, this technique is primarily only used within intertidal or shoreline interfaces of export cables, outside of the AoA (Worzyk 2009). Where cables are buried, guidelines indicate a burial depth of approximately 4 to 6 feet outside of shipping channels is recommended; however, burial regulations are driven by multiple governmental and industry agencies including the U.S. Army Corps of Engineers (Dresser 2021), and, as such, recommended burial depths will be agency, site, and context specific. For floating structures that require tethering between platforms and anchors, use of taut line chains (e.g., tension leg platforms) rather than slack or catenary chain may minimize the risk of physical damage to the seafloor from chain contact. In general, direct effects on benthic habitats would likely be minimized by selecting floating OSW energy over use of monopile foundations (ICF 2021). However, careful consideration of the siting of cables and anchoring would be required.

4.2 Changes in Water Quality

While changes in water quality may present a risk to benthic receptors, mitigation of impacts from activities that resuspend sediments may be accomplished by phasing out additives or considering dispersal potential of pollutants and sediments. Pile driving, trenching and other activities that may increase sediment resuspension should be appropriately managed to reduce dispersal to areas that contain sensitive benthic receptors. This may include limiting the duration of construction activities, selecting alternative infrastructure which require less bottom disturbance (section 5.1) such as suction caissons. Gravity anchors, meanwhile, incur the largest sedimentation impacts into the water column and should be avoided if water quality is a primary impact consideration (ICF 2021). Construction methods that reduce bottom disturbance (section 5.1) should be prioritized where possible. For instance, installation of bottom-laid export cables can be performed by jet plowing in soft bottom substrates as opposed to other techniques which more severely perturb bottom sediment (Bennum et al. 2021). Timed avoidance of specific activities that impact water quality (e.g., construction, vessel operations) should be considered during sensitive time periods, such as during reproductive periods, as discussed in the previous section (section 4.1). Mitigation techniques for chronic sedimentation driven by scour should also be considered in tandem with scour protection measures, discussed in section 4.3. Waste disposal should be well-managed to mitigate dispersant impacts, and protocols should be in place to rapidly respond to chemical leaks or spills (Bennun et al. 2021). Where possible, non-toxic antifouling coatings should be prioritized over biocidal chemical agents for submerged structures to minimize the risk of chemical leachants (Nurioglu et al. 2015; see section 4.3).

In addition to spatial avoidance of benthic receptors, developers should consider the timeframes during which construction and installation will take place with respect to ecologically sensitive events, which may occur over diel or seasonal cycles (Cordes et al. 2016). For instance, developers may avoid construction periods that overlap with coral or sponge spawning events, which may occur between late January and early March in the North Atlantic (in the case of the reef-forming coral *Desmophyllum pertusum*) (Brooke & Järnegren 2013). Seasonal restrictions are recommended by BOEM for foundation installation activities in other OSW development projects within the Mid-Atlantic; however, most seasonal restrictions are for protection of marine mammals and migratory fish (BOEM 2021; BOEM 2023). When possible, construction should be paused for several weeks prior to and following these timeframes, to minimize stressors that could reduce coral fecundity leading up to spawning (Le Goff-Vitry et al. 2004; Waller and Tyler 2005) or impact larval survival and transport after the spawning event (Järnegren et al. 2017). The severity of impacts on benthic receptors during the phases of OSW farms can be compounded by variable sensitivity of life cycle stages of benthic receptors.

In general, larval life stages of corals, sponges, and sea pens have been shown to exhibit increased sensitivity to stressors, including reduction of water quality from sedimentation events and accidental release of oil, and noise pollution during construction (see section 3). These stressors can result in mortality of larvae in the water column, impact recruitment to healthy reef sites, and affect their ability to settle on benthic substrates. Despite the importance of timing windfarm impacts with life-cycle stages to reduce the severity of impacts within these benthic receptors our initial understanding of their spawning dynamics remains limited. As an example, only 4% of all known deep-sea coral species (including sea pens) have published assessments of reproduction dynamics (Waller et al. 2023), including seasonal periodicity or lack thereof, which can impede informed timing of windfarm phases to reduce severity of impacts. Within deep-sea sponges an assessment of reproductive strategies has been performed for a limited number of species. Deep-sea sponge species in the genus *Geodia* exhibited periodicity of spawning during summer months (May-September) (Koutsouveli et al. 2020; Spetland et al. 2007) with a similar pattern of summer periodicity (June-August) observed in *Thenea abyssorum* (Witte 1996). It should be noted that all deep-sea corals investigated exhibit this periodicity, with *Radiella sol* exhibiting uncoordinated gamete production suggesting an extended aperiodic reproduction cycle (Witte 1996). Based on the limited availability of reported spawning periodicity it is currently not possible to suggest a window of time during which the impacts to benthic receptor larvae would be most impactful, but available data suggests that avoidance of construction work associated with noise pollution and sedimentation events during August to September could minimize impacts of these stressors to receptors with published periodicity within the AoA (Table 5). However, water quality effects may be present over all phases of OSW projects including the operational phase, and thus moratoria on the sources of all stressors which could have time-dependent effects on reproductive success may not be feasible (e.g., operational artificial light at night or mechanical noises).

Table 5. Summary of Available Spawning Periodicity of Abundant Members of Benthic Receptor Groups within Area of Analysis Adapted from Waller et al. (2023)

Assessment of published reproductive periodicity was performed at the species level when available, those receptors that were assessed only at the genus level are indicated with an asterisk (*). Periodicity is indicated for benthic receptors as follows, P; exhibits periodic reproduction, AP; exhibits aperiodic reproduction.

Receptor	Periodicity	Reference
Stony Corals		
Desmophyllum dianthus	P (August-September)	Feehan et al. 2019
Solenosmilia variabilis	P (April-September)	Pires et al. 2014
Gorgonian Corals		
Keratoisididae	-	-
Acanthogorgia	-	-
Acanella	-	-
*Paramuricea**	P(September-October)	Grinyó et al. 2018
Soft/Stoloniferan Coral		
*Anthomastus**	AP	Cordes et al., 2001
Sea Pens		
*Kophobelemnon**	AP	Rice et al.1992
Protoptilum	-	-
Black Coral		
Parantipathes	-	-
Bathypathes	-	-
Sponges		
Polymastia	-	-
Asconema foliatum	-	-
Regadrella	-	-

4.3 New Structures and Scouring Around Sea Floor Structures

Many studies of OSW energy structures and other offshore platforms have noted the potential for installed infrastructure to create habitat in the form of artificial reefs. While artificial reefs are viewed by some as potentially ecologically "positive" (e.g., Macreadie et al. 2011; Fowler et al. 2018), any introduction of additional hard bottom from OSW energy foundations, anchors, and associated features that alter existing habitat must be carefully considered with respect to ecological effects that may impact surrounding benthic communities (Degraer et al. 2020). Colonization of OSW energy structures by sessile invertebrates like mussels, barnacles, corals, tunicates, and algae can increase biodiversity and biomass, but may also allow for a “stepping-stone” effect for non-native species to access new areas and exert pressures on native benthic ecosystems (Bulleri and Airoldi 2005; SEER 2022). For this reason, proximity of OSW energy sites to nearby communities should be assessed in conjunction with local current regimes and other factors that create connectivity between artificial reefs and native benthic habitats. Proactive anti-biofouling measures can also be employed to mitigate artificial reef effects, including mechanical removal, such as scraping and high-pressure jet washing, or chemical removal, such as biocidal paints or dips. However, while mechanical removal is highly effective in removing foul, these methods may exacerbate biological impacts by releasing non-native propagules, contaminants, or organic material from a fouled structure (Hopkins et al. 2021). On the other hand, biocidal chemical agents may also impact local water quality as a result of leaching into the water column and/or uptake by fouling organisms especially when paired with co-stressors such as high temperatures, e.g., from substation cooling circuits (Taylor 2006). Recent years have shown an increase in the development of various non-toxic/non-biocidal antifouling coatings that are effective for submarine applications, and these should be prioritized for project components wherever feasible (Nurioglu et al. 2015). All efforts should be made to prevent the initial introduction of non-native species or pathogens (e.g., via ballast water from construction vessels or fishing vessels) that might be attracted or promoted by artificial substrate. Comprehensive post-construction monitoring may allow for response in the event of non-native species introductions, such that these organisms might be quickly identified and potentially removed before they become spread to surrounding habitats and mitigation becomes unmanageable. Post-construction monitoring can also mitigate stresses from introduced organisms by helping to identify any realized impacts to benthic receptors that might be prioritized for offset by future restoration efforts.

One potential risk from the development of OSW energy areas is the displacement of fishing or other human activities into adjacent areas that are otherwise relatively unimpacted (e.g., in the event that new structures create habitat which attracts fish into a new area, or if fish are displaced to other areas due to avoidance of OSW impacts). If this is the case for the AoA, activities such as recreational or commercial fishing may be displaced into areas that have not historically been fished and therefore may have an impact on relatively “pristine” benthic habitat (e.g., Davies et al. 2007). Spatial models and socio-economic studies should be explored to assess risk of displacement, and precautionary approaches put in place to reduce any potential impact in areas with high-quality benthic receptor habitat that may be at risk to activity displacement.

Several methods have been developed for the mitigation of scour around marine structures. Placement of boulders or riprap around anchors, foundations, and other bottom-contacting structures are the most common methods but should be carefully planned to avoid failures due to local shear forces or structure-induced bed degradation (Tang et al. 2022). Scour protection can also be achieved by altering flow via sea floor "collars" around foundations, which can prevent hydrodynamic vortex downstream of marine structures (Pandey et al. 2020). However, placement of both riprap and collar structures can also inherently increase the footprint of introduced hard bottom that can exacerbate impacts from artificial reef effects and the overall area of habitat conversion from soft bottom to hard bottom. Scour could alternatively be reduced by treating sediment around foundations or other sea floor structures to immobilize particles and mitigate liquefaction. One method of treatment is the use of microbially (or enzyme) induced calcite precipitation (MICP, EICP) by which calcium-carbonate-producing bacteria or enzymes are injected into sediment to bind sand particles for improved stability. However, this method also may produce adverse effects, such as release of ammonia or biogases as a byproduct of the biochemical processes (Tang et al. 2022). Overall, reduction of the seafloor footprint that would reduce scour from the outset and minimize the need for additional scour protection measures likely a primary mitigation step to proactively reduce impacts from scour around sea floor structures (Bennun et al. 2021). Shared anchor systems in which multiple moorings are attached to single anchors can also reduce the footprint of introduced structures, thereby reducing the need for additional scour protection materials and the colonizable area that contributes to the artificial reef effect (Fontana 2019; Tetra Tech Report).

4.4 Changes to Atmospheric/Oceanographic Dynamics

Changes to oceanographic and/or wind dynamics in the area may be unavoidable with the implementation of OSW energy structures, but impacts may be mitigated primarily through appropriate site selection, such that altered primary production at the surface and/or transport to depth is far away from vulnerable benthic receptors (see also: Bottom Disturbance) (Van Der Molen et al. 2014). Disruption of hydrodynamics below the surface may be additionally mitigated by selecting a floating windfarm option over a bottom-foundation structure, which may alter current dynamics as a physical flow barrier within the water column. Understanding OSW driven changes to oceanographic and atmospheric dynamics are difficult to quantify *in situ,* which necessitates the use of models to predict OSW impacts on ecosystems (Van Der Molen et al. 2014), shelf seas (Cazenave et al. 2016), and upwelling regions (Raghukumar et al. 2023). Changes to oceanographic dynamics could lead to changes (e.g., biogeochemical, nutrient flow, and food supply) that have potential impacts on benthic communities (e.g., Davies et al. 2009; 2010; Mienis et al. 2012). In a study by Van Der Molen et al. (2014), the presence of large-scale OSW arrays suggested environmental changes of 17% wave height reduction and 25% reduction in suspended sediment, but generated relatively weak impacts on biogeochemical cycles, with most changes occurring within the arrays and small changes tens of kilometers away. Greater distances between turbine structures in the array led to decreased environmental impacts, which suggests that fewer, larger turbines may introduce less impact on oceanographic dynamics than a higher number of smaller turbines (Van Der Molen et al. 2014). Guidance on avoiding, minimizing, and mitigating impacts created from OSW driven environmental changes on oceanographic conditions can be taken from modelling studies in combination with remote sensing techniques (as used in Cazenave et al. 2016) to monitor OSW impacts with associated monitoring.

4.5 Noise

While noise is not considered a major impact stressor with respect to benthic receptors, noise may be mitigated primarily during the construction phase with the selection of alternative foundation and anchor types and installation technologies. For instance, installation of monopile foundations that require extensive piling might be avoided with the use of “quiet” alternative foundation types, which include gravity bases or suction caissons (although these options should be weighed against the potential impacts from bottom disturbance and/or sedimentation effects) (IUCN 2021). However, floating wind foundations may incur less noise during construction, as the noise required during foundation installation would be altogether avoided. The mitigation concept of a “soft start,” a gradual ramping of construction activities in an area, may be appropriate for mitigation of noise with respect to mobile species (BOEM 2021; IUCN 2021; BOEM 2023), but will likely not minimize risks to benthic receptors of interest, which are sessile in the adult stage. As described in section 3, noise may impact early life stages more than mature organisms. For this reason, best practices instead indicate time closures for construction activities during sensitive spawning time frames. BOEM does recommend seasonal restrictions for fish and marine mammals in the Ocean Wind 1 and South Fork Wind Farm RODs, but does not currently recommend restrictions for benthic species, which could be considered for deepwater benthic species (BOEM 2021a; BOEM 2023) (see also: Bottom Disturbance). However, data on reproduction and spawning attributes remains lacking for many deep benthic receptors. Other possible noise mitigation methodologies include “channel mitigation” practices, which involve reflection of noise waves away from sensitive areas. Types of channel mitigation might include pneumatic barriers (“bubble curtains”) around construction activities, noise mitigation screens and use of hydro-sound dampening (Dahne et al. 2017; IUCN 2021).

4.6 Unexploded Ordnance Detonation

As impacts from UXO detonation to benthic receptors remains poorly understood, recommendations for best practices with respect to this stressor are lacking. However, based on evidence from bottom disturbance (see section 3), a commonsense approach suggests complete avoidance of UXO detonation near benthic receptors with a significant buffer distance to mitigate any direct damage (i.e., from initial explosion and shrapnel) or indirect (i.e., from resuspension) (See also: Bottom Disturbance/Avoidance).

4.7 Artificial Lighting

Potential impacts of artificial lighting on deep-sea communities in the form of altered diel cycling and organic material supply to deep-sea habitats can be avoided by restricting use of artificial light in the following ways (Orr et al. 2013), but may be difficult to achieve due to safety requirements:

- Minimize the number of lights, light intensity and/or duration of lights used in the OSW energy development area, particularly at night (limited by safety requirements).
- Prioritize flashing lights over continuous light and minimize the flashing rate.
- Avoid “floodlighting” of areas larger than the necessary targets for construction or maintenance operations.
- Avoid direct lighting of the ocean surface when unnecessary.
- Use automatic shut-off timers and/or adjustable light-intensity devices.

These best practice mitigation measures apply to all phases of the OSW energy development lifespan but may be especially relevant to periods where acute light intensity is exhibited, for example, during the construction phase, and long-term safety lighting during the post-construction/operational phase.

4.8 Electromagnetic Fields

No data currently exists on impacts of electromagnetic fields (EMFs) from submerged power cables on the benthic receptors analyzed in this study, but direct or indirect impacts cannot be ruled out. To mitigate EMFs as well as associated thermal emissions, alternative cable types, which have reduced emission potential should be considered. In particular, it has been recommended that three-phase alternating current (AC) or bipolar high-voltage direct current (HVDC) transmission systems, which generally emit weaker magnetic fields, be used rather than high-emission monopolar direct current (DC) cables (Taormina et al. 2018). Besides cable type, EMFs may also be mitigated through trenching/burial of cables below the seafloor, or armoring/sheathing of cables with non-magnetic concrete mattresses, rocks, or half-pipe shell covers. If these tactics are employed, it is also important to consider the tradeoff impacts of introducing new structures to existing marine habitats, particularly where cable are to be laid near or within sensitive benthic habitats (see also: New Structures; Bottom Disturbance).

4.9 Vessel Traffic

Implementation of operational/construction protocols during multiple phases of OSW energy development can minimize potential impacts from vessel traffic (IUCN 2021). These protocols may include:

- Management or restriction of movement within the zone of the AoA.
- Avoidance of re-anchoring for vessels to reduce the bottom areas effected by anchoring impact (see also: Bottom Disturbance).
- Enforcement of vessel closures for non-personnel within the AoA (e.g., fishing, diving vessels, depending on marine use policy of the area).
- Minimizing the number of vessels present to essential personnel only during each phase of development.

5 Knowledge Gaps and Future Considerations

5.1 Biological Data Gaps

A key observation of the literature review was that there is a lack of direct information for receptor groups and OSW energy development and technologies, particularly for deeper living species due to a current lack of any overlap in activities and species distributions. Therefore, studies were utilized that described impacts from other anthropogenic activities, including oil and gas exploration/exploitation, deep-sea mining, and bottom impact fisheries.

Additionally, understanding the distribution of selected organismal benthic receptors diminishes offshore and within deeper waters. Most occurrences currently fall within Zone 2, where topographically complex canyons intersect the shelf break, which provides hard substrata for colonization. This does not preclude the fact that historical data suggests the presence of benthic receptors in both Zones 1 and 3. However, there is not a clear expression of sampling effort throughout the AoA, as all the data available for biological receptors are based upon surveys that were unsystematic in nature. For both biological and geophysical (section 5.2) data gaps, future studies and monitoring designs should be coordinated with the appropriate federal agencies (e.g., NOAA), with respect to federal environmental programs, including data collection for EFH, the Endangered Species Act (ESA), National Environmental Policy Act (NEPA), and other policies. The following monitoring or modeling activities could fill biological data gaps:

- **Habitat Suitability Modeling**. Exploratory high-resolution habitat suitability modeling would be a useful tool to provide information on the potential distribution of benthic receptor groups within the AoA region. Such models should utilize the best available bathymetric data products including multibeam bathymetry, along with species taxonomic and location data. Multiple data sources could be explored for species occurrences including national and international data providers such as NOAA and OBIS, but also regional providers such as state agencies, non-profits and museums, to add value to the data compiled for this study. Best efforts should be made to utilize presence-absence models over presence-only, providing absence data can be located for the region. These studies will help establish potential presence of sensitive benthic receptors and improve quality of data available, as well as feeding into ground truthing surveys.
- **Ground truthing**. Habitat mapping and ground truthing in the AoA would also provide valuable data, with specific focus on exploring both topographically complex emergent hard substrata for the presence of VME indicator species such as deep-sea corals and deep-sea sponges, and areas of soft sediment, which may host sea pen communities. Such an approach should consider the utilization of remotely operated vehicles and uncrewed autonomous vehicles over extractive or bottom impact sampling technologies to reduce potential impact on benthic receptors.

- **Characterization of Physical Environment in areas with vulnerable marine species.** Environmental characterization activities would help to establish detailed physical oceanographic observations for areas that contain benthic receptor species. Such activities may include benthic observatories or moorings which will help better understand the environmental drivers that govern the distribution and health of receptors in the region. Resulting data from these activities will also enable detailed monitoring of any impacts of OSW.
- **Benthic receptors as EFH.** Developing a deeper understanding of the important role benthic habitats in the AoA play as EFH or for other species would fill critical knowledge gaps as to how impacts to benthic communities may occur in areas of OSW development. *In situ* monitoring systems (i.e., cameras, ROV) and experiments (i.e., *in situ* and laboratory) can help evidence behavioral and distributional changes in marine organisms associated with OSW impacts. Efforts to this end should coordinate with NOAA, other state and federal agencies, and scientific research groups to determine critical species of interest. As OSW develops, changes in EFH should be monitored to provide ongoing information with regard to the provision of EFH.
- **Cumulative effects of multiple wind projects.** The cumulative impact of construction, operation and decommissioning of multiple wind projects is uncertain. Stressors to benthic habitat from OSW development are the same as those described in this study; however, the stressors could potentially become compounded depending upon the number, location, and spacing of new wind lease sites with respect to existing leases. The commitment by BOEM to deploy 30 gigawatts (GW) of OSW energy by the year 2030 and 15 GW of floating OSW capacity by 2035 has triggered rapid succession of OSW energy development in U.S. waters. As of early 2023, there existed two demonstration-scale projects operating in federal and state U.S. waters (offshore Virginia and Rhode Island), and two utility-scale projects in federal waters approved by BOEM (offshore Massachusetts and Rhode Island). With recent OSW energy auctions, over two dozen lease areas are planned for the Atlantic, at the time this study was released. This rapid advancement has led BOEM to prepare its first draft Programmatic Environmental Impact Statement (PEIS) for the six proposed lease areas in the New York Bight. A focused, regional cumulative analysis is part of this PEIS and will likely be central to future regional planning processes. To address cumulative impacts, The Vineyard Wind Final Environmental Impact Statement assessed "impacts that could result from the incremental impact of the Proposed Action and action alternatives when combined with past, present, or reasonably foreseeable activities, including other future offshore wind activities" (BOEM 2021b). Additionally, the Final Environmental Impact Statement for the Empire Offshore Wind Projects off the coast of New York included cumulative impact analysis (BOEM 2023a). Accompanying cumulative effects of development comes with a high level of uncertainty generated from incomplete information in the past, present, and future.

5.2 Physical Data Gaps

Comprehensive and high-resolution data on seafloor structure and composition is paramount to proper siting for offshore energy development and protection of biological resources and ecosystem services. Paired with information on sensitive biological receptors, these provide valuable starting points for identifying potential areas for new leases and development. As with biological receptors, data paucity increases with depth and distance from shore. Similarly, as with biological receptors, this gap may be filled or partially filled by OSW developer exploratory sampling after this report is published. The following activities are recommended to fill the physical data gaps in the AoA:

- **Geophysical.** Broad scale bathymetric information exists across the AoA. However, given that the resolution (i.e., level of discernable detail) of these data vary, periodic updates and improvements to these regional bathymetric models are recommended. For example, backscatter data are not processed and utilized as routinely as bathymetry and can be challenging to synthesize over large regional extents. Inclusion of backscatter in focused and spatially limited studies combined with application of existing processing and interpretation standards may assist with providing additional data on seafloor surface composition. Synthesized data on subsurface composition (e.g., derived from sub-bottom profilers and geotechnical surveys) are not available on the regional scale for the AoA and could guide the identification of locations that would support the installation of buried structures, such as cables.
- **Geomorphology.** Development of standard terminology and visual examples is recommended for collection of geomorphological information (i.e., formations on seafloor, such as abyssal plains, canyons, etc.) interpreted from high-resolution geophysical data. These surveys are typically required by OSW developers for their permitting submissions to BOEM. The standardization of these methods would allow for better information sharing which would provide consistent and valuable data to supplement regional models of geomorphology derived from bathymetry.
- **Sediment.** Interpolated soft sediment data are available for most of the AoA and modeled data on predicted hard bottom likelihood are available for most of the southern portion of Zones 1 and 2 of the AoA. These data, along with seabed forms, were used in combination to provide a single combined ranking of hard bottom likelihood data set for the sensitivity analysis provided in this study. However, more comprehensive and consistent data specific to mapping the presence, extent, and nature of hard bottom habitats would greatly assist in pre-siting and permitting activities in the AoA. Existing and ongoing regional seafloor mapping activities and associated recommendations are currently being collated and proposed by the Regional Wildlife Science Collaborative for Offshore Wind (RWSC). Close coordination with this group and use of their mapping activities database is therefore recommended.

5.3 Data Gaps in Potential Stressors

During the development, operation, and decommissioning of OSW, the greatest potential impact to benthic receptors of deep-sea corals, deep-sea sponges, and sea pens is physical damage from direct contact with equipment and structures, particularly, OSW energy developments, vessel anchors and mooring lines, and bottom-impacting survey technologies. Other impacts during the lifetime of OSW energy operations include stressors such as increased sedimentation, noise pollution, and changes in hydrodynamics that could have adverse impacts on the recovery rate of these habitats and the ecosystem services they provide (e.g., EFH). The cumulative impacts on receptor recovery are uncertain, as the baseline health of receptors and the extent of primary damage, if any, may influence their susceptibility to cumulative stressors.

The potential and degree of indirect impacts from some stressors are also uncertain as they are dependent on site-specific conditions and hydrodynamics; these indirect impacts are discussed below:

- **Artificial light.** Artificial light resulting from both increased vessel traffic and windfarm platforms is likely to have a minimal direct impact on benthic receptors within this study, due to the attenuation of light at depths greater than 50 meters. While primary impacts may be unlikely, artificial light at night can result in the modification of behavioral patterns in other trophic groups, including zooplankton, who use negative phototaxis to coordinate vertical migration patterns associated with their grazing of phytoplankton in the upper water column. Alterations of these migration and grazing patterns have the potential to alter the nutritional density of both zooplankton and their fecal pellets, which serve as part of the food supply for benthic filter feeders. The potential impact on zooplankton nutrition on benthic is uncertain and may be counteracted by increased primary production in surface waters due to changes in hydrodynamics in the wake of the windfarm.
- **Changes in Water Quality.** Interest in the impacts of pollution and sedimentation within a multi-stressor context has increased for many benthic organisms that are impacted by other offshore industries such as oil and gas exploration and exploitation. However, no studies are available from OSW for deep benthic species. Key uncertainties include the effects of sedimentation and additional pollution from spills or leaks from infrastructure or vessels. Additional considerations include how changes in food supply may have implications for organisms that are exposed to one or more additional stressors.
- **Changes in Atmospheric and Current Dynamics.** The severity of impacts resulting from the changes in local hydrodynamics on benthic receptors during the operational lifetime of offshore wind energy platforms is in part dependent on the selected sites and the surrounding bathymetric features. Pre-constructions surveys can provide an understanding of existing hydrodynamic features, including ocean currents, thermocline depth, and mixed layer depth, as well as baseline environmental conditions including salinity, temperature, dissolved oxygen, and food supply. An understanding of these local dynamics will provide further information of how reduced wind speeds within the wake of wind farm platforms may result in secondary

impacts on benthic receptors, including alteration of upwelling and downwelling dynamics and generation of oxygen minimum zones in bathymetric depressions. Long-term changes in cold-pool dynamics, bands of cold near-bottom water found in the Middle Atlantic Bight (Lentz et al. 2017), could lead to changes in fish communities associated with benthic communities (Miller et al. 2017) and potentially lead to changes to the benthic communities themselves. For example, benthic infaunal functional communities in the Bering Sea experienced a 24% increase in biomass following cooling of mean bottom temperature from 2.7 °C (1958-59) to 0.9 °C (1975-76) (Coyle et al. 2007). Much remains unknown regarding how changes to cold-pool dynamics will impact benthic receptors in the AoA and future assessments should consider how changes in oceanographic conditions may impact benthic receptors and EFH.

- **EMF.** The impact of electromagnetic fields, generated from windfarm power cables, on deep-sea corals, deep-sea sponges and sea pens remains uncertain with no published studies conducted. Within our systematic literature review only 10 publications were identified for the EMF as a stressor, and none had direct information pertaining to the proposed benthic receptors.
- **Climate change implications.** The benthic receptors of deep-sea corals, deep-sea sponges and sea pens will be influenced by changing ocean conditions because of climate change (Mora et al. 2013; Sweetman et al. 2017). Some species will experience range contractions (e.g., Morato et al. 2020; Gasbarro et al. 2022) while others may experience range expansion (Beazley et al. 2021; Bell et al. 2018). In a climate vulnerability assessment that included deep-sea corals and sponges for estuarine, riverine, and marine habitats in the Northeast U.S., climate change is expected to negatively affect 80% of marine habitats with deep-sea corals and sponges categorized as "very high" sensitivity and "moderate to high" exposure (Farr et al. 2021). These risks are a function of deep-sea corals and sponges lacking specific adaptations to frequent disturbance, which lowers their ability to resist or recover from climate disturbances, and their sensitivity to abiotic changes such as ocean acidification (Farr et al. 2021). It is likely that some receptors will experience changing conditions during the operational lifetime of OSW energy infrastructure, and the combined impacts of climate change and human activity, will have yet unknown cumulative and interactive effects with other potential stress producing factors that are likely more severe than a single stress producing factor.

5.4 Future Considerations

Current scientific understanding of how benthic receptors such as deep-sea corals, deep-sea sponges, and sea pens will be impacted by deepwater offshore wind development is largely based on data from analogous studies from more established anthropogenic activities such as fisheries, oil and gas activities, deep-sea mining, etc. More site-, receptor-, and habitat-specific studies are needed to improve understanding of the direct and indirect impacts of OSW on benthic habitats and benthic species. The following are several key areas for exploration to better inform potential deepwater OSW energy developments in regions where activities overlap with sensitive benthic habitats:

- **Establishment of environmental and ecological baselines for benthic receptor groups.** Given the limited understanding of these receptors within the AoA, environmental and ecological baselines through data collection and modeling efforts are recommended to be created for each benthic receptor. This could include broadscale mapping, quantification of the status of these habitats (including biodiversity, organismal health, and status) and characterization of food supplies and environmental conditions in the immediate area of receptors. Additionally, more information on fundamental biological processes such as the periodicity and seasonality of reproduction, larval behavior and genetic connectivity would further add to our understanding of potential impacts of OSW development.
- **Experimental assessment of the response of benthic receptors to major impact-producing factors.** Many responses of benthic receptors to deepwater OSW energy development are difficult to predict due to a lack of experimental evidence that is focused on a range of expected disturbance levels. Although most literature on impacts comes from well-established activities such as oil and gas, with deep-sea mining rapidly emerging, there will undoubtedly be differences in the magnitude and duration of any given impact-producing factor depending on the technologies used. Studies that address these knowledge gaps related to OSW will give more appropriate information on the potential responses of benthic receptors, especially as OSW technology develops, and the footprint of activity from cabling, turbines, and other associated structures is better defined.
- **Implications of changing climate on cumulative impacts from OSW energy development, if any.** Recent research has highlighted the potential susceptibility of benthic receptors to environmental change, but how organisms will be impacted considering additional stressors from industrial activity from OSW energy development should be explored. This may include studies that consider distributional changes due to climate-related range shifts into areas that overlap with OSW (both expansion and contraction) or increased sensitivity over time due to climate-related stressors to better understand potential cumulative impacts from OSW activity.
- *Sustained monitoring to establish ongoing ecosystem impacts, if any.* Once operations begin, monitoring should assist with establishing the magnitude and footprint of potential impacts to benthic receptor groups. These could incorporate direct physical oceanographic and geophysical surveys within impacted regions. Biological monitoring may include assessments of receptor health such as physiological metrics, recruitment, growth rates and additional observations from associated biodiversity such as benthic invertebrate and pelagic communities. Coordination with regional initiatives (e.g., RWSC) related to understanding impacts of OSW on benthic habitats and communities should be included to enhance shared knowledge.

6 References

Abadie, A, Lejeune, P; Pergent, G, and Gobert, S. 2016. "From Mechanical to Chemical Impact of Anchoring in Seagrasses: The Premises of Anthropogenic Patch Generation in *Posidonia oceanica* Meadows." *Marine Pollution Bulletin* 109 (1): 61–71. Doi: 10.1016/j.marpolbul.2016.06.022

Adams, TP, Miller, RG, Aleynik, D, Burrows, MT. 2014. "Offshore Marine Renewable Energy Devices as Stepping Stones across Biogeographical Boundaries." *Journal of Applied Ecology* 51 (2): 330–38. doi:10.1111/1365-2664.12207

Addamo, AM, Vertino, A, Stolarski, J, García-Jiménez, R, Taviani, M, and Machordom, A. 2016. "Merging scleractinian genera: the overwhelming genetic similarity between solitary *Desmophyllum* and colonial *Lophelia*." *BMC Evolutionary Biology* 16 (1). Doi: 10.1186/s12862-016-0654-8

Aleynik, D, Inall, ME, Dale, A, and Vink, A. 2017. "Impact of remotely generated eddies on plume dispersion at abyssal mining sites in the Pacific." *Scientific Reports* 7 (1). Doi: 10.1038/s41598-017-16912-2

Allen, MC, Campo, M. 2020. "Ecological Monitoring and Mitigation Policies and Practices at Offshore Wind Installations in the United States and Europe." *New Jersey Climate Change Alliance*. Rutgers, The State University of New Jersey. Doi:10.7282/T3-WN1P-CZ80. 46pp

Allers, E, Abed, RMM, Wehrmann, LM, Wang, T, Larsson, AI, Purser, A, and de Beer, D. 2013. "Resistance of *Lophelia pertusa* to coverage by sediment and petroleum drill cuttings." *Marine Pollution Bulletin* 74 (1):132-140. Doi: https://doi.org/10.1016/j.marpolbul.2013.07.016

Althaus, F, Williams, A, Schlacher, T, Kloser, R, Green, M, Barker, B, Bax, N, Brodie, P, and Hoenlinger-Schlacher, M. 2009. "Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting." *Marine Ecology Progress Series* 397:279-294. Doi: 10.3354/meps08248

Altvater, L., Messano, L., Andrade, M., Apolinario, M., & Coutinho, R. 2017. "Use of sodium hypochlorite as a control method for the non-indigenous coral species Tubastraea coccinea Lesson, 1829." *Management of Biological Invasions*, 8, 197–204.

Anderson, OF, Guinotte, JM, Rowden, AA, Clark, MR, Mormede, S, Davies, AJ, and Bowden, DA. 2016a. "Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: Implications for the use of broad-scale models in fisheries management." *Ocean & Coastal Management* 120:110-126.

Anderson, OF, Guinotte, JM, Rowden, AA, Tracey, DM, Mackay, KA, and Clark, MR. 2016b. "Habitat suitability models for predicting the occurrence of vulnerable marine ecosystems in the seas around New Zealand." *Deep Sea Research Part I: Oceanographic Research Papers* 115:265-292.

Ashjian, CJ, Smith, SL, Flagg, CN, Wilson, C. 1998. "Patterns and Occurrence of Diel Vertical Migration of Zooplankton Biomass in the Mid-Atlantic Bight Described by an Acoustic Doppler Current Profiler." *Continental Shelf Research* 18 (8): 831–58. doi:10.1016/S0278-4343(98)00019-3

Auscavitch, SR, Deere, MC, Keller, AG, Rotjan, RD, Shank, TM, and Cordes, EE. 2020. “Oceanographic Drivers of Deep-Sea Coral Species Distribution and Community Assembly on Seamounts, Islands, Atolls, and Reefs Within the Phoenix Islands Protected Area.” *Frontiers in Marine Science* 7. Doi: 10.3389/fmars.2020.00042

Auster, PJ, Gjerde, K, Heupel, E, Watling, L, Grehan, A, and Rogers, AD. 2011. “Definition and detection of vulnerable marine ecosystems on the high seas: problems with the” move-on” rule.” *ICES Journal of Marine Science* 68 (2):254-264.

Ayalon, I, Rosenberg, Y, Benichou, JIC, Campos, CLD, Sayco, SLG, Nada, MAL, Baquiran, JIP, Ligson, CA, Avisar, D, Conaco, C, Kuechly, HU, Kyba, CCM, Cabaitan, PC, and Levy, O. 2021. “Coral Gametogenesis Collapse under Artificial Light Pollution.” *Current Biology* 31 (2):413-419.e3. Doi: 10.1016/j.cub.2020.10.039

Baillon, S, Hamel, JF, Wareham, VE and Mercier, A. 2012. “Deep Cold Water Corals as Nurseries for Fish Larvae.” *Frontiers in Ecology and the Environment* 10 (7): 351–56. doi:10.1890/120022

Barker, VA., and Cowan, JH. 2018. “The Effect of Artificial Light on the Community Structure of Reef-Associated Fishes at Oil and Gas Platforms in the Northern Gulf of Mexico.” *Environmental Biology of Fishes* 101 (1): 153–66. doi:10.1007/s10641-017-0688-9

Battista, T., W. Sautter, M. Poti, E. Ebert, L. Kracker, J. Kraus, A. Mabrouk, B. Williams, D.S. Dorfman, R. Husted, and C.J. Jenkins. 2019. Comprehensive Seafloor Substrate Mapping and Model Validation in the New York Bight. NOAA Technical Memorandum NOS NCCOS 255 and BOEM OCS Study 2019-069. Silver Spring, MD. 187 pp. doi:10.25923/yys0-aa98

Beazley, L, Kenchington, E, Murillo, FJ, Brickman, D, Wang, Z, Davies, AJ, Roberts, EM, and Rapp, HT. 2021. “Climate change winner in the deep sea? Predicting the impacts of climate change on the distribution of the glass sponge *Vazella pourtalesi*.” *Marine Ecology Progress Series* 657:1-23.

Beazley, L, Wang, Z, Kenchington, E, Yashayaev, I, Rapp, HT, Xavier, JR, Murillo, FJ, Fenton, D, and Fuller, S. 2018. “Predicted distribution of the glass sponge *Vazella pourtalesi* on the Scotian Shelf and its persistence in the face of climatic variability.” *PLoS ONE* 13 (10):e0205505.

Bell, JJ, Bennett, HM, Rovellini, A, and Webster, NS. 2018. “Sponges to Be Winners under Near-Future Climate Scenarios.” *BioScience* 68 (12):955-968. Doi: 10.1093/biosci/biy142

Bell, N, and Smith, J. 1999. “Coral growing on North Sea oil rigs.” *Nature* 402 (6762):601-601.

Bennun, L, van Bochove, J, Ng, C, Fletcher, C, Wilson, D, Phair, N, Carbone, G. 2021. “Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers.” *Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.* 260pp.

Bernasconi, Michele, Christine Choirat, and Raffaello Seri. 2009. “The Analytic Hierarchy Process and the Theory of Measurement.” *University of Venice “Ca’ Foscari,” Department of Economics, Working Papers* 56 (January). https://doi.org/10.2307/27784145

Beyer, J, Trannum, HC, Bakke, T, Hodson, PV, and Collier, TK. 2016. "Environmental effects of the Deepwater Horizon oil spill: A review." *Marine Pollution Bulletin* 110 (1):28-51. Doi: 10.1016/j.marpolbul.2016.06.027

Biles, CL, Paterson, DM, Ford, RB, Solan, M, and Raffaelli, DG. 2002. "Bioturbation, ecosystem functioning and community structure." *Hydrology and Earth System Sciences* 6 (6):999-1005. Doi: 10.5194/hess-6-999-2002

Bo, M, Baker, A, Gaino, E, Wirshing, H, Scoccia, F, and Bavestrello, G. 2011. "First description of algal mutualistic endosymbiosis in a black coral (Anthozoa: Antipatharia)." *Marine Ecology Progress Series* 435:1-11. Doi: 10.3354/meps09228

Bochert, R, Zettler, M l. 2004. "Long-Term Exposure of Several Marine Benthic Animals to Static Magnetic Fields." *Bioelectromagnetics* 25 (7): 498–502. doi:10.1002/bem.20019

Bolle, LJ, Jong, CAF de, Bierman, SM, Beek, PJG van, Wessels, PW, Blom, E, Damme, CJG van, Winter, HV, Dekeling, RPA. 2016. "Effect of Pile-Driving Sounds on the Survival of Larval Fish." In *The Effects of Noise on Aquatic Life II*, edited by Arthur N. Popper and Anthony Hawkins, 91–100. Advances in Experimental Medicine and Biology. New York, NY: Springer. doi:10.1007/978-1-4939-2981-8_11

Bolton, D., Mayer-Pinto, M., Clark, G. F., Dafforn, K. A., Brassil, W. A., Becker, A., Johnston, E. L. 2017. "Coastal Urban Lighting Has Ecological Consequences for Multiple Trophic Levels under the Sea." Science of The Total Environment 576 (January): 1–9. doi:10.1016/j.scitotenv.2016.10.037

Bonaldo, D, Benetazzo, A, Bergamasco, A, Falcieri, F, Carniel, S, Aurighi, M, Sclavo, M. 2014. "Sediment transport modifications induced by submerged artificial reef systems: a case study for the Gulf of Venice." *Oceanological and Hydrobiological Studies* 43 (1): 7–20. doi:10.2478/s13545-014-0112-4

Boyd, PW, Claustre, H, Levy, M, Siegel, DA, and Weber, T. 2019. "Multi-faceted particle pumps drive carbon sequestration in the ocean." *Nature* 568 (7752):327-335. Doi: 10.1038/s41586-019-1098-2

Bradshaw, C, Collins, P, and Brand, AR. 2003. "To what extent does upright sessile epifauna affect benthic biodiversity and community composition?" *Marine Biology* 143 (4):783-791. Doi: 10.1007/s00227-003-1115-7

Broad A. 2023. "Anchor Scour from Shipping and the Defaunation of Rocky Reefs: A Quantitative Assessment." *Science of the Total Environment* 863.

Broad, A, Rees, MJ, and Davis, AR. 2020. "Anchor and chain scour as disturbance agents in benthic environments: trends in the literature and charting a course to more sustainable boating and shipping." *Marine Pollution Bulletin* 161:111683. Doi: 10.1016/j.marpolbul.2020.111683

Brooke, S, and Ross, SW. 2014. "First Observations of the Cold-Water Coral *Lophelia pertusa* in Mid-Atlantic Canyons of the USA." *Deep Sea Research Part-II: Topical Studies in Oceanography*, 104:245–51. Doi: 10.1016/j.dsr2.2013.06.011

Brooke, S, Holmes, MW, and Young, CM. 2009. "Sediment tolerance of two different morphotypes of the deep-sea coral *Lophelia pertusa* from the Gulf of Mexico." *Marine Ecology Progress Series* 390:137-144.

Brooke, S, Järnegren, J. 2013. "Reproductive Periodicity of the Scleractinian Coral *Lophelia pertusa* from the Trondheim Fjord, Norway." *Marine Biology* 160 (1): 139–53. Doi:10.1007/s00227-012-2071-x

Brooke, S, Ross, SW, Bane, JM, Seim, HE, and Young, CM. 2013. "Temperature tolerance of the deep-sea coral *Lophelia pertusa* from the southeastern United States." *Deep-Sea Research Part II-Topical Studies in Oceanography* 92:240-248. Doi: 10.1016/j.dsr2.2012.12.001

Brooke, S, Watts, MW, Heil, AD, Rhode, M, Mienis, F, Duineveld, GCA, Davies, AJ, and Ross, SW. 2017. "Distributions and Habitat Associations of Deep-Water Corals in Norfolk and Baltimore Canyons, Mid-Atlantic Bight, USA." *Deep Sea Research Part-II: Topical Studies in Oceanography*, 137:131–47. Doi: 10.1016/j.dsr2.2016.05.008

Brown C.J., J. Beaudoin, M. Brissette, and V. Gazzola. 2019. Multispectral Multibeam Echo Sounder Backscatter as a Tool for Improved Seafloor Characterization. Geosciences 9(3):126.

Brown, C.J., S.J. Smith, P. Lawton, and J.T. Anderson. 2011. Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. Estuarine, Coastal and Shelf Science 92(3): 502–520.

Buhl-Mortensen, L, Vanreusel, A, Gooday, AJ, Levin, LA, Priede, IG, Buhl-Mortensen, P, Gheerardyn, H, King, NJ, and Raes, M. 2010. "Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins." *Marine Ecology* 31 (1):21-50. Doi: 10.1111/j.1439-0485.2010.00359.x

Bulleri, F, and Airoldi, L. 2005. "Artificial Marine Structures Facilitate the Spread of a Non-Indigenous Green Alga, *Codium Fragile* ssp. *Tomentosoides*, in the North Adriatic Sea." *Journal of Applied Ecology* 42 (6):1063–72. Doi: 10.1111/j.1365-2664.2005.01096.x

Bureau of Ocean Energy Management (BOEM). 2019. National Environmental Policy Act Documentation for Impact-Producing Factors in the Offshore Wind Cumulative Impacts Scenario on the North Atlantic Continental Shelf. US Dept. of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA. OCS Study 2019- 036.

Bureau of Ocean Energy Management (BOEM). 2021a. Record of Decision. South Fork Wind Farm and South Fork Export Cable Project Construction and Operations Plan. US Dept. of Interior, Bureau of Ocean Energy Management, US Department of Commerce.

Bureau of Ocean Energy Management (BOEM). 2021b. Vinyard Wind 1 Offshore Wind Energy Project Final Environmental Impact Statement Volume 1. US Dept. of Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs.

Bureau of Ocean Energy Management (BOEM). 2023a. Empire Offshore Wind Final Environmental Impact Assessment. US Dept. of Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs.

Bureau of Ocean Energy Management (BOEM). 2023b. Record of Decision. Ocean Wind 1 Offshore Wind Farm Construction and Operations Plan. US Dept. of Interior, Bureau of Ocean Energy Management, US Department of Commerce.

Butman, Bradford, Danforth, W.W., Twichell, D.C., and Rona, P.A. 2017. Bathymetry, backscatter intensity, and geomorphology of the sea floor of the Hudson Canyon and adjacent slope and rise: U.S. Geological Survey data release, https://doi.org/10.5066/F77H1GSLucieer, V., M. Roche, K. Degrendele, M. Malik, M. Dolan, and G. Lamarche. 2017. User expectations for multibeam echo sounders backscatter strength data-looking back into the future. Marine Geophysical Research 39:23-40.

Cairns, SD. 2007. "Deep-water corals: An overview with special reference to diversity and distribution of deep-water Scleractinian corals." *Bulletin of Marine Science* 81 (3):311-322.

Cazenave, PW, Torres, R, and Allen, JI. 2016. "Unstructured Grid Modelling of Offshore Wind Farm Impacts on Seasonally Stratified Shelf Seas." *Progress in Oceanography* 145 (June): 25–41. doi:10.1016/j.pocean.2016.04.004.Christiansen, MB, and Hasager, CB. 2006. "Using airborne and satellite SAR for wake mapping offshore." *Wind Energy* 9 (5):437-455. Doi: 10.1002/we.196

Clark, MR, Althaus, F, Schlacher, TA, Williams, A, Bowden, DA, and Rowden, AA. 2016. "The impacts of deep-sea fisheries on benthic communities: a review." *ICES Journal of Marine Science* 73 (suppl_1):i51-i69.

Cordes, EE, Jones, DOB, Schlacher, TA, Amon, DJ, Bernardino, AF, Brooke, S, Carney, R, et al. 2016. "Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies." *Frontiers in Environmental Science* 4. Doi: 10.3389/fenvs.2016.00058

Cordes, EE, Nybakken, JW, and Vandykhuizen, G. 2001. "Reproduction and growth of Anthomastus ritteri (Octocorallia: Alcyonacea) from Monterey Bay, California, USA." *Marine Biology* 138 (3):491-501. Doi: 10.1007/s002270000470

Coyle, K. O., Konar, B., Blanchard, A., Highsmith, R. C., Carroll, J., Carroll, M., Denisenko, S. G., Sirenko, B. I. 2007. "Potential Effects of Temperature on the Benthic Infaunal Community on the Southeastern Bering Sea Shelf: Possible Impacts of Climate Change." Deep Sea Research Part II: Topical Studies in Oceanography, Effects of Climate Variability on Sub-Arctic Marine Ecosystems, 54 (23): 2885–2905. doi:10.1016/j.dsr2.2007.08.025

Cresci, A, Durif, CMF, Larsen, T, Bjelland, R, Skiftesvik, AB, Browman, HI. 2022. "Magnetic Fields Produced by Subsea High-Voltage Direct Current Cables Reduce Swimming Activity of Haddock Larvae (Melanogrammus Aeglefinus)." *PNAS Nexus* 1 (4): pgac175. doi:10.1093/pnasnexus/pgac175

Daewel, U, Akhtar, N, Christiansen, N, and Schrum, C. 2022. "Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea." *Communications Earth & Environment* 3 (1). Doi: 10.1038/s43247-022-00625-0

Dähne, M, Tougaard, J, Carstensen, J, Rose, A, and Nabe-Nielsen, J. 2017. "Bubble Curtains Attenuate Noise from Offshore Wind Farm Construction and Reduce Temporary Habitat Loss for Harbour Porpoises." *Marine Ecology Progress Series* 580 :221–37. Doi:10.3354/meps12257

Daly, M, Fautin, DG, and Cappola, VA. 2003. "Systematics of the Hexacorallia (Cnidaria: Anthozoa)." *Zoological Journal of the Linnean Society* 139 (3):419–37. Doi: 10.1046/j.1096-3642.2003.00084.x

Dang, H, and Lovell, CR. 2016. "Microbial surface colonization and biofilm development in marine environments." *Microbiology and Molecular Biology Reviews* 80 (1):91-138.

Danovaro R. 2021. "Marine Ecosystem Restoration in a Changing Ocean." *Restoration Ecology* 29. doi:10.1111/rec.13432

Danovaro, R, Corinaldesi, C, Dell'Anno, A, and Snelgrove, PV. 2017. "The deep-sea under global change." *Current Biology* 27 (11):R461-R465.

Danovaro, R, Fanelli, E, Aguzzi, J, Billett, D, Carugati, L, Corinaldesi, C, Dell'Anno, A, Gjerde, K, Jamieson, AJ, and Kark, S. 2020. "Ecological variables for developing a global deep-ocean monitoring and conservation strategy." *Nature Ecology & Evolution* 4 (2):181-192.

Danovaro, R, Gambi, C, Dell'Anno, A, Corinaldesi, C, Fraschetti, S, Vanreusel, A, Vincx, M, and Gooday, AJ. 2008. "Exponential Decline of Deep-Sea Ecosystem Functioning Linked to Benthic Biodiversity Loss." *Current Biology* 18 (1):1-8. Doi: 10.1016/j.cub.2007.11.056

Davies, A, and Guinotte, J. 2011. "Global Habitat Suitability for Framework-Forming Cold-Water Corals." *PloS ONE* 6 (4). Doi: 10.1371/journal.pone.0018483

Davies, AJ, Duineveld, GCA, Lavaleye, MSS, Bergman, MJN, Van Haren, H, and Roberts, JM. 2009. "Downwelling and deep-water bottom currents as food supply mechanisms to the cold-water coral *Lophelia pertusa* (Scleractinia) at the Mingulay Reef Complex." *Limnology and Oceanography* 54 (2):620-629.

Davies, AJ, Duineveld, GCA, Van Weering, TCE, Mienis, F, Quattrini, AM, Seim, HE, Bane, JM, and Ross, SW. 2010. "Short-term environmental variability in cold-water coral habitat at Viosca Knoll, Gulf of Mexico." *Deep Sea Research Part I: Oceanographic Research Papers* 57:199-212.

Davies, AJ, Roberts, JM, and Hall-Spencer, J. 2007. "Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management." *Biological Conservation* 138:299-312.

Davies, TW, McKee, D, Fishwick, J, Tidau, S, and Smyth, T. 2020. "Biologically important artificial light at night on the seafloor." *Scientific Reports* 10 (1). Doi: 10.1038/s41598-020-69461-6

Davis, AR, Broad, A, Gullett, W, Reveley, J, Steele, C, and Schofield, C. 2016. "Anchors away? The impacts of anchor scour by ocean-going vessels and potential response options." *Marine Policy* 73:1-7. Doi: 10.1016/j.marpol.2016.07.021

De Clippele, LH, Huvenne, VA, Molodtsova, TN, and Roberts, JM. 2019. “The diversity and ecological role of non-scleractinian corals (Antipatharia and Alcyonacea) on scleractinian cold-water coral mounds.” *Frontiers in Marine Science* 6:184.

De Goeij, JM, Van Oevelen, D, Vermeij, MJA, Osinga, R, Middelburg, JJ, De Goeij, AFPM, and Admiraal, W. 2013. “Surviving in a Marine Desert: The Sponge Loop Retains Resources Within Coral Reefs.” *Science* 342 (6154):108-110. Doi: 10.1126/science.1241981

Degraer, S, Carey, D, Coolen, J, Hutchison, Z, Kerckhof, F, Rumes, B, and Vanaverbeke, J. 2020. “Offshore Wind Farm Artificial Reefs Affect Ecosystem Structure and Functioning: A Synthesis.” *Oceanography* 33 (4): 48–57. Doi:10.5670/oceanog.2020.405

Demopoulos, AWJ, Bourque, JR, Frometa, J. 2014. “Biodiversity and Community Composition of Sediment Macrofauna Associated with Deep-Sea Lophelia Pertusa Habitats in the Gulf of Mexico.” *Deep Sea Research Part I: Oceanographic Research Papers* 93 (November): 91–103. doi:10.1016/j.dsr.2014.07.014

Diaz, B.D., M. Rasulo, C.P. Aubeny, C.M. Fontana, S.R. Arwade, D.J. DeGroot, and M. Landon. 2016. Multiline anchors for floating offshore wind towers. OCEANS 2016 MTS/IEEE Monterey.

Dodds, LA, Roberts, JM, Taylor, AC, and Marubini, F. 2007. “Metabolic Tolerance of the Cold-Water Coral *Lophelia pertusa* (Scleractinia) to Temperature and Dissolved Oxygen Change.” *Journal of Experimental Marine Biology and Ecology* 349 (2):205–14. Doi: 10.1016/j.jembe.2007.05.013

Department of the Interior (DOI). 2010. “Notice to Lessees and Operators of Federal Oil, Gas, and Sulphur Leases and Pipeline Right-of-Way Holders, Outer Continental Shelf, Gulf of Mexico OCS Region.” NTL 2009-G40. Minerals Management Service. https://www.boem.gov/sites/default/files/regulations/Notices-To-Lessees/2009/09-G40.pdf

Dresser, B. 2021. “Offshore Wind Submarine Cabling Overview.” Albany (NY): New York State Energy Research and Development Authority (NYSERDA). Report 21-14. Contract 111608A.

Duarte, CM, Chapuis, L, Collin, SP, Costa, DP, Devassy, RP, Eguiluz, VM, Erbe, C, Gordon, TAC, Halpern, BS, Harding, HR, Havlik, MN, Meekan, M, Merchant, ND, Miksis-Olds, JL, Parsons, M, Predragovic, M, Radford, AN, Radford, CA, Simpson, SD, Slabbekoorn, H, Staaterman, E, Van Opzeeland, IC, Winderen, J, Zhang, X, and Juanes, F. 2021. “The soundscape of the Anthropocene ocean.” *Science* 371 (6529):eaba4658. Doi:10.1126/science.aba4658

Duineveld, GCA, Lavaleye, MSS, and Berghuis, EM. 2004. “Particle flux and food supply to a seamount cold-water coral community (Galicia Bank, NW Spain).” *Marine Ecology-Progress Series* 277:13-23.

Durden, JM, Clare, MA, Vad, J, and Gates, AR. 2023. “First in-situ monitoring of sponge response and recovery to an industrial sedimentation event.” *Marine Pollution Bulletin* 191:114870. Doi: 10.1016/j.marpolbul.2023.114870.

Edinger, EN, Wareham, VE, and Haedrich, RL. 2007. "Patterns of groundfish diversity and abundance in relation to deep-sea coral distributions in Newfoundland and Labrador waters." *Bulletin of Marine Science* 81:101-122.

Elith, J, and Graham, CH. 2009. "Do they? How do they? WHY do they differ? On finding reasons for differing performances of species distribution models." *Ecography* 32 (1):66-77. Doi: 10.1111/j.1600-0587.2008.05505.x

Ellis, J, Fraser, G, and Russell, J. 2012. "Discharged drilling waste from oil and gas platforms and its effects on benthic communities." *Marine Ecology Progress Series* 456:285-302. Doi: 10.3354/meps09622

Emslie, MJ., Cheal, AJ, and Johns, KA. 2014. "Retention of Habitat Complexity Minimizes Disassembly of Reef Fish Communities Following Disturbance: A Large-Scale Natural Experiment." *PLOS ONE* 9 (8). Public Library of Science: e105384. doi:10.1371/journal.pone.0105384.ESRI ArcGIS Pro. 2021. ESRI.

ESRI. 2023. "Understanding Overlay Analysis." https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/understanding-overlay-analysis.htm

FAO (2009). International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (Rome, Italy). Food and Agriculture Organization of the United Nations.

Farr, E. R., Johnson, M. R., Nelson, M. W., Hare, J. A., Morrison, W. E., Lettrich, M. D., Vogt, B., Meaney, C., Howson, U. A., Auster, P. J., Borsuk, F. A., Brady, D. C., Cashman, M. J., Colarusso, P., Grabowski, J. H., Hawkes, J. P., Mercaldo-Allen, R., Packer, D. B., & Stevenson, D. K. 2021. "An Assessment of Marine, Estuarine, and Riverine Habitat Vulnerability to Climate Change in the Northeast U.S." PLOS ONE 16 (12). Public Library of Science: e0260654. doi:10.1371/journal.pone.0260654

Feehan, KA, Waller, RG, and Häussermann, V. 2019. "Highly Seasonal Reproduction in Deep-Water Emergent *Desmophyllum dianthus* (Scleractinia: Caryophylliidae) from the Northern Patagonian Fjords." *Marine Biology* 166(4):52. Doi:10.1007/s00227-019-3495-3

Ferrier-Pagès, C, Leal, MC, Calado, R, Schmid, DW, Bertucci, F, Lecchini, D, and Allemand, D. 2021. "Noise Pollution on Coral Reefs? — A yet Underestimated Threat to Coral Reef Communities." Marine Pollution Bulletin 165 (April): 112129. doi:10.1016/j.marpolbul.2021.112129

Fisher, CR, Hsing, P-Y, Kaiser, CL, Yoerger, DR, Roberts, HH, Shedd, WW, Cordes, EE, Shank, TM, Berlet, SP, Saunders, MG, Larcom, EA, and Brooks, JM. 2014. "Footprint of *Deepwater Horizon* blowout impact to deep-water coral communities." *Proceedings of the National Academy of Sciences* 111 (32):11744-11749. Doi: 10.1073/pnas.1403492111

Floeter, J, Pohlmann, T, Harmer, A, and Möllmann, C. 2022. "Chasing the offshore wind farm wind-wake-induced upwelling/downwelling dipole." *Frontiers in Marine Science* 9. Doi: 10.3389/fmars.2022.884943

Fontana, C. 2019. “A Multiline Anchor Concept for Floating Offshore Wind Turbines.” University of Massachusetts Amherst. *Doctoral Dissertations* 1486. doi:10.7275/13483708

Försterra, G, Beuck, L, Häussermann, V, Freiwald, A. 2005. “Shallow-Water Desmophyllum Dianthus (Scleractinia) from Chile: Characteristics of the Biocoenoses, the Bioeroding Community, Heterotrophic Interactions and (Paleo)-Bathymetric Implications.” In *Cold-Water Corals and Ecosystems*, edited by André Freiwald and J. Murray Roberts, 937–77. Erlangen Earth Conference Series. Berlin, Heidelberg: Springer. doi:10.1007/3-540-27673-4_48

Forsyth, J, Andres, M, Gawarkiewicz, G. 2020. “Shelfbreak Jet Structure and Variability off New Jersey Using Ship of Opportunity Data From the CMV Oleander.” *Journal of Geophysical Research: Oceans* 125 (9): e2020JC016455. doi:10.1029/2020JC016455

Forward, R. 1988. “Diel vertical migration: zooplankton photobiology and behaviour.” *Oceanography and Marine Biology: An Annual Review* 26 (36):1-393.

Freiwald, A, Fosså, JH, Grehan, A, Koslow, T, and Roberts, JM. 2004. *Cold-water coral reefs*. UNEP-WCMC, Cambridge, UK.

Gasbarro, R, Sowers, D, Margolin, A, and Cordes, EE. 2022. “Distribution and predicted climatic refugia for a reef-building cold-water coral on the southeast US margin.” *Global Change Biology* 28 (23):7108-7125. Doi: 10.1111/gcb.16415

Gass, SE, and Roberts, JM. 2006. “The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution.” *Marine Pollution Bulletin* 52 (5):549-559.

Gawarkiewicz, G, Monismith, S, Largier, J. 2007. “Observing Larval Transport Processes Affecting Population Connectivity: PROGRESS AND CHALLENGES.” Oceanography 20 (3). *Oceanography Society*: 40–53.

Gawarkiewicz, GG, Todd, RE, Plueddemann, AJ, Andres, M, Manning, JP. 2012. “Direct Interaction between the Gulf Stream and the Shelfbreak South of New England.” *Scientific Reports* 2 (August): 553. doi:10.1038/srep00553

Genin, A, Dayton, PK, Lonsdale, PF, and Speiss, FN. 1986. “Corals on seamount peaks provide evidence of current acceleration over deep-sea topography.” *Nature* 322:59-61.

Girard, F, Cruz, R, Glickman, O, Harpster, T, and Fisher, CR. 2019. “In Situ Growth of Deep-Sea Octocorals after the Deepwater Horizon Oil Spill.” *Elementa: Science of the Anthropocene* 7 (February): 12. Doi:10.1525/elementa.349

Glasby, TM, Connell, SD, Holloway, MG, and Hewitt, CL. 2007. “Nonindigenous Biota on Artificial Structures: Could Habitat Creation Facilitate Biological Invasions?” *Marine Biology* 151 (3): 887–95. Doi: 10.1007/s00227-006-0552-5

Goldberg, WM. 1976. “Comparative study of the chemistry and structure of gorgonian and antipatharian coral skeletons.” *Marine Biology* 35 (3):253-267. Doi: 10.1007/bf00396873

Griffiths, JR, Kadin, M, Nascimento, FJA, Tamelander, T, Törnroos, A, Bonaglia, S, Bonsdorff, E, Brüchert, V, Gårdmark, A, Järnström, M, Kotta, J, Lindegren, M, Nordström, MC, Norkko, A, Olsson, J, Weigel, B, Žydelis, R, Blenckner, T, Niiranen, S, and Winder, M. 2017. “The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world.” *Global Change Biology* 23 (6):2179-2196. Doi: 10.1111/gcb.13642

Grinyó, J, Viladrich, N, Díaz, D, Muñoz, A, Mallol, S, Salazar, J, Castillo, R, Gili, J-M, and Gori, A. 2018. “Reproduction, energy storage and metabolic requirements in a mesophotic population of the gorgonian *Paramuricea macrospina*.” *PLoS ONE* 13 (9):e0203308. Doi: 10.1371/journal.pone.0203308

Gros, C, Jansen, J, Dunstan, PK, Welsford, DC, and Hill, NA. 2022. “Vulnerable, but Still Poorly Known, Marine Ecosystems: How to Make Distribution Models More Relevant and Impactful for Conservation and Management of VMEs?” *Frontiers in Marine Science* 9. Doi: 10.3389/fmars.2022.870145

Guinotte, JM, and Davies, AJ. 2014. “Predicted Deep-Sea Coral Habitat Suitability for the US West Coast.” *PLoS ONE* 9 (4). Doi: 10.1371/journal.pone.0093918

Gunter, CT. 2014. “Potential Impacts from a Worst Case Discharge from an United States Offshore Wind Farm.” *International Oil Spill Conference Proceedings* 2014 (1):869–77. Doi:10.7901/2169-3358-2014.1.869

Hall-Spencer, J, Allain, V, and Fosså, JH. 2002. “Trawling damage to Northeast Atlantic ancient coral reefs.” *Proceedings of The Royal Society of London Series B-Biological Sciences* 269 (1490):507-511.

Halpern, BS, Selkoe, KA, Micheli, F, and Kappel, CV. 2007. “Evaluating and Ranking the Vulnerability of Global Marine Ecosystems to Anthropogenic Threats.” *Conservation Biology* 21 (5):1301-1315. Doi: 10.1111/j.1523-1739.2007.00752.x.

Hawkes, N, Korabik, M, Beazley, L, Rapp, H, Xavier, Jr., and Kenchington, E. 2019. “Glass sponge grounds on the Scotian Shelf and their associated biodiversity.” *Marine Ecology Progress Series* 614:91-109. Doi: 10.3354/meps12903

Hebbeln, D, Wienberg, C, Dullo, W-C, Freiwald, A, Mienis, F, Orejas, C, and Titschack, J. 2020. “Cold-water coral reefs thriving under hypoxia.” *Coral Reefs* 39 (4):853-859. Doi: 10.1007/s00338-020-01934-6

Henry, L-A, and Roberts, JM. 2007. “Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic.” *Deep Sea Research Part I: Oceanographic Research Papers* 54:654-672.

Henry, LA, Davies, AJ, and Roberts, JM. 2010. “Beta diversity of cold-water coral reef communities off western Scotland.” *Coral Reefs* 29:427-436.

Hirzel, A, and Le Lay, G. 2008. “Habitat suitability modelling and niche theory.” *Journal of Applied Ecology.* 45 (5):1372-1381.

Hirzel, AJ, Alatalo, P, Oliver, H, Petitpas, CM, Turner, JT, Zhang, W (Gordon), McGillicuddy, DJ. 2023. “High Resolution Analysis of Plankton Distributions at the Middle Atlantic Bight Shelf-Break Front.” C*ontinental Shelf Research* 267 (September): 105113. doi:10.1016/j.csr.2023.105113.

Hogg, M, Tendal, O, Conway, K, Pomponi, S, van Soest, R, Gutt, J, Krautter, M, and Roberts, J. 2010. *Deep-sea sponge grounds: Reservoirs of biodiversity.* UNEP-WCMC, Cambridge, UK.

Hopkins, G, Davidson, I, Georgiades, E, Floerl, O, Morrisey, D, Cahill, P. 2021. “Managing Biofouling on Submerged Static Artificial Structures in the Marine Environment – Assessment of Current and Emerging Approaches.” *Frontiers in Marine Science* 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.759194

Husebø, Å, Nøttestad, L, Fosså, JH, Furevik, DM, Jørgensen, SB. 2002. “Distribution and Abundance of Fish in Deep-Sea Coral Habitats.” *Hydrobiologia* 471 (1): 91–99. doi:10.1023/A:1016549203368

Hutchison, Z, Sigray, P, He, H, Gill, AB, King, J, Gibson, C. 2018. “Electromagnetic Field (EMF) Impacts on Elasmobranch (Shark, Rays, and Skates) and American Lobster Movement and Migration from Direct Current Cables.” Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2018-00. doi:10.13140/RG.2.2.10830.97602

Huvenne, VAI, Bett, BJ, Masson, DG, Le Bas, TP, and Wheeler, AJ. 2016. “Effectiveness of a deep-sea cold-water coral Marine Protected Area, following eight years of fisheries closure.” *Biological Conservation* 200:60-69. Doi: 10.1016/j.biocon.2016.05.030

ICF. 2021. “Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations.” *U.S. Dept. of the Interior, Bureau of Ocean Energy Management*, Sterling, VA. OCS Study BOEM 2021-053. 48pp.

Järnegren, J, Brooke, S, and Jensen, H. 2017. “Effects of Drill Cuttings on Larvae of the Cold-Water Coral Lophelia Pertusa.” *Deep Sea Research Part-II: Topical Studies in Oceanography* 137:454–62. Doi: 10.1016/j.dsr2.2016.06.014

Jørgensen, LL, Planque, B, Thangstad, TH, and Certain, G. 2016. “Vulnerability of megabenthic species to trawling in the Barents Sea.” *ICES Journal of Marine Science* 73 (suppl_1):i84-i97. Doi: 10.1093/icesjms/fsv107

Kahng, SE, Akkaynak, D, Shlesinger, T, Hochberg, EJ, Wiedenmann, J, Tamir, R, Tchernov, D. 2019. “Light, Temperature, Photosynthesis, Heterotrophy, and the Lower Depth Limits of Mesophotic Coral Ecosystems.” In *Mesophotic Coral Ecosystems*, edited by Yossi Loya, Kimberly A. Puglise, and Tom C.L. Bridge, 801–28. Coral Reefs of the World. Cham: Springer International Publishing. doi:10.1007/978-3-319-92735-0_42

Kahng, SE, Garcia-Sais, JR, Spalding, HL, Brokovich, E, Wagner, D, Weil, E, Hinderstein, L, Toonen, RJ. 2010. “Community Ecology of Mesophotic Coral Reef Ecosystems.” *Coral Reefs* 29 (2): 255–75. doi:10.1007/s00338-010-0593-6

Kells, JA, Balachandar, R, Hagel, KP. 2001. “Effect of Grain Size on Local Channel Scour below a Sluice Gate.” *Canadian Journal of Civil Engineering* 28 (3). Canadian Science Publishing: 440–51. doi:10.1139/l01-012

Kinlan, B, Poti, M, Drohan, A, Packer, D, Nizinski, M, Dorfman, D, and Caldow, C. 2013. “Digital data: Predictive models of deep-sea coral habitat suitability in the U.S. Northeast Atlantic and Mid-Atlantic regions.” *Downloadable digital data package. Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA), Biogeography Branch and NOAA National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).* Released August 2013. Available at: http://coastalscience.noaa.gov/projects/detail?key=35

Kinlan, BP, Poti, M, Drohan, AF, Packer, DB, Dorfman, DS, and Nizinski, MS. 2020. “Predictive modeling of suitable habitat for deep-sea corals offshore the Northeast United States.” *Deep Sea Research Part I: Oceanographic Research Papers* 158:103229. Doi: 10.1016/j.dsr.2020.103229

Kiriakoulakis, K, Bett, BJ, White, M, and Wolff, GA. 2004. “Organic biogeochemistry of the Darwin Mounds, a deep-water coral ecosystem, of the NE Atlantic.” *Deep-Sea Research Part I-Oceanographic Research Papers* 51 (12):1937-1954.

Kiriakoulakis, K, Freiwald, A, Fisher, E, and Wolff, GA. 2007. “Organic matter quality and supply to deep-water coral/mound systems of the NW European Continental Margin.” *International Journal of Earth Sciences* V96 (1):159-170.

Klitgaard, AB, and Tendal, OS. 2004. “Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic.” *Progress in Oceanography* 61 (1):57-98. Doi: 10.1016/j.pocean.2004.06.002

Koutsouveli, V, Cárdenas, P, Conejero, M, Rapp, HT, Riesgo, A. 2020. “Reproductive Biology of Geodia Species (Porifera, Tetractinellida) From Boreo-Arctic North-Atlantic Deep-Sea Sponge Grounds.” *Frontiers in Marine Science* 7. Doi: 10.3389/fmars.2020.59526

Kramer, N, Tamir, R, Galindo-Martínez, CT, Wangpraseurt, D, Loya, Y. 2023. “Light Pollution Alters the Skeletal Morphology of Coral Juveniles and Impairs Their Light Capture Capacity.” *Marine Pollution Bulletin* 193 (August): 115212. doi:10.1016/j.marpolbul.2023.115212

Kulkarni, SS, and Edwards, DJ. 2022. “A bibliometric review on the implications of renewable offshore marine energy development on marine species.” *Aquaculture and Fisheries* 7 (2):211-222. Doi: 10.1016/j.aaf.2021.10.005

Langhamer, O. 2012. “Artificial Reef Effect in Relation to Offshore Renewable Energy Conversion: State of the Art.” *The Scientific World Journal* 2012 (December). Hindawi. Doi: 10.1100/2012/386713

Larcom, EA., McKean, DL, Brooks, JM, and Fisher, CR. 2014. “Growth Rates, Densities, and Distribution of Lophelia Pertusa on Artificial Structures in the Gulf of Mexico.” Deep Sea Research Part I: Oceanographic Research Papers 85 (March): 101–9. doi:10.1016/j.dsr.2013.12.005

Largier, JL. 2003. “Considerations in Estimating Larval Dispersal Distances from Oceanographic Data.” *Ecological Applications* 13 (1). Ecological Society of America: S71–89.

Larsson, AI, van Oevelen, D, Purser, A, and Thomsen, L. 2013. “Tolerance to long-term exposure of suspended benthic sediments and drill cuttings in the cold-water coral *Lophelia pertusa*.” *Marine Pollution Bulletin* 70 (1):176-188. Doi: 10.1016/j.marpolbul.2013.02.033

Le Goff-Vitry, MC, Pybus, OG, and Rogers, AD. 2004. “Genetic Structure of the Deep-Sea Coral *Lophelia pertusa* in the Northeast Atlantic Revealed by Microsatellites and Internal Transcribed Spacer Sequences.” *Molecular Ecology* 13 (3):537–49. Doi:10.1046/j.1365-294X.2004.2079.x

Le Guilloux, E., Olu, K, Bourillet, J. F., Savoye, B., Iglésias, S. P., and Sibuet, M. 2009. “First Observations of Deep-Sea Coral Reefs along the Angola Margin.” *Deep Sea Research Part II: Topical Studies in Oceanography*, Deep-Sea Benthic Ecosystems of the Equatorial African Margin: The Multidisciplinary BIOZAIRE Program, 56 (23): 2394–2403. doi:10.1016/j.dsr2.2009.04.014

Lecchini, D, Bertucci, F, Gache, C, Khalife, A, Besson, M, Roux, N, and Berthe, C. 2018. “Boat Noise Prevents Soundscape-Based Habitat Selection by Coral Planulae.” *Scientific Reports* 8 (1). Doi:10.1038/s41598-018-27674-w

Lentz, S. J. 2017. “Seasonal Warming of the Middle Atlantic Bight Cold Pool.” *Journal of Geophysical Research: Oceans* 122 (2): 941–54. doi:10.1002/2016JC012201.Lessard-Pilon, SA, Podowski, EL, Cordes, EE, Fisher, CR. 2010. “Megafauna Community Composition Associated with Lophelia Pertusa Colonies in the Gulf of Mexico.” *Deep Sea Research Part II: Topical Studies in Oceanography*, Gulf of Mexico Cold Seeps, 57 (21): 1882–90. doi:10.1016/j.dsr2.2010.05.013

Levy, O, Achituv, Y, Yacobi, YZ, Dubinsky, Z, Stambler, N. 2006. “Diel `tuning’ of Coral Metabolism: Physiological Responses to Light Cues.” *Journal of Experimental Biology* 209 (2): 273–83. doi:10.1242/jeb.01983

Lillis, A, Apprill, A, Suca, JJ, Becker, C, Llopiz, JK, Mooney, TA. 2018. “Soundscapes Influence the Settlement of the Common Caribbean Coral Porites Astreoides Irrespective of Light Conditions.” *Royal Society Open Science* 5 (12). Royal Society: 181358. doi:10.1098/rsos.181358

Love, MS, Yoklavich, MM, Black, BA, and Andrews, AH. 2007. “Age of black coral (*Antipathes dendrochristos*) colonies, with notes on associated invertebrate species.” *Bulletin of Marine Science* 80 (2):391-399.

Lunden, JJ, McNicholl, CG, Sears, CR, Morrison, CL, and Cordes, EE. 2014. "Acute survivorship of the deep-sea coral L*ophelia pertusa* from the Gulf of Mexico under acidification, warming, and deoxygenation." *Frontiers in Marine Science* 1. Doi: 10.3389/fmars.2014.00078

Lurton, X. and G. Lamarche (Eds). 2015. Backscatter measurements by seafloor-mapping sonars. Guidelines and Recommendations. 200p. http://geohab.org/wp-content/uploads/2014/05/ BSWGREPORT-MAY2015.pdf.

Luter, HM, Whalan, S, Andreakis, N, Abdul Wahab, M, Botté, ES, Negri, AP, and Webster, NS. 2019. "The Effects of Crude Oil and Dispersant on the Larval Sponge Holobiont." *Msystems* 4 (6): e00743-19. Doi: 10.1128/mSystems.00743-19

Ma, J, and Smith, WO. 2022. "Primary Productivity in the Mid-Atlantic Bight: Is the Shelf Break a Location of Enhanced Productivity?" *Frontiers in Marine Science* 9. https://www.frontiersin.org/articles/10.3389/fmars.2022.824303

Macreadie, PI, Fowler, AM, and Booth, DJ. 2011. "Rigs-to-reefs: will the deep sea benefit from artificial habitat?" *Frontiers in Ecology and the Environment* 9 (8):455-461. Doi: 10.1890/100112

Madsen, PT, Whalberg, M, Tougaard, J, Lucke, K, and Tyack,P. 2006. "Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs." *Marine Ecology Progress Series* 309:279–295.

Maier, SR, Brooke, S, De Clippele, LH, De Froe, E, Van Der Kaaden, AS, Kutti, T, Mienis, F, and Van Oevelen, D. 2023. "On the paradox of thriving cold-water coral reefs in the food-limited deep sea." *Biological Reviews*. Doi: 10.1111/brv.12976

Maldonado, M, Aguilar, R, Bannister, RJ, Bell, JJ, Conway, KW, Dayton, PK, Díaz, C, Gutt, J, Kelly, M, and Kenchington, EL. 2017. "Sponge grounds as key marine habitats: a synthetic review of types, structure, functional roles, and conservation concerns." In *Marine Animal Forests,* edited by Rossi S, Bramanti L, Gori A, and Orejas C, 1-39.

Maldonado, M, López-Acosta, M, Sitjà, C, García-Puig, M, Galobart, C, Ercilla, G, and Leynaert, A. 2019. "Sponge skeletons as an important sink of silicon in the global oceans." *Nature Geoscience* 12 (10):815-822. Doi: 10.1038/s41561-019-0430-7

Maldonado, M. 2006. "The ecology of the sponge larva." *Canadian Journal of Zoology*, 84(2), 175–194. https://doi.org/10.1139/z05-177

Malecha, P, and Heifetz, J. 2017. "Long-term effects of bottom trawling on large sponges in the Gulf of Alaska." *Continental Shelf Research* 150:18-26. Doi: 10.1016/j.csr.2017.09.003

Mardones, ML, Lambert, J, Wiedenmann, J, Davies, TW, Levy, O, D'Angelo, C. 2023. "Artificial Light at Night (ALAN) Disrupts Behavioural Patterns of Reef Corals." *Marine Pollution Bulletin* 194 (September): 115365. doi:10.1016/j.marpolbul.2023.115365

Martín, J, Puig, P, Palanques, A, Masqué, P, and García-Orellana, J. 2008. “Effect of commercial trawling on the deep sedimentation in a Mediterranean submarine canyon.” *Marine Geology* 252 (3-4):150-155.

Matuschek, R., and K. Betke. 2009. Measurements of Construction Noise During Pile Driving of Offshore Research Platforms and Wind Farms. Proceedings of the International Conference on Acoustics, Rotterdam, Netherlands.

Maxwell, SM, Kershaw, F, Locke, CC, Conners, MG, Dawson, C, Aylesworth, S, Loomis, R, Johnson, AF. 2022. “Potential Impacts of Floating Wind Turbine Technology for Marine Species and Habitats.” *Journal of Environmental Management* 307 (April): 114577. doi:10.1016/j.jenvman.2022.114577

McConnaughey, RA, Hiddink, JG, Jennings, S, Pitcher, CR, Kaiser, MJ, Suuronen, P, Sciberras, M, Rijnsdorp, AD, Collie, JS, Mazor, T, Amoroso, RO, Parma, AM, and Hilborn, R. 2020. “Choosing best practices for managing impacts of trawl fishing on seabed habitats and biota.” *Fish and Fisheries* 21 (2):319-337. Doi: 10.1111/faf.12431

McFadden, CS, Ofwegen, LP van, and Quattrini, AM. 2022. “Revisionary Systematics of Octocorallia (Cnidaria: Anthozoa) Guided by Phylogenomics.” *Bulletin of the Society of Systematic Biologists* 1 (3). Doi: 10.18061/bssb.v1i3.8735

Meyer, HK, Roberts, EM, Rapp, HT, and Davies, AJ. 2019. “Spatial patterns of arctic sponge ground fauna and demersal fish are detectable in autonomous underwater vehicle (AUV) imagery.” *Deep Sea Research Part I: Oceanographic Research Papers* 153:103137. Doi: 10.1016/j.dsr.2019.103137

Meyer, K, Brooke, S, Sweetman, A, Wolf, M, and Young, C. 2017. “Invertebrate communities on historical shipwrecks in the western Atlantic: relation to islands.” *Marine Ecology Progress Series* 566:17-29. Doi: 10.3354/meps12058

Micaroni, V, Strano, F, McAllen, R, Woods, L, Turner, J, Harman, L, and Bell, JJ. 2022. “Adaptive strategies of sponges to deoxygenated oceans.” *Global Change Biology* 28 (6):1972-1989. Doi: 10.1111/gcb.16013

Middleton, P., Barnhart, B. 2022. “Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to High Voltage Direct Current Cooling Systems.” Washington (DC): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2022-023. 13 p.

Mienis, F, Duineveld, GCA, Davies, AJ, Ross, SW, Seim, HE, Bane, JM, and van Weering, TCE. 2012. “The influence of near-bed hydrodynamic conditions on cold-water corals in the Viosca Knoll area, Gulf of Mexico.” *Deep Sea Research Part I: Oceanographic Research Papers* 60:32-45.

Milazzo, M, Badalamenti, F, Ceccherelli, G, Chemello, R. 2004. “Boat Anchoring on Posidonia Oceanica Beds in a Marine Protected Area (Italy, Western Mediterranean): Effect of Anchor Types in Different Anchoring Stages.” *Journal of Experimental Marine Biology and Ecology* 299 (1): 51–62. doi:10.1016/j.jembe.2003.09.003

Miller, T. J., Hare, J. A., Alade, L.A. 2016. "A State-Space Approach to Incorporating Environmental Effects on Recruitment in an Age-Structured Assessment Model with an Application to Southern New England Yellowtail Flounder." *Canadian Journal of Fisheries and Aquatic Sciences* 73 (8). NRC Research Press: 1261–70. doi:10.1139/cjfas-2015-0339

Mobilia, V, Cummings, VJ, Clark, MR, Tracey, D, and Bell, JJ. 2021. "Short-term physiological responses of the New Zealand deep-sea sponge *Ecionemia novaezealandiae* to elevated concentrations of suspended sediments." *Journal of Experimental Marine Biology and Ecology* 541:151579. Doi: 10.1016/j.jembe.2021.151579

Montgomery, JC, Jeffs, A, Simpson, SD, Meekan, M, and Tindle, C. 2006. "Sound as an Orientation Cue for the Pelagic Larvae of Reef Fishes and Decapod Crustaceans." *Advances in Marine Biology*, 51:143-196.

Montseny M. 2020. "A New Large-Scale and Cost-Effective Restoration Method for Cold-Water Coral Gardens." *Aquatic Conservation: Marine and Freshwater Ecosystems* 30: 977–87. doi:10.1002/aqc.3303

Mooney, TA, Andersson, MH, and Stanley, J. 2020. "Acoustic impacts of offshore wind energy on fishery resources." *Oceanography* 33(4):83–95.

Mora, C, Wei, C-L, Rollo, A, Amaro, T, Baco, AR, Billett, D, Bopp, L, Chen, Q, Collier, M, Danovaro, R, Gooday, AJ, Grupe, BM, Halloran, PR, Ingels, J, Jones, DOB, Levin, LA, Nakano, H, Norling, K, Ramirez-Llodra, E, Rex, M, Ruhl, HA, Smith, CR, Sweetman, AK, Thurber, AR, Tjiputra, JF, Usseglio, P, Watling, L, Wu, T, and Yasuhara, M. 2013. "Biotic and Human Vulnerability to Projected Changes in Ocean Biogeochemistry over the 21st Century." *PLoS Biology* 11 (10):e1001682. Doi: 10.1371/journal.pbio.1001682

Morato, T, González-Irusta, JM, Dominguez-Carrió, C, Wei, CL, Davies, A, Sweetman, AK, Taranto, GH, Beazley, L, García-Alegre, A, Grehan, A, Laffargue, P, Murillo, FJ, Sacau, M, Vaz, S, Kenchington, E, Arnaud-Haond, S, Callery, O, Chimienti, G, Cordes, E, Egilsdottir, H, Freiwald, A, Gasbarro, R, Gutiérrez-Zárate, C, Gianni, M, Gilkinson, K, Wareham Hayes, VE, Hebbeln, D, Hedges, K, Henry, LA, Johnson, D, Koen-Alonso, M, Lirette, C, Mastrototaro, F, Menot, L, Molodtsova, T, Durán Muñoz, P, Orejas, C, Pennino, MG, Puerta, P, Ragnarsson, SÁ, Ramiro-Sánchez, B, Rice, J, Rivera, J, Roberts, JM, Ross, SW, Rueda, JL, Sampaio, Í, Snelgrove, P, Stirling, D, Treble, MA, Urra, J, Vad, J, Oevelen, D, Watling, L, Walkusz, W, Wienberg, C, Woillez, M, Levin, LA, and Carreiro-Silva, M. 2020. "Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic." Global Change Biology 26 (4):2181-2202. Doi: 10.1111/gcb.14996

Morato, T, Pham, CK, Pinto, C, Golding, N, Ardron, JA, Durán Muñoz, P, and Neat, F. 2018. "A Multi Criteria Assessment Method for Identifying Vulnerable Marine Ecosystems in the North-East Atlantic." *Frontiers in Marine Science* 5. Doi: 10.3389/fmars.2018.00460

Morrison, KM, Meyer, HK, Roberts, EM, Rapp, HT, Colaço, A, and Pham, CK. 2020. "The First Cut Is the Deepest: Trawl Effects on a Deep-Sea Sponge Ground Are Pronounced Four Years on." *Frontiers in Marine Science* 7. Doi: 10.3389/fmars.2020.605281

Muir, PR, Pichon, M. 2019. "Biodiversity of Reef-Building, Scleractinian Corals." In *Mesophotic Coral Ecosystems*, edited by Yossi Loya, Kimberly A. Puglise, and Tom C.L. Bridge, 589–620. Coral Reefs of the World. Cham: Springer International Publishing. doi:10.1007/978-3-319-92735-0_33

Murillo, FJ, Muñoz, PD, Cristobo, J, Ríos, P, González, C, Kenchington, E, and Serrano, A. 2012. "Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): Distribution and species composition." *Marine Biology Research* 8 (9):842-854. Doi: 10.1080/17451000.2012.682583

Nedwell, J., J. Langworthy, and D. Howell. 2003. Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise. Report No. 544 R 0424 commissioned by COWRIE. May 2003.

Neves, BDM, Edinger, E, Layne, GD, and Wareham, VE. 2015. "Decadal longevity and slow growth rates in the deep-water sea pen *Halipteris finmarchica* (Sars, 1851) (Octocorallia: Pennatulacea): implications for vulnerability and recovery from anthropogenic disturbance." *Hydrobiologia* 759 (1):147-170. Doi: 10.1007/s10750-015-2229-x

New York State Energy Research and Development Authority (NYSERDA). 2025. "Offshore Wind Planning in the New York Bight: Deepwater Wind Technologies–Technical Concepts Study," NYSERDA Report Number 25-11., Prepared by Tetra Tech, Boston, MA. nyserda.ny.gov/publications

New York State Energy and Research Development Authority (NYSERDA). 2025. "Offshore Wind Planning in the New York Bight: Fish and Fisheries Data Aggregation Study," NYSERDA Report Number 25-07. Prepared by Henningson, Durham & Richardson Architecture & Engineering, P.C., New York, NY. nyserda.ny.gov/publications

New York State Energy and Research Development Authority (NYSERDA). 2025. "Offshore Wind Planning in the New York Bight: Environmental Sensitivity Analysis," NYSERDA Report Number 25-10. Prepared by Henningson, Durham & Richardson Architecture & Engineering, P.C., New York, NY. nyserda.ny.gov/publications

NOAA. 2016. "Deep Sea Coral Research and Technology Program (DSCRTP). Observations of Deep-Sea Coral and Sponge Occurrences from the NOAA National Deep-Sea Coral and Sponge Database, 1842-Present (NCEI Accession 0145037). *Database version 20230428-8." NOAA National Centers for Environmental Information. Dataset.* https://www.ncei.noaa.gov/archive/accession/0145037. Accessed June 20, 2023.

NREL (National Renewable Energy Lab). 2022. A Systematic Framework for Projecting the Future Cost of Offshore Wind Energy. Available at https://www.nrel.gov/docs/fy23osti/81819.pdf

Nurioglu, AG, Esteves, ACC, With, G de. 2015. “Non-Toxic, Non-Biocide-Release Antifouling Coatings Based on Molecular Structure Design for Marine Applications.” *Journal of Materials Chemistry B* 3 (32). The Royal Society of Chemistry: 6547–70. doi:10.1039/C5TB00232J

OBIS. 2023. “Ocean Biodiversity Information System. Intergovernmental Oceanographic Commission of UNESCO.” www.obis.org. Accessed June 20, 2023.

Opresko, D. 2002. “Revision of the Antipatharia (Cnidaria: Anthozoa). Part II. Schizopathidae.” *Zoologische Mededelingen* 76:411-442.

Orejas, C, Gori, A, Gili, JM. 2008. “Growth Rates of Live *Lophelia pertusa* and *Madrepora oculata* from the Mediterranean Sea Maintained in Aquaria.” *Coral Reefs* 27 (2):255–255. Doi:10.1007/s00338-007-0350-7

Orejas, C, Gori, A, Rad-Menéndez, C, Last, KS, Davies, AJ, Beveridge, CM, Sadd, D, Kiriakoulakis, K, Witte, U, and Roberts, JM. 2016. “The effect of flow speed and food size on the capture efficiency and feeding behaviour of the cold-water coral *Lophelia pertusa*.” *Journal of Experimental Marine Biology and Ecology* 481:34-40. Doi: 10.1016/j.jembe.2016.04.002

Orr, T, Herz, S, and Oakley, D. 2013. “Evaluation of Lighting Schemes for Offshore Wind Facilities and Impacts to Local Environments” *U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs.* Herndon, VA. OCS Study BOEM 2013-0116. 429pp.

OSPAR 2012. “Guidelines on Best Environmental Practice (BEP) in Cable Laying and Operating.” *OSPAR Commission (OSPAR 12/22/1, Annex 14).* London, UK. 18pp.

Packer, D, and Dorfman, D. 2012. “Chapter 5: Deep Sea Corals.” In A Biogeographic Assessment of Seabirds, Deep Sea Corals and Ocean Habitats of the New York Bight: Science to Support Offshore Spatial Planning, edited by Menza C, Kinlan BP, Dorfman DS, Poti M and Caldow C, 224 pp. Silver Spring, MD: NOAA Technical Memorandum NOS NCCOS 141.

Packer, D, Boelke, D, Guida, V, and McGee, LA. 2007. “State of deep coral ecosystems in the Northeastern U.S. region: Maine to Cape Hatteras.” In *The state of deep coral ecosystems of the United States*, edited by Lumsden SE, Hourigan TF, Bruckner AW and Dorr G, 195-232. Silver Spring, MD: NOAA Tech Memo CRCP-3.

Packer, D, Nizinski, M, Bachman, M, Drohan, A, Poti, M, and Kinlan, B. 2017. “State of Deep-Sea Coral and Sponge Ecosystems of the Northeast United States.” In *The State of Deep-Sea Coral and Sponge Ecosystems of the United States*, edited by Hourigan TF, Etnoyer PJ and Cairns SD, 237-297. Silver Spring, MD: NOAA Technical Memorandum NMFS-OHC-4.

Packer, DB, Nizinski, MS, and Cairns, SD. n.d. “List of Deep-Sea Coral Taxa in the U.S. Northeast Region: Depth and Geographic Distribution (v. 2021).”

Pandey, M, Azamathulla, HM, Chaudhuri, S, Pu, JH, Pourshahbaz, H. 2020. “Reduction of Time-Dependent Scour around Piers Using Collars.” *Ocean Engineering* 213 (October): 107692. doi:10.1016/j.oceaneng.2020.107692

Peters, JL, Remmers, T, Wheeler, AJ, Murphy, J, and Cummins, V. 2020. “A systematic review and meta-analysis of GIS use to reveal trends in offshore wind energy research and offer insights on best practices.” *Renewable and Sustainable Energy Reviews* 128:109916. Doi: 10.1016/j.rser.2020.109916

Pham, CK, Murillo, FJ, Lirette, C, Maldonado, M, Colaço, A, Ottaviani, D, and Kenchington, E. 2019. “Removal of deep-sea sponges by bottom trawling in the Flemish Cap area: conservation, ecology and economic assessment.” *Scientific Reports* 9 (1). Doi: 10.1038/s41598-019-52250-1

Phillips, SJ, Anderson, RP, and Schapire, RE. 2006. “Maximum entropy modeling of species geographic distributions.” *Ecological Modelling* 190 (3-4):231-259.

Pierdomenico, M, Gori, A, Guida, VG, and Gili, J-M. 2017. “Megabenthic assemblages at the Hudson Canyon head (NW Atlantic margin): Habitat-faunal relationships.” *Progress In Oceanography* 157:12-26. Doi: https://doi.org/10.1016/j.pocean.2017.08.001

Pierdomenico, M, Russo, T, Ambroso, S, Gori, A, Martorelli, E, D’Andrea, L, Gili, J-M, and Chiocci, FL. 2018. “Effects of trawling activity on the bamboo-coral *Isidella longate* and the sea pen *Funiculina quadrangularis* along the Gioia Canyon (Western Mediterranean, southern Tyrrhenian Sea).” *Progress in Oceanography* 169:214-226. Doi: 10.1016/j.pocean.2018.02.019

Pires, DO, Silva, JC, and Bastos, ND. 2014. “Reproduction of deep-sea reef-building corals from the southwestern Atlantic.” *Deep Sea Research Part-II: Topical Studies in Oceanography* 99:51-63. Doi: 10.1016/j.dsr2.2013.07.008

Platis, A, Bange, J, Bärfuss, K, Canadillas, B, Hundhausen, M, Djath, B, Lampert, A, Schulz-Stellenfleth, J, Siedersleben, S, Neumann, T, and Emeis, S. 2020. “Long-range modifications of the wind field by offshore wind parks – results of the project WIPAFF.” *Meteorologische Zeitschrift* 29. Doi: 10.1127/metz/2020/1023

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, M.B. Halvorsen, S. Lokkeborg, P.H. Rogers, B.L. Southall, D.G. Zeddies, and W.N. Tavolga. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A technical report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. April 2014.

Raghukumar, K, Nelson, T, Jacox, M, Chartrand, C, Fiechter, J, Chang, G, Cheung, L, Roberts, J. 2023. “Projected Cross-Shore Changes in Upwelling Induced by Offshore Wind Farm Development along the California Coast.” *Communications Earth & Environment* 4 (1). Nature Publishing Group: 1–12. doi:10.1038/s43247-023-00780-y

Rakka, M, Godinho, A, Orejas, C, & Carreiro-Silva, M. 2021. “Embryo and larval biology of the deep-sea octocoral Dentomuricea aff. Meteor under different temperature regimes.” *PeerJ*, 9, e11604. https://doi.org/10.7717/peerj.11604

Ramirez-Llodra, E, Brandt, A, Danovaro, R, De Mol, B, Escobar, E, German, CR, Levin, LA, Martinez Arbizu, P, Menot, L, Buhl-Mortensen, P, Narayanaswamy, BE, Smith, CR, Tittensor, DP, Tyler, PA, Vanreusel, A, and Vecchione, M. 2010. “Deep, diverse and definitely different: unique attributes of the world’s largest ecosystem.” *Biogeosciences* 7 (9):2851-2899. Doi: 10.5194/bg-7-2851-2010

Rengstorf, AM, Yesson, C, Brown, C, and Grehan, AJ. 2013. “High-resolution habitat suitability modelling can improve conservation of vulnerable marine ecosystems in the deep sea.” *Journal of Biogeography* 40 (9):1702-1714. Doi: 10.1111/jbi.12123

Rentschler, MUT, Adam, F, Chainho, P, Krügel, K, and Vicente, PC. 2020. “Parametric study of dynamic inter-array cable systems for floating offshore wind turbines.” *Marine Systems & Ocean Technology* 15 (1):16-25. Doi: 10.1007/s40868-020-00071-7

Rice, AL, Tyler, PA, and Paterson, GJL. 1992. “The Pennatulid *Kophobelemnon stelliferum* (Cnidaria: Octocorallia) in the Porcupine Seabight (north-east Atlantic Ocean).” *Journal of the Marine Biological Association of the United Kingdom* 72 (2):417-434. Doi: 10.1017/s0025315400037796

Risch, D., G. Favill, B. Marmo, N. van Geel, S. Benjamins, P. Thompson, A. Wittich, and B. Wilson. 2023. Characterization of underwater operational noise of two types of floating offshore wind turbines. Scottish Association for Marine Science.

Roark, EB, Guilderson, TP, Dunbar, RB, Fallon, SJ, and Mucciarone, DA. 2009. “Extreme longevity in proteinaceous deep-sea corals.” *Proceedings of the National Academy of Sciences* 106 (13):5204-5208. Doi: 10.1073/pnas.0810875106

Roberts, JM, Wheeler, AJ, and Freiwald, A. 2006. “Reefs of the deep: The biology and geology of cold-water coral ecosystems.” *Science* 213 (5773):543-547.

Roberts, JM, Wheeler, AJ, Freiwald, A, and Cairns, S. 2009. *Cold-water corals: the biology and geology of deep-sea coral habitats*. Vol. 1. Cambridge: Cambridge University Press.

Rooper, CN, Wilkins, ME, Rose, CS, and Coon, C. 2011. “Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska.” *Continental Shelf Research* 31 (17):1827-1834. Doi: 10.1016/j.csr.2011.08.003

Rowden, AA, Anderson, OF, Georgian, SE, Bowden, DA, Clark, MR, Pallentin, A, and Miller, A. 2017. “High-resolution habitat suitability models for the conservation and management of vulnerable marine ecosystems on the Louisville Seamount Chain, South Pacific Ocean.” *Frontiers in Marine Science* 4:335.

Rumes, B, Byford, D, De Mesel, I, Derweduwen, J, Kerckhof, F, Reubens, J, and Vandendriessche, S, (2013). “Does it really matter? Changes in species richness and biomass at different spatial scales. Environmental Impacts of Offshore Windfarms in the Belgian Part of the North Sea” in *Learning from the Past to Optimise Future Monitoring Programmes,* edited by Degraer S, Brabant R, and Rumes B, 183-189. Royal Belgian Institute of Natural Sciences.

Saaty, T. L. 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Saaty, Thomas L. 1977. “A Scaling Method for Priorities in Hierarchical Structures.” Journal of Mathematical Psychology 15 (3): 234–81. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, Thomas L. 2004. “Fundamentals of the Analytic Network Process — Dependence and Feedback in Decision-Making with a Single Network.” Journal of Systems Science and Systems Engineering 13 (2): 129–57. https://doi.org/10.1007/s11518-006-0158-y

Sammarco, P, Atchison, A, and Boland, G. 2004. “Expansion of coral communities within the Northern Gulf of Mexico via offshore oil and gas platforms.” *Marine Ecology Progress Series* 280:129-143. Doi: 10.3354/meps280129

Schimel, A.C.G., J. Beaudoin, I.M. Parnum, T. Le Bas, V. Schmidt, G. Keith, and D. Ierodiaconou. 2018. “Multibeam sonar backscatter data processing.” *Marine Geophysical Research* 39:121–137.

Schöttner, S, Hoffmann, F, Wild, C, Rapp, HT, Boetius, A, Ramette, A. 2009. “Inter- and Intra-Habitat Bacterial Diversity Associated with Cold-Water Corals.” *The ISME Journal* 3 (6). Nature Publishing Group: 756–59. doi:10.1038/ismej.2009.15

SEER U.S. Offshore Wind Synthesis of Environmental Effects Research. 2022. “Benthic Disturbance from Offshore Wind Foundations, Anchors, and Cables.” Report by National Renewable Energy Laboratory and Pacific Northwest National Laboratory for the U.S. Department of Energy, Wind Energy Technologies Office. Available at https://tethys.pnnl.gov/seer

Siddaway, AP, Wood, AM, and Hedges, LV. 2019. “How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses.” *Annual Review of Psychology* 70 (1):747-770. Doi: 10.1146/annurev-psych-010418-102803

Simpson, S, Meekan, M, McCauley, R, and Jeffs, A. 2004. “Attraction of settlement-stage coral reef fishes to reef noise.” *Marine Ecology Progress Series* 276:263-268. Doi: 10.3354/meps276263

Slabbekoorn, H, Bouton, N, Van Opzeeland, I, Coers, A, Ten Cate, C, Popper, AN. 2010. “A Noisy Spring: The Impact of Globally Rising Underwater Sound Levels on Fish.” *Trends in Ecology & Evolution* 25 (7): 419–27. doi:10.1016/j.tree.2010.04.005

Smith, TB, Holstein, DM, Ennis, RS. 2019. “Disturbance in Mesophotic Coral Ecosystems and Linkages to Conservation and Management.” In *Mesophotic Coral Ecosystems*, edited by Yossi Loya, Kimberly A. Puglise, and Tom C.L. Bridge, 911–29. Coral Reefs of the World. Cham: Springer International Publishing. doi:10.1007/978-3-319-92735-0_47

Söffker, M, Sloman, KA, and Hall-Spencer, JM. 2011. “In Situ Observations of Fish Associated with Coral Reefs off Ireland.” *Deep Sea Research Part I: Oceanographic Research Papers* 58 (8): 818–25. doi:10.1016/j.dsr.2011.06.002

Solan, M, Hauton, C, Godbold, JA, Wood, CL, Leighton, TG, White, P. 2016. “Anthropogenic Sources of Underwater Sound Can Modify How Sediment-Dwelling Invertebrates Mediate Ecosystem Properties.” *Scientific Reports* 6 (February): 20540. doi:10.1038/srep20540

Spetland, F, Rapp, HT, Hoffmann, F, and Tendal, OS. 2007 “Sexual reproduction of *Geodia barretti* Bowerbank, 1858 (*Porifera,Astrophorida*) in two Scandinavian fjords.” In: *Porifera Research:Biodiversity, Innovation, Sustainability*, edited by Lôbo-Hajdu, G. 613–620. Série Livros. Museu Nacional, Rio de Janeiro.

Steimle, FJ. 1990. “Benthic macrofauna and habitat monitoring on the continental shelf of the Northeastern United States 1. Biomass.” In *NOAA Technical Report NMFS-86; 28 p.*

Strand, R, Whalan, S, Webster, N. S, Kutti, T, Fang, J. K. H, Luter, H. M., & Bannister, R. J. 2017. “The response of a boreal deep-sea sponge holobiont to acute thermal stress.” *Scientific Reports*, *7*(1), Article 1. https://doi.org/10.1038/s41598-017-01091-x

Strehlow, BW, Pineda, M-C, Duckworth, A, Kendrick, GA, Renton, M, Abdul Wahab, MA, Webster, NS, and Clode, PL. 2017. “Sediment Tolerance Mechanisms Identified in Sponges Using Advanced Imaging Techniques.” *PeerJ 5* (November): e3904. Doi:10.7717/peerj.3904

Strømgren, T. 1971. “Vertical and horizontal distribution of *Lophelia pertusa* (Linné) in Trondheimsfjorden on the west coast of Norway.” *Kongel Norske Vidensk Selsk Skrifter* 6:1–9.

Sweetman, AK, Thurber, AR, Smith, CR, Levin, LA, Mora, C, Wei, C-L, Gooday, AJ, Jones, DOB, Rex, M, Yasuhara, M, Ingels, J, Ruhl, HA, Frieder, CA, Danovaro, R, Würzberg, L, Baco, A, Grupe, BM, Pasulka, A, Meyer, KS, Dunlop, KM, Henry, L-A, and Roberts, JM. 2017. “Major impacts of climate change on deep-sea benthic ecosystems.” *Elementa: Science of the Anthropocene* 5. Doi: 10.1525/elementa.203

Tamir, R, Eyal, G, Cohen, I, Loya, Y. 2020. “Effects of Light Pollution on the Early Life Stages of the Most Abundant Northern Red Sea Coral.” *Microorganisms* 8 (2). Multidisciplinary Digital Publishing Institute: 193. doi:10.3390/microorganisms8020193

Tang, Z, Melville, B, Singhal, N, Shamseldin, A, Zheng, J, Guan, D, Cheng, L. 2022. “Countermeasures for Local Scour at Offshore Wind Turbine Monopile Foundations: A Review.” *Water Science and Engineering* 15 (1): 15–28. doi:10.1016/j.wse.2021.12.010

Taormina, B, Bald, J, Want, A, Thouzeau, G, Lejart, M, Desroy, N, Carlier, A. 2018. “A Review of Potential Impacts of Submarine Power Cables on the Marine Environment: Knowledge Gaps, Recommendations and Future Directions.” *Renewable and Sustainable Energy Reviews* 96 (November): 380–91. doi:10.1016/j.rser.2018.07.026

Taylor, CJL. 2006. “The Effects of Biological Fouling Control at Coastal and Estuarine Power Stations.” *Marine Pollution Bulletin*, Recent Developments in Estuarine Ecology and Management, 53 (1): 30–48. doi:10.1016/j.marpolbul.2006.01.004.

Theroux, R, and Wigley, R. 1998. Quantitative composition and distribution of macrobenthic invertebrate fauna of the continental shelf ecosystems of the Northeastern United States. In *NOAA Technical Report NMFS-140; 240 p*.

Thrush, S, Schultz, D, Hewitt, J, and Talley, D. 2002. “Habitat structure in soft-sediment environments and abundance of juvenile snapper *Pagrus auratus*.” *Marine Ecology Progress Series* 245:273-280. Doi: 10.3354/meps245273

Thurber, AR, Sweetman, AK, Narayanaswamy, BE, Jones, DOB, Ingels, J, and Hansman, RL. 2014. “Ecosystem function and services provided by the deep sea.” *Biogeosciences* 11 (14):3941-3963. Doi: 10.5194/bg-11-3941-2014

Trannum, HC, Nilsson, HC, Schaanning, MT, and Øxnevad, S. 2010. "Effects of sedimentation from water-based drill cuttings and natural sediment on benthic macrofaunal community structure and ecosystem processes." *Journal of Experimental Marine Biology and Ecology* 383 (2):111-121. Doi: 10.1016/j.jembe.2009.12.004

UNGA (2006). 61/105. "Sustainable Fisheries, Including Through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and Related Instruments." New York, NY, USA. UNGA.

Vad, J, Kazanidis, G, Henry, L-A, Jones, DOB, Tendal, OS, Christiansen, S, Henry, TB, and Roberts, JM. 2018. "Potential Impacts of Offshore Oil and Gas Activities on Deep-Sea Sponges and the Habitats They Form." *Advances in Marine Biology* 79:33-60. Doi: 10.1016/bs.amb.2018.01.001

Van Der Molen, J, Smith, HCM, Lepper, P, Limpenny, S, and Rees, J. 2014. "Predicting the Large-Scale Consequences of Offshore Wind Turbine Array Development on a North Sea Ecosystem." *Continental Shelf Research* 85 (August): 60–72. doi:10.1016/j.csr.2014.05.018.Van Dolah, RF, Wendt, PH, and Nicholson, N. 1987. "Effects of a research trawl on a hard-bottom assemblage of sponges and corals." *Fisheries Research* 5 (1):39-54. Doi: 10.1016/0165-7836(87)90014-2

Van Dover C.L. 2014. "Ecological Restoration in the Deep Sea: Desiderata." *Marine Policy* 44: 98–106. doi:10.1016/j.marpol.2013.07.006

Vanhellemont, Q, Ruddick, K. 2014. "Turbid Wakes Associated with Offshore Wind Turbines Observed with Landsat 8." *Remote Sensing of Environment* 145 (April): 105–15. doi:10.1016/j.rse.2014.01.009

Vermeij, MJA, Marhaver, KL, Huijbers, CM, Nagelkerken, I, and Simpson, SD. 2010. "Coral Larvae Move toward Reef Sounds." *PLoS ONE 5* (5):e10660. Doi: 10.1371/journal.pone.0010660

Vertino, A, Savini, A, Rosso, A, Di Geronimo, I, Mastrototaro, F, Sanfilippo, R, Gay, G, Etiope, G. 2010. "Benthic Habitat Characterization and Distribution from Two Representative Sites of the Deep-Water SML Coral Province (Mediterranean)." *Deep Sea Research Part II: Topical Studies in Oceanography*, The APLABES Programme: Physical, Chemical and Biological Characterization of Deep-Water Coral Ecosystems from the Ionian Sea (Mediterranean), 57 (5): 380–96. doi:10.1016/j.dsr2.2009.08.023

Vieira, RP, Bett, BJ, Jones, DOB, Durden, JM, Morris, KJ, Cunha, MR, Trueman, CN, and Ruhl, HA. 2020. "Deep-sea sponge aggregations (*Pheronema carpenteri*) in the Porcupine Seabight (NE Atlantic) potentially degraded by demersal fishing." *Progress In Oceanography* 183:102189. Doi: 10.1016/j.pocean.2019.102189

Vierod, ADT, Guinotte, JM, and Davies, AJ. 2014. "Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models." *Deep Sea Research Part-II: Topical Studies in Oceanography* 99:6-18. Doi: 10.1016/j.dsr2.2013.06.010

Wagner, D, Luck, DG, and Toonen, RJ. 2012. "Chapter Two - The Biology and Ecology of Black Corals (Cnidaria: Anthozoa: Hexacorallia: Antipatharia)." *Advances in Marine Biology* 63:67-132. Doi: 10.1016/B978-0-12-394282-1.00002-8

Waldbusser, GG, Marinelli, RL, Whitlatch, RB, and Visscher, PT. 2004. "The effects of infaunal biodiversity on biogeochemistry of coastal marine sediments." *Limnology and Oceanography* 49 (5):1482-1492. Doi: 10.4319/lo.2004.49.5.1482

Waller, RG, and Tyler, PA. 2005. "The Reproductive Biology of Two Deep-Water, Reef-Building Scleractinians from the NE Atlantic Ocean." *Coral Reefs* 24 (3):514–22. Doi: 10.1007/s00338-005-0501-7

Waller, RG, Goode, S, Tracey, D, Johnstone, J, and Mercier, A. 2023. "A review of current knowledge on reproductive and larval processes of deep-sea corals." *Marine Biology* 170 (5). Doi: 10.1007/s00227-023-04182-8

Wang, SV, Wrede, A, Tremblay, N, and Beermann, J. 2022. "Low-Frequency Noise Pollution Impairs Burrowing Activities of Marine Benthic Invertebrates." *Environmental Pollution* 310 (October): 119899. doi:10.1016/j.envpol.2022.119899

WaterProof. 2020. Coastal Virginia Offshore Windpark. "Noise monitoring during monopile installation A01 and A02." WaterProof Marine Consultancy & Services BV.

Watling, L, and Norse, EA. 1998. "Disturbance of the Seabed by Mobile Fishing Gear: A Comparison to Forest Clearcutting." *Conservation Biology* 12 (6): 1180–97. doi:10.1046/j.1523-1739.1998.0120061180.x

Weilgart, L. 2018. "The Impact of Ocean Noise Pollution on Fish and Invertebrates." Report by Oceancare.Weinnig, AM, Gómez, CE, Hallaj, A, Cordes, EE. 2020. "Cold-Water Coral (Lophelia pertusa) Response to Multiple Stressors: High Temperature Affects Recovery from Short-Term Pollution Exposure." *Scientific Reports* 10 (1):1768. doi:10.1038/s41598-020-58556-9

Wells, MG, and Dorrell, RM. 2021. "Turbulence Processes Within Turbidity Currents." A*nnual Review of Fluid Mechanics* 53 (1): 59–83. doi:10.1146/annurev-fluid-010719-060309

White, HK, Hsing, P-Y, Cho, W, Shank, TM, Cordes, EE, Quattrini, AM, and Nelson, RK, 2012. "Impact of the Deepwater Horizon Oil Spill on a Deep-Water Coral Community in the Gulf of Mexico." Proceedings of the National Academy of Sciences 109 (50). *Proceedings of the National Academy of Sciences*: 20303–8. Doi:10.1073/pnas.1118029109

Williams, GC. 2011. "The Global Diversity of Sea Pens (Cnidaria: Octocorallia: Pennatulacea)." *PLoS ONE* 6 (7):e22747. Doi: 10.1371/journal.pone.0022747

Winship, AJ, Thorson, JT, Clarke, ME, Coleman, HM, Costa, B, Georgian, SE, Gillett, D, Grüss, A, Henderson, MJ, Hourigan, TF, Huff, DD, Kreidler, N, Pirtle, JL, Olson, JV, Poti, M, Rooper, CN, Sigler, MF, Viehman, S, and Whitmire, CE. 2020. "Good Practices for Species Distribution Modeling of Deep-Sea Corals and Sponges for Resource Management: Data Collection, Analysis, Validation, and Communication." *Frontiers in Marine Science* 7. Doi: 10.3389/fmars.2020.00303

Witte, U. 1996. “Seasonal Reproduction in Deep-Sea Sponges-Triggered by Vertical Particle Flux?” *Marine Biology* 124 (4):571–81. Doi:10.1007/BF00351038

Worzyk, T. 2009. “Submarine Power Cables and Their Design Elements,” June. doi:10.1007/978-3-642-01270-9_2

Yesson, C, Bedford, F, Rogers, AD, and Taylor, ML. 2017a. “The global distribution of deep-water Antipatharia habitat.” *Deep Sea Research Part-II: Topical Studies in Oceanography* 145:79-86.

Yesson, C, Fisher, J, Gorham, T, Turner, CJ, Hammeken Arboe, N, Blicher, ME, and Kemp, KM. 2017b. “The impact of trawling on the epibenthic megafauna of the west Greenland shelf.” *ICES Journal of Marine Science* 74 (3):866-876. Doi: 10.1093/icesjms/fsw206

Yesson, C, Taylor, ML, Tittensor, DP, Davies, AJ, Guinotte, J, Baco, A, Black, J, Hall-Spencer, JM, and Rogers, AD. 2012. “Global habitat suitability of cold-water octocorals.” *Journal of Biogeography* 39 (7):1278-1292. Doi: 10.1111/j.1365-2699.2011.02681.x

Appendix A – Benthic Habitat Data Sources

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Geophysical	**Bathymetry, backscatter, and geomorphology - Backscatter layer**	Butman, Bradford, Danforth, W.W., Twichell, D.C., and Rona, P.A. 2017. Bathymetry, backscatter intensity, and geomorphology of the sea floor of the Hudson Canyon and adjacent slope and rise: U.S. Geological Survey data release, https://doi.org/10.5066/F77H1GS	Identifies unique habitat/ properties of seafloor	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.sciencebase.gov/catalog/item/58bdf624e4b01a6517dc0fc3
Geophysical	**Bathymetry, backscatter, and geomorphology - Geomorphology layer**	Butman, Bradford, Danforth, W.W., Twichell, D.C., and Rona, P.A. 2017. Bathymetry, backscatter intensity, and geomorphology of the sea floor of the Hudson Canyon and adjacent slope and rise: U.S. Geological Survey data release, https://doi.org/10.5066/F77H1GS	Identifies unique habitat/ properties of seafloor	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.sciencebase.gov/catalog/item/58bdf624e4b01a6517dc0fc3
Geophysical	**Northwest Atlantic Marine Ecoregional Assessment (NAMERA) - Bathymetry**	Greene, J.K., M.G. Anderson, J. Odell, and N. Steinberg, eds. 2010. The Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems. Phase One. The Nature Conservancy, Eastern U.S. Division, Boston, MA. (2020 data update provided by TNC)	Identifies unique habitat/ properties of seafloor	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/marine/namera/namera/Pages/default.aspx
Geophysical	**Bathymetry**	NOAA OER. 2015. Multibeam Report for EX1502L1.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/okeanos_explorer/EX1502L1_mb.html
Geophysical	**Bathymetry**	NOAA. 2013. Multibeam Report for EX1303.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/okeanos_explorer/EX1303_mb.html
Geophysical	**Bathymetry**	NOAA. 2023. National Centers for Environmental Information – U.S. Coastal Relief Model, bathymetric and geophysical data products	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ncei.noaa.gov/products/coastal-relief-model
Geophysical	**Bathymetry**	NOAA. 2023. National Centers for Environmental Information (NCEI) - National Ocean Service (NOS) Office of Coast Survey U.S. Bathymetric & Fishing Maps	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ncei.noaa.gov/products/coastal-relief-model

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Geophysical	**Bathymetry**	NOAA. 2023. NOAA's Ocean Service and Office for Coastal Management. U.S. Interagency Elevation Inventory.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://coast.noaa.gov/inventory/
Geophysical	**Bathymetry**	UNH CCOM. 2004. Multibeam Report for HEN04-3.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/henson/HEN04-3_mb.html
Geophysical	**Bathymetry**	UNH CCOM. 2015. Multibeam Report for MGL1512.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/marcus_g_langseth/MGL1512_mb.html
Geophysical	**Bathymetry**	WHOI. 2004. Multibeam Report for KN178.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/knorr/KN178_mb.html
Geophysical	**Bathymetry**	WHOI. 2006. Multibeam Report for AT13.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or provided through compilation data sets being used for the sensitivity analysis or risk maps	https://www.ngdc.noaa.gov/ships/atlantis/AT13_mb.html
Sediment	**Northwest Atlantic Marine Ecoregional Assessment (NAMERA) - Seabed Forms**	Greene, J.K., M.G. Anderson, J. Odell, and N. Steinberg, eds. 2010. The Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems. Phase One. The Nature Conservancy, Eastern U.S. Division, Boston, MA. (2020 data update provided by TNC)	Identifies unique habitat / properties of seafloor.	Spatial	Primary data to feed into sensitivity analysis or risk maps	http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/marine/namera/namera/Pages/Spatial-Data.aspx
Sediment	**Northwest Atlantic Marine Ecoregional Assessment (NAMERA) - Soft Sediments**	Greene, J.K., M.G. Anderson, J. Odell, and N. Steinberg, eds. 2010. The Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems. Phase One. The Nature Conservancy, Eastern U.S. Division, Boston, MA. (2020 data update provided by TNC)	Identifies unique habitat / properties of seafloor.	Spatial	Primary data to feed into sensitivity analysis or risk maps	http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/marine/namera/namera/Pages/Spatial-Data.aspx

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Sediment	**Seafloor Substrate Mapping - Hard Bottom Likelihood**	Battista, T. W. Sautter, M. Poti, E. Ebert, L. Kracker, J. Kraus, A. Mabrouk, B. Williams, D.S. Dorfman, R. Husted, and C.J. Jenkins. 2019. Comprehensive Seafloor Substrate Mapping and Model Validation in the New York Bight. NOAA Technical Memorandum NOS NCCOS 255 and BOEM OCS Study 2019-069. Silver Spring, MD. 187 pp. doi:10.25923/yys0-aa98	Identifies unique habitat / properties of seafloor.	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0204737
Sediment	**Seafloor Substrate Mapping - Median Grain Size**	Battista, T. W. Sautter, M. Poti, E. Ebert, L. Kracker, J. Kraus, A. Mabrouk, B. Williams, D.S. Dorfman, R. Husted, and C.J. Jenkins. 2019. Comprehensive Seafloor Substrate Mapping and Model Validation in the New York Bight. NOAA Technical Memorandum NOS NCCOS 255 and BOEM OCS Study 2019-069. Silver Spring, MD. 187 pp. doi:10.25923/yys0-aa98	Identifies unique habitat / properties of seafloor.	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0204737
Sediment	**Northwest Atlantic Marine Ecoregional Assessment (NAMERA) - Benthic Habitat (SMAST video analysis)**	Anderson, M. G., Greene, J., Morse, D., Shumway, D. and Clark, M. 2010. Benthic Habitats. In the Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems. Phase One. J.K. Greene, M.G. Anderson, J. Odell, and N. Steinberg, eds. The Nature Conservancy, Eastern U.S. Division, Boston, MA. (2020 data update provided by TNC)	Identifies unique habitat / properties of seafloor.	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/marine/namera/namera/Pages/Spatial-Data.aspx
Sediment	**Sand Shoals**	NCCOS Assessment: Modeled Distribution of Sand Shoals of the Gulf of Mexico and the US Atlantic Coast	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.ncei.noaa.gov/access/metadata/landing- page/bin/iso?d=gov.noaa.nodc:0221906
Sediment	**Sediment texture**	INSAAR. 2023. dbSEABED: Information integrated system for marine substrates. University of Colorado, Boulder.	Identifies unique habitat / properties of seafloor.	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://instaar.colorado.edu/~jenkinsc/dbseabed/
Sediment	**Sediment texture**	USGS. 2014. USGS East Coast Sediment Texture Database. Woods Hole Coastal and Marine Science Center.	Identifies unique habitat / properties of seafloor.	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://woodshole.er.usgs.gov/project-pages/sediment/
Sediment	**Surficial Sediment Database**	USGS. 2020. UsSEABED: Offshore surficial-sediment database for samples collected within the United States Exclusive Economic Zone.	Identifies unique habitat / properties of seafloor.	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.usgs.gov/data/usseabed-offshore-surficial-sediment-database-samples-collected-within-united-states-exclusive
Sediment	**USGS usSEABED database**	Buczkowski, B.J., Reid, J.A., and Jenkins, C.J., 2020, Sediments and the sea floor of the continental shelves and coastal waters of the United States—About the usSEABED integrated sea-floor-characterization database, built with the dbSEABED processing system: U.S. Geological Survey Open-File Report 2020–1046, 14 p., https://doi.org/10.3133/ofr20201046	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://pubs.er.usgs.gov/publication/ofr20201046
Sediment Biodiversity / Habitat Suitability	**Benthic survey**	NYSERDA. 2017. NY State Offshore Wind Master Plan Analysis of Multibeam Echo Sound and Benthic Survey Data (INSPIRE Environmental 2017)	Identifies unique habitat/ properties of seafloor	Non-spatial/ report AND Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Biomass-Solar-Wind/Master-Plan/17-25a-MBES-and-Benthic-Survey-Data.pdf

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Biodiversity / Habitat Suitability	**Deep sea stony coral habitat suitability**	Office for Coastal Management, 2023: Deep-sea Stony Coral Habitat Suitability.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/inport/item/48878
Biodiversity / Habitat Suitability	**Distribution maps**	OBIS. 2016. Distribution Map. UNESCO, Ocean Biogeographic Information System.	Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://obis.org/
Biodiversity / Habitat Suitability	**Coral and sponge observations**	USGS. 2023. Coral and Sponge observations in deep sea canyons and on seamounts in the northwest Atlantic.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.gbif.org/dataset/602e1bdf-385d-447c-818a-58266b7c7fc6
Biodiversity / Habitat Suitability	**Coral observations**	MADP. 2023. Coral Observations, Version 1.0. Obtained through the Mid-Atlantic Ocean Data Portal.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://portal.midatlanticocean.org/static/data_manager/metadata/html/corals.html
Biodiversity / Habitat Suitability	**Deep sea coral**	NOAA 2012. Deep Sea Coral Research and Technology Program. National Geodatabase of Deep Sea Corals and Sponges. National Oceanic and Atmospheric Administration.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://deepseacoraldata.noaa.gov/
Biodiversity / Habitat Suitability	**Deep sea coral**	NOAA 2014. Deep Sea Coral Research and Technology Program 2014 Report to Congress. National Oceanic and Atmospheric Administration.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Non-spatial/ report	Risk rating guidance	https://www.coris.noaa.gov/activities/reportcongress_dscrtp_2014/welcome.html

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Biodiversity / Habitat Suitability	**Deep sea soft coral habitat suitability**	Office for Coastal Management, 2023: Deep-sea Soft Coral Habitat Suitability. (Model output for deep-sea coral habitat suitability in the U.S. North and Mid-Atlantic from 2013)	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:145923
Biodiversity / Habitat Suitability	**Hudson Canyon benthic habitats characterization and mapping by integrated analysis of multidisciplinary data**	Pierdomenico, Martina & Guida, Vincent & Rona, Peter & Macelloni, Leonardo & Scranton, Mary & Asper, Vernon & Diercks, Arne. (2013). Hudson Canyon benthic habitats characterization and mapping by integrated analysis of multidisciplinary data. Pierdomenico M, Guida VG, Macelloni L, Chiocci FL, Rona PA, Scranton MI, Asper V, Diercks A (2015) Sedimentary facies, geomorphic features and habitat distribution at the Hudson Canyon head from AUV multibeam data. Deep Sea Research Part II: Topical Studies in Oceanography 121:112-125. Pierdomenico M, Gori A, Guida V.G., Gili J-M (2017) Megabenthic assemblages at the Hudson Canyon head (NW Atlantic margin): Habitat-faunal relationships.	Identifies unique habitat/ properties of seafloor	Non-spatial/ report	Supplementary data available for the AoA and/or sensitvity analysis; Risk rating guidance	https://www-sciencedirect-com.une.idm.oclc.org/science/article/pii/S0967064515001332#s0115
Biodiversity / Habitat Suitability	**Marine habitat**	Marine Habitat, Corals, lobster. Woods Hole Coastal and Marine Science Center. 2023.	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	MarineCadastre.gov
Biodiversity / Habitat Suitability	**Sponge**	Climate Change Winner in the Deep Sea? Predicting the Impacts of Climate Change on the Distribution of the Glass Sponge Vazella pourtalesii	Information may be useful when assessing cumulative impacts or impacts from OSW development.	Non-spatial/ report	Risk rating guidance	Climate Change Winner in the Deep Sea? Predicting the Impacts of Climate Change on the Distribution of the Glass Sponge Vazella pourtalesii (uri.edu) https://www.int-res.com/articles/feature/m657p001.pdf
Resource Management Areas	**Frank R. Lautenberg Deep Sea Coral Protection Area**	MAFMC/NMFS. 2016. Amendment 16 to the Atlantic Mackerek, Squid, and Butterfish Fishery Management Plan. Measures to Protect Deep Sea Corals from the Impacts of Fishing Gear.	Identifies unique habitat to show how species are using the AoA.	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/resource/map/frank-r-lautenberg-deep-sea-coral-protection-areas-map-gis
Resource Management Areas	**New York Bight Scallop Management Areas**	NOAA Greater Atlantic Regional Fisheries Office, 2022: Atlantic Sea Scallop Managed Waters Fishing Year 2022;	Identifies potential use conflicts	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/resource/map/atlantic-sea-scallop-managed-waters-fishing-year-2022

Category	Type / Specifics	Description	Data Application	Resource Type	Study Relevance	Resource
Resource Management Areas	**Proposed Designation of Hudson Canyon National Marine Sanctuary**	NOAA. 2022. Notice of Intent to Conduct Scoping and To Prepare a Draft Environmental Impact Statement for the Proposed Hudson Canyon National Marine Sancutary. Document Citation 87 FR 34853.	Identifies unique habitat/ properties of seafloor	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://sanctuaries.noaa.gov/hudson-canyon/
Resource Management Areas	**Tilefish Gear Restricted Area**	50 CFR Chapter VI Part 648 Subpart N 648.297. 2011. Tilefish gear restircted areas (NOAA GARFFO).	Identifies habitat and species presence.	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://www.fisheries.noaa.gov/resource/map/tilefish-gear-restricted-areas
Anthropogenic Benthic Constraints	**Artificial Reefs**	Office for Coastal Management, 2023: Artificial Reefs,	Identifies unique habitat/ properties of seafloor	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/inport/item/54191.
Anthropogenic Benthic Constraints	**Ocean Disposal Sites**	NOAA Office for Coastal Management, 2023: Ocean Disposal Sites,	Identifies potential use conflicts/hazards	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/inport/item/54193.
Anthropogenic Benthic Constraints	**Shipwrecks and Obstructions**	NOAA Office of Coast Survey, 2016: Wrecks and Obstructions Database,	Identifies potential use conflicts/hazards	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html
Anthropogenic Benthic Constraints	**Submarine Cables**	NOAA Office for Coastal Management, 2018: NOAA Charted Submarine Cables,	Identifies potential use conflicts/hazards	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://www.fisheries.noaa.gov/inport/item/57238
Anthropogenic Benthic Constraints	**Unexplored ordnances**	NOAA. 2020(b). Unexploded Ordnance Areas	Identifies potential use conflicts/hazards	Spatial	Primary data to feed into sensitivity analysis or risk maps	https://data.noaa.gov/dataset/dataset/unexploded-ordnance-areas1
Anthropogenic Benthic Constraints	**Unexplored ordnances**	NOAA. 2020(a). Unexploded Ordnances,	Identifies potential use conflicts/hazards	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	https://data.noaa.gov/dataset/dataset/unexploded-ordnance-areas1/resource/42b7f452-cb91-4a00-a7c7-4c044bb016e9
Biodiversity / Habitat Suitability	**Deep sea soft coral habitat suitability**	Kinlan BP, Poti M, Drohan AF, Packer DB, Dorfman DS, Nizinski MS (2020) Predictive modeling of suitable habitat for deep-sea corals offshore the Northeast United States. Deep Sea Research Part I: Oceanographic Research Papers 158: 103229 ; Updated habitat suitability model vis a vis 2013 NCEI coral habitat suitability. *Not yet available in public repository	Identifies unique habitat to show how species are using the AoA. Identifies TES present and where concentrated in AoA or how using AoA (time of year or life stage)	Spatial	Supplementary data available for the AoA and/or sensitvity analysis	(Not yet available in NOAA repository - Data shared with permission from authors of study listed in description)

Appendix B. Detailed Literature Review Methods and Results

The terms from each of the three columns (Table 1) were used in a matrix of 684 combinations to search for relevant literature using the ”rscopus” package in R, which searched literature records from the Scopus database, including title, abstract, keywords, and any full text search that was available. In 2004, publisher Elsevier created Scopus, a widely used database that indexes over 34,000 peer-reviewed journals (www.scopus.com), representing a similar level of data to other citation search engines. No date limitation or journal/field of study constraint was applied to the search.

Table 1. Benthic spatial data search categories.

Category	Examples
Geophysical	Multibeam echosounder bathymetry and backscatter; side-scan sonar; geoforms
Sediment	Sediment type (grain size, CMECS substrate classification)
Biodiversity / Habitat Suitability	Metrics on presence and/or distribution of sensitive, threatened, and endangered species; designated essential fish habitat and habitat areas of particular concern
Resource Management Areas	Areas designated to prohibit or restrict fisheries-related seafloor disturbance activities to protect seafloor habitats and demersal species
Anthropogenic Benthic Constraints	Charted submarine cables; disposal areas; unexploded ordnance; shipwrecks

From the initial search, 19,388 sources were returned from the matrix of 684 search terms, which includes duplicate records that appeared in more than one search term. For the receptor search terms, sources pertaining to “deep-sea/cold-water corals” were the most abundant with 59 percent of records, followed by “hard ground/bottom” with 26 percent of records. Both “deep-sea sponges” and “sea pens” returned limited amounts of matches (< 10 percent). For stressors, “hydrodynamics” was the most frequently returned term with 25 percent of records returned, followed by “thermal stress” and “pollution", with 16 percent and 15 percent of records, respectively.

For constraint group terms, “offshore wind energy” terms only consisted of 6 percent of the returned sources with “oil” and “gas” representing the majority of sources with 60 percent. This demonstrates that at the unscreened level, publication output and by proxy, research intensity, is heavily weighted to the impacts of oil and gas exploration and extraction, which further skew toward deep-sea corals over other benthic receptor groups. This was expected, as OSW is a new industry.

Following this initial search, each returned record was manually screened for direct relevance to the Benthic Habitat Study; firstly, using the screen_titles function from the ‘revtools’ package in R (Westgate, 2019). Each title was screened for keywords that demonstrated direct relevance to the Benthic Habitat Study, for example, incorporation of benthic receptors in the title or anthropogenic impacts, and were retained for further analysis. Irrelevant sources were removed. This process returned 611 sources that were then further reviewed by reviewing each abstract to further identify relevant sources, again using the ”revtools” package, but this time using the screen_abstracts function. In total, 350 sources were retained for the final source database.

Following the screening, patterns within the returned sources largely followed the unscreened analysis, “deep-sea/cold-water corals” were the most extensive receptor group in the database with 258 sources returned, followed by “hard ground/bottom” with 107, and “deep-sea sponge” and “sea pen” with 48 and 30, respectively (some sources can have relevance across several receptor groups). The vast majority of screened studies were constrained by anthropogenic impacts originating from “oil” and “gas,” with 217 records returned, followed by “bottom impact fishery,” “deep-sea mining” and “long-lining” with 74, 56, and 15 sources, respectively. The constraint “offshore wind energy” returned 60 sources, with 25 sources published since 2020. However, none of the returned sources demonstrated any direct application to the study of offshore wind energy on the selected benthic receptors in this Benthic Habitat Study. For search terms pertaining to stressors, the term “hydrodynamics” matched with 288 sources, followed by “pollution” with 242, and “thermal stress” with 119.

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on X, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

State of New York

Kathy Hochul, Governor

New York State Energy Research and Development Authority

Richard L. Kauffman, Chair | Doreen M. Harris, President and CEO