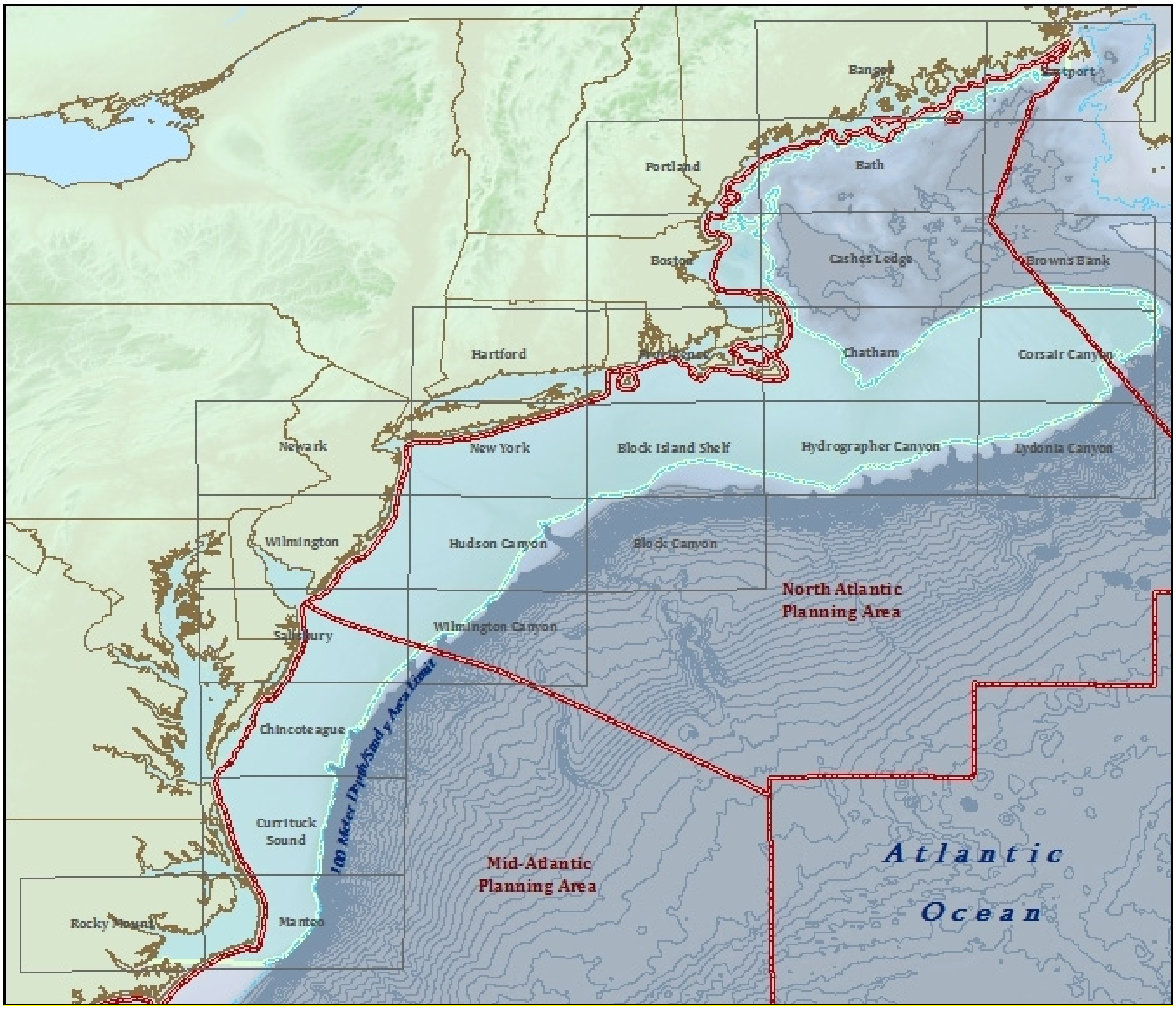
OCS Study
BOEMRE 2011-012

Literature Synthesis for the North and Central Atlantic Ocean



U.S. Department of the Interior
Bureau of Ocean Energy Management,
Regulation and Enforcement
Gulf of Mexico OCS Region

OCS Study
BOEMRE 2011-012

Literature Synthesis for the North and Central Atlantic Ocean

Editor

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ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius
$\mu g /m^2 yr$	Micrograms per square meter per year
µmol/kg	Micromoles per kilogram
10^{12} grams	Teragrams
10^9 g N /yr	Gigagrams of nitrogen per year
^{14}C	Carbon
ACS	Atlantic Continental Shelf
ANEP	Association of National Estuary Programs
API	American Petroleum Institute
APS	Acyl polysaccharide
ATM	Asynchronous transfer mode
AVS	Acid volatile sulfides
AWEA	American Wind Energy Association
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
BWEA	British Wind Energy Association
C/m^3d	Carbon per cubic meter per day
CB	Casco Bay
CDOM	Chromophoric dissolved organic material
CEC	Current energy conversion
CHN	Carbon, hydrogen, and nitrogen
cm	Centimeters
cm/s	Centimeters per second
cm^2/s	Centimeters squared per second
CO_2	Carbon dioxide
CONMAP	United States Geological Survey Continental Margin Mapping Project
CRM	National Oceanic & Atmospheric Administration Coastal Relief Model
DIC	Dissolved inorganic carbon
DIN	Dissolved inorganic nitrogen
DMS	Dimethyl sulfide
DNV	Det Norske Veritas
DOC	Dissolved organic carbon
DOM	Dissolved organic material
DON	Dissolved organic nitrogen
dpm/kg	Disintegrations per minute per kilogram
DW	Dry weight
EIS	Environmental Impact Statement
EMCC	Eastern Maine Coastal Current
EPRI	Electric Power Research Institute

ESP	Electric service platform
FDOM	Fluorescent dissolved organic material
FERC	Federal Energy Regulatory Commission
ft	Foot
g	Grams
g/m	Grams per meter
g-at	Gram-atom, equal to a mole
GB	Georges Bank
GE	General Electric
GIS	Geographic information system
GLOBE	Global Ocean Ecosystem Dynamics
GOM	Gulf of Maine
GSR	Gulf Stream ring
H_2	Hydrogen
HARS	Historic area remediation site
hPa	Hecto Pascal
IEEE	Institute of Electrical and Electronic Engineers
IMPLAN	Impact Analysis for Planning
IOPAC	Inverse offshore pump accumulation station
JEDI	Job and Economic Development Impact Model
kg N /hectare	Kilograms of nitrogen per hectare
km	Kilometer
kW/m	Kilowatts per meter
L	Liter
LIDAR	Light Detection and Ranging
LIPA	Long Island Power Authority
LIS	Long Island Sound
m	Meter
m/s	Meters per second
M_2	Principal lunar semi-diurnal tidal frequency
m^3 /yr	Cubic meters per year
MAB	Mid-Atlantic Bight
MAtl	Mid-Atlantic Region from southern Massachusetts to Cape Hatteras
mbsf	Meters below sea floor
ME	Maine
mg $C/m^3/d$	Milligrams of carbon per cubic meter per day
mg/L	Milligrams per liter
mm	Millimeter
$mmols/m^2/year$	Millimoles per square meter per year
MMS	Minerals Management Service

moles/yr	Moles per year
MW	Megawatt
$N/m^2/d$	Nitrogen per square meter per day
N/yr	Nitrate per year
N_2	Molecular nitrogen, nitrogen gas
N_2	Larger lunar elliptic semi-diurnal tidal frequency
Natl	North Atlantic Region from Canadian border to southern Massachusetts
NGDC	National Geophysical Data Center
NH_4^+	Ammonium ion
NIMBY	Not In My Back Yard
NJDEP	New Jersey Department of Environmental Protection
nmi^2	Square nautical mile
NO_2^-	Nitrite
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NOEP	National Ocean Economic Program
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
ODP	Ocean Drilling Program
ONR	Office of Naval Research
OPD	Official Protraction Diagram
OSRP	Oil-Spill Response Plan
OWC	Oscillating water column
OWEP	Offshore Wind Energy Project
P	Phosphate
PAHs	Polyaromatic hydrocarbons
Pb	Lead
PB	Penobscot Bay
PCBs	Polychlorinated biphenyls
PHA	Peak horizontal ground (bedrock) acceleration
Po	Polonium
PO_4	Inorganic phosphate
POASI	Physical oceanography and air-sea interaction
POC	Particulate organic carbon
POM	Particulate organic matter
PON	Particulate organic nitrogen
POPs	Persistent organic pollutants
ppb	Parts per billion
R&D	Research and development

S_2	Principal solar semi-diurnal tidal constituent
SAV	Submerged Aquatic Vegetation
SCOPEX	South Channel Ocean Productivity Experiment
SSW	Scotian Shelf Water
Tg N/yr	Teragrams nitrogen per year
Tg P/yr	Teragrams phosphorus per year
Th	Thorium
TMF	Tidal mixing front
TOC	Total organic carbon
TOC	Total organic carbon
U.S.	United States
USACE	U.S. Army Corps of Engineers
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
VOS	Volatile organic substances
WEC	Wave energy conversion
WHOI	Woods Hole Oceanographic Institute
WIS	Wave Information Study
WMCC	Western Maine Coastal Current
WTG	Wind turbine generator
yd^3	Cubic yards
yr	Year
μg/g	Micrograms per gram
μmol/L	Micromoles per liter
μPa	micropascal
μPa-m	micropascal-meter

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) of the U.S. Department of the Interior (Department) is charged with environmentally responsible management of Federal Outer Continental Shelf (OCS) resources (e.g., oil and gas, sand and gravel). The OCS includes the submerged lands, subsoil, and seabed lying between the seaward extent of the states' jurisdiction and the seaward extent of Federal jurisdiction.

Section 388 of the Energy Policy Act of 2005 amended the OCS Lands Act to authorize the Secretary of the Department to issue leases, easements, or rights-of-way for activities on the OCS that support exploration, development, production, or storage of oil or natural gas; produce or support production, transportation, or transmission of energy from sources other than oil and gas, and are not otherwise authorized by other applicable law. The Department delegated this authority to the BOEMRE. Examples of the general types of alternative energy project activities that the BOEMRE has the discretion to authorize include, but are not limited to: wind energy, wave energy, ocean current energy, solar energy, and hydrogen production. The BOEMRE was also delegated discretionary authority to issue leases, easements, or rights-of-way for other OCS project activities that make alternate use of existing OCS facilities for "energy-related purposes or for other authorized marine-related purposes," to the extent such activities are not otherwise authorized by other applicable law. Such activities may include, but are not limited to: offshore aquaculture, research, education, recreation, and support for offshore operations and facilities.

The northern United States (U.S.) Atlantic seaboard between Cape Hatteras, North Carolina, and Canada has not been developed for potential renewable and alternative energy reserves. This temperate region is distinctive for the Atlantic coastline, with unique physical oceanography, physiography, and zoogeography; several valuable fisheries; and characteristic weather patterns. It harbors a suite of protected coastal and offshore marine organisms including sea turtles, birds, fishes, and marine mammals, many of which are considered endangered or threatened.

The most recent previous synthesis of physical oceanographic information in the U.S. Atlantic Coast conducted for BOEMRE was in 1992 and indicated information gaps. Given the date of the review and the certain advance of knowledge since then, a synthesis of current knowledge was commissioned. This literature synthesis is intended to help in understanding the unique and varied oceanographic resources in the study area and in analyzing how they will be able to respond to potential alternative energy development.

1.2 STUDY AREA (MAPS)

The study area for this project is depicted in the maps below (Figures 1.1 and 1.2), broken into the North and Mid-Atlantic Regions, which include relevant marine features and the seaward boundary of the study: the 100-m isobath.

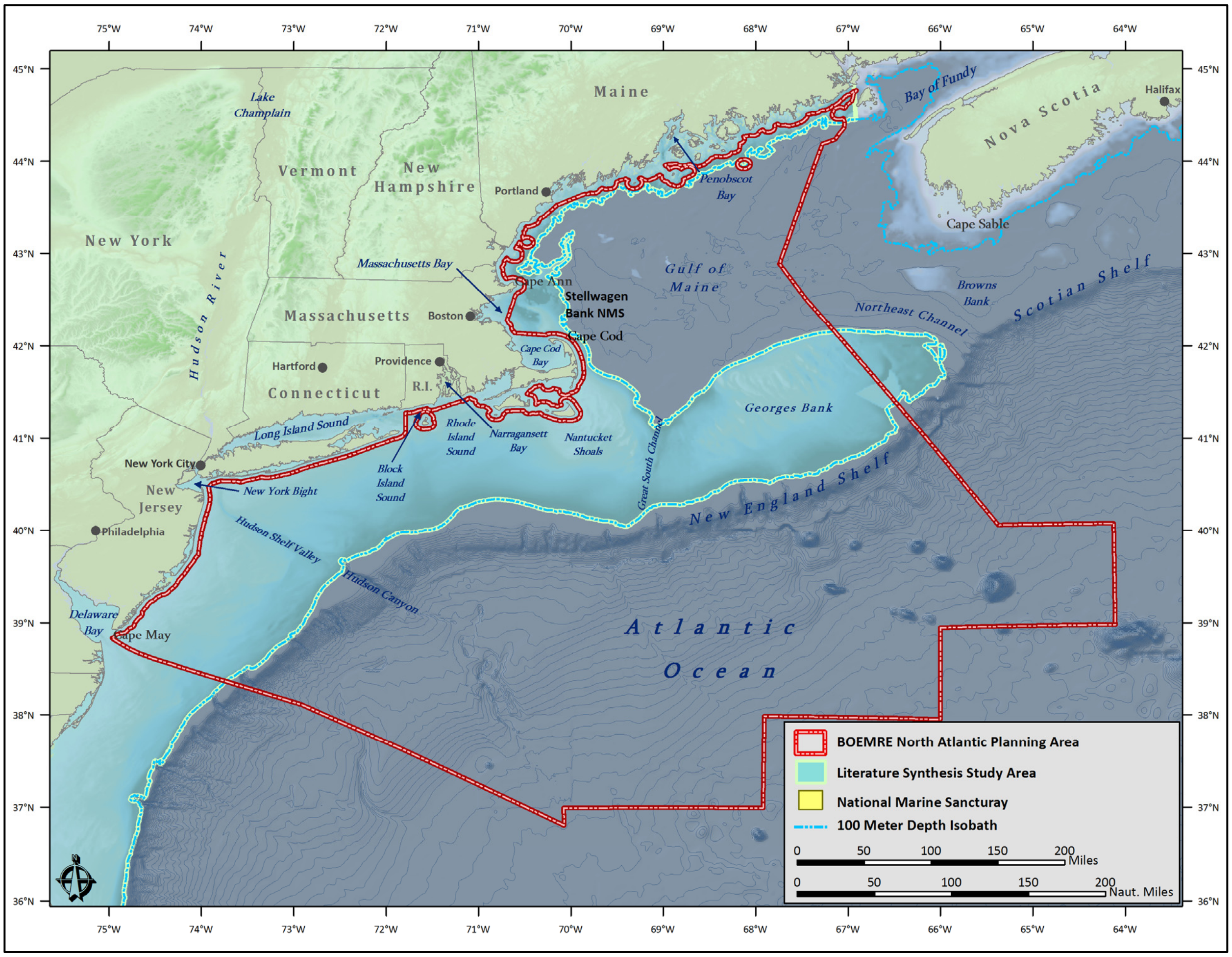


Figure 1.1. North Atlantic Region.

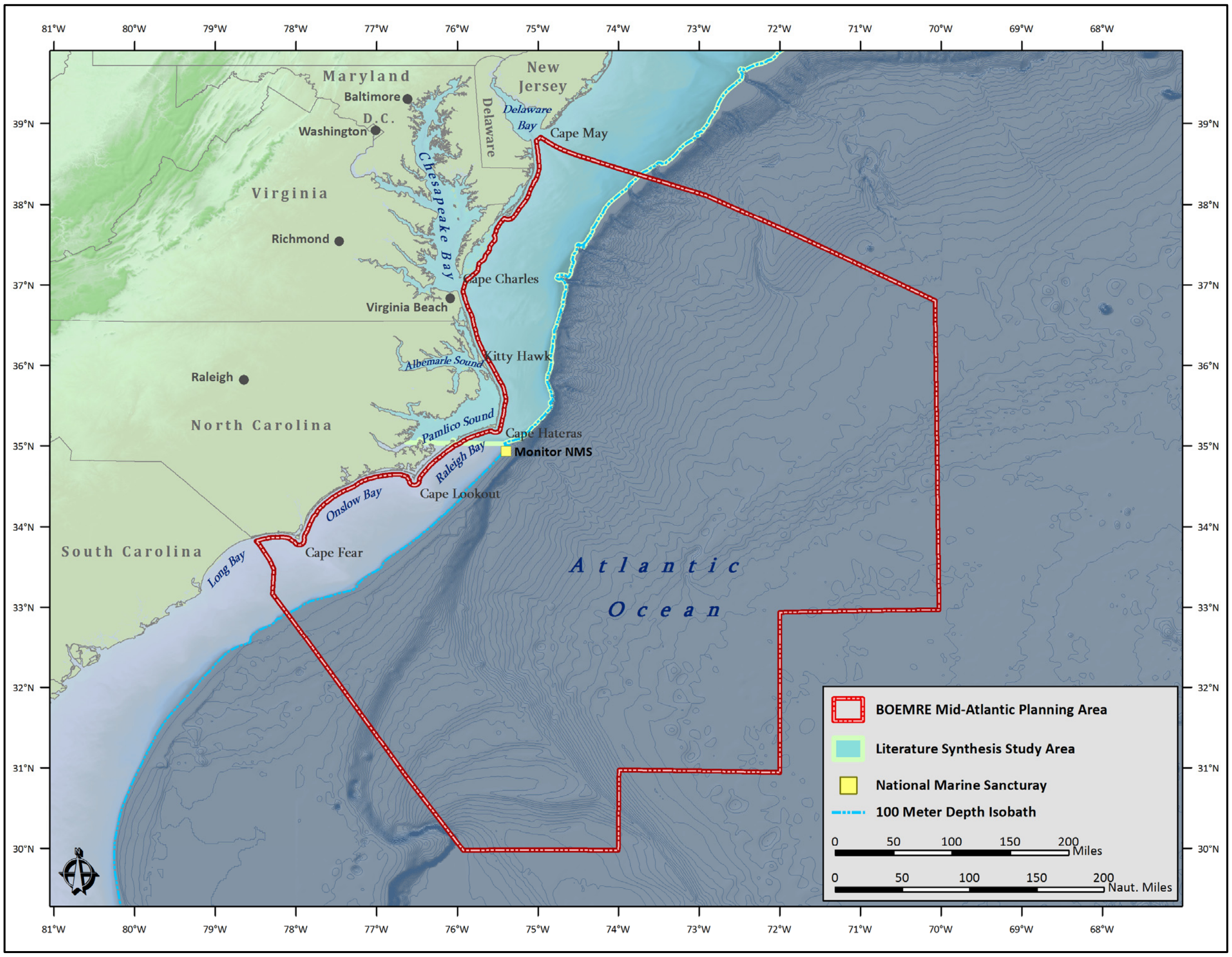


Figure 1.2. Mid-Atlantic Region.

1.3 STUDY OBJECTIVES

The objectives of this study are: (1) to develop comprehensive information on the human and environmental aspects of the region; (2) to update the understanding of the ecological communities, the dominant oceanographic and other processes that drive the shelf and deep-sea ecosystems, and the potential sensitivities of the area; and (3) to identify relevant data gaps in the current state of knowledge of the study area.

For the purposes of this project, the study area is defined geographically as extending south from the Canadian border to Cape Hatteras, North Carolina, and seaward from state waters (exclusive of estuarine waters) to the 100-m isobath.

Specific objectives were to develop: (1) a computer-searchable reference database (annotated bibliography) incorporating existing literature, relevant data, and ongoing research pertaining to the geological, physical, chemical, and biological processes of the study area, as well as to social and economic data and literature, and to research and development technology in alternative energy development; (2) a synthesis report that characterizes the study area and the scope and depth of information available in the different disciplines. The synthesis "shall consider present levels of possible environmental, social and economic perturbation," especially emphasizing the BOEMRE's potential offshore activities in support of alternative energy development (USDOI, MMS 2009).

1.4 STUDY METHODS

1.4.1 Research Plan

A research plan was developed for the project that focused on topics, issues, impacts and regions that are most relevant to the BOEMRE's mandate to develop alternative and renewable energy sources in the OCS.

The research plan consisted of the following for each discipline:

> (1) A topic outline that set out the broad parameters of research. The outline includes a subset of topics within the broader areas of each discipline for which there are extensive and well-developed resources in the scientific literature. The subset chosen for inclusion was guided by the project focus of renewable/alternative energy development with emphasis on wind energy, wave energy, and tidal kinetic (current) energy.
>
> (2) A set of research questions for each discipline which the literature search will attempt to answer or at least explore. To facilitate a manageable process for gathering and organizing information in support of the synthesis, a list of specific research questions was identified to complement the above topic area outline. For most disciplines, the questions were assigned to two groups, those relating primarily to resources and those relating primarily to impacts. The impact questions follow a single format, answering the generic question, "How does *resource X* in *region Y of the study area* respond to *impact-producing factor Z?*" Each of the three components of such a question was drawn from a listing of relevant subjects for each discipline.
>
> (3) A data collection strategy for the project overall, which will include a list of databases, key search terms, and other likely sources as well as contacts or requests for information. Guided by the research questions posed previously, this strategy provided a methodical approach for conducting the search.

The fundamental research question driving the Literature Search and Data Synthesis project was the following:

What are the relevant descriptors of those human and natural systems that could be impacted by the development of renewable and alternative energy reserves in the North and Central Atlantic Regions of the U.S. OCS?

1.4.2 Literature Search

A comprehensive literature search was completed and organized by oceanographic discipline to identify relevant existing information on resources in the study area and the potential impacts of offshore alternative energy development. Specialists in each discipline developed search strategies that encompassed commercial and government databases, Internet sources, and direct contacts with individuals and institutions with involvement in, knowledge of, or special access to relevant information.

The first step of the search involved online commercial and government databases. The search specifically included the databases listed below:

- Aquatic Sciences and Fisheries Abstracts (ASFA)
- American FactFinder
- ASCE Civil Engineering Database
- Biological Sciences
- BioOne
- BIOSIS (BasicBIOSIS)
- Bureau of the Census
- Bureau of Labor Statistics
- Civil Engineering Abstracts
- COMPENDEX Conference Papers Index
- DOE Information Bridge
- Dissertation Abstracts,
- Encyclopedia of Ocean Sciences
- Energy Citations Database
- Engineering Village 2
- FedStats
- GeoBase
- GeoRef
- Geospatial and Statistical Data Center
- Google Scholar
- EEE Xplore
- IEEE/IEE Electronic Library Online
- Index to Scientific and Technical Proceedings (ISTP)
- Ingenta
- JSTOR
- Meteorological and Geoastrophysical Abstracts (MGA)
- National Sea Grant Library Database
- National Technical Information Service (NTIS)
- Oceanic Abstracts
- Science Citation Index (SCI)
- Science Direct
- Technology Research Database
- U.S. Geological Survey (USGS) Publications Warehouse
- usSEABED
- Web of Science (ISI Science Citation Index)
- WHOI Contributions to the Scientific Literature
- WorldCat
- Zoological Record Plus

The databases included above provide the ability to search dissertations, scientific proceedings, government reports, and academic papers. The search terms were developed for geographic and topic relevance. Topic keywords were specific to each discipline, and numbered in the hundreds overall. Geographic keywords included:

> Northwest Atlantic; North Atlantic; Mid-Atlantic; Mid-Atlantic Bight; Continental Shelf; Gulf of Maine; Massachusetts Bay; Georges Bank; Stellwagen Bank; Stellwagen National Marine Sanctuary; New England Seamount; Hudson Shelf Valley; Baltimore Canyon Trough; Jeffreys Ledge; West Jeffreys Ledge; Jeffreys Basin; Hudson Canyon; Mid-Shelf Valley; Casco Bay; Penobscot Bay; Jericho Bay; Pemaquid; Massachusetts Bay; Cape Cod Bay; Nantucket Sound; Broad Sound; Buzzards Bay; Vineyard Sound; Horseshoe Shoal; Mutton Shoal; Nantucket Shoals; Rhode Island Sound; Northeast Peak; Great South Channel; Northeast Channel; Long Island Sound; New York Bight; Block Channel; Shark Ledge; Veatch Canyon; Atlantis Canyon; Bloc Canyon; Hudson Canyon; Wilmington Canyon; Baltimore Canyon; Barnegat Ridge; Middle Lump; Fenwick Shoal; Chincoteague Shoal; Winter Quarter Shoal; 26-Mile Lump; Smith Island Shoal; Nautilus Shoal; Inshore Southeast Lumps; False Cape; Washington Canyon; Norfolk Canyon; Diamond Shoals; Wimble Shoals; Platt Shoals.

The second step in the literature search was a broad Internet search using search terms similar to the online database searches. The literature search was refined to focus on literature for the resources and impacts most relevant to the development of alternative energy in the study area.

In addition, academic and research institutions were contacted as appropriate to gain access to information not available through our electronic searches or to pursue specific lines of inquiry.

1.4.3 Annotated Bibliography

All references were compiled in an electronic Annotated Bibliography using EndNote reference software (subsequently converted for optional use in Reference Manager). The records were organized into separate volumes within the master database for each of the six oceanographic disciplines. Records in the database can be searched by standard fields in the reference database (author, title, date, publisher, journal, keywords, etc.), and also by two additional custom fields created for this study: habitat type and geographic region. In addition, complete PDF files were attached to the record for non-copyrighted studies, if available.

1.4.4 Geospatial Data

Geospatial data was available for a limited number of references collected during the literature search. These sources of geospatial data were included as references in the Annotated Bibliography, and the datasets themselves were also delivered in geospatial data formats for upload to the BOEMRE Coastal and Offshore Resource Information System (CORIS), part of the BOEMRE corporate Technical Information Management System (TIMS) database.

In addition, there was a subset of references whose subject geographic scope was sufficiently narrow to enable creation of a "footprint" file, which delineated the boundaries of the area under specific study through the creation of geospatial shapefiles. After consultation between the BOEMRE and the study authors, it was agreed that such footprint files would be created for all references that contained a BOEMRE Official Protraction Diagram (OPD) map codes in the field "Geographic Location." These footprint files are also compatible with the CORIS database. Each record in this geospatial file is identified using a common identifier with the Annotated Bibliography, so that a user can toggle between the two databases to access the bibliographic information and the footprint data conveniently.

1.5 STRUCTURE OF THE REPORT

The report is organized into two major parts: Part I includes the characterization of ecological resources and processes of the study area, broken down into chapters corresponding to the oceanographic disciplines; Part II contains the discussion of the literature on environmental impacts of alternative energy development on these resources. Finally, Chapter 12 summarizes the state of research and development activities for the three principal alternative energy technologies: wind, wave, and current, and Chapter 13 summarizes gaps in our current understanding of resource and impact issues.

The report structure is as follows:

Chapter Number	**Discipline**
1	Introduction
Part I	*Resources in the North and Central Atlantic*
2	Physical Oceanography and Air-Sea Interaction
3	Biological Oceanography
4	Chemical Oceanography
5	Geological Oceanography
6	Socioeconomic Issues
Part II	*Potential Impacts of Alternative Energy Development*
7	Physical Oceanography and Air-Sea Interaction
8	Biological Oceanography
9	Chemical Oceanography
10	Geological Oceanography
11	Socioeconomic Issues
12	Research & Development Technology
13	Gaps in Current Understanding

LITERATURE CITED

U.S. Dept. of the Interior, Minerals Management Service (MMS) 2009. Statement of Work: Data search and literature synthesis for the North and Central Atlantic OCS, September 2007. 31pp.

PART I

RESOURCES IN THE NORTH AND CENTRAL ATLANTIC OCEAN

2. PHYSICAL OCEANOGRAPHY AND AIR-SEA INTERACTION

This section reviews present understanding of physical oceanography and air-sea interaction (POASI) characteristics and resources on the Outer Continental Shelf (OCS) in the North Atlantic and Mid-Atlantic Regions. The emphasis is on information relevant to possible development of the OCS for marine and hydrokinetic alternative energy generation, and potential associated environmental impacts. Thus, as opposed to a comprehensive review of all POASI topics, the scope here extends mainly to material that pertains most closely to the three alternative energy technologies that are presently developing most rapidly: wind turbine generators (WTGs), wave energy conversion (WEC) devices, and current energy conversion (CEC) devices. The OCS is defined here as the area between the state-waters boundary, which is 3 nm offshore from the coast, and the 100-m isobath. In POASI sections areas from the Canadian border southward to the shelf off southern Massachusetts (including Georges Bank) are referred to as the North Atlantic Region; areas southward from there to Cape Hatteras are referred to as the Mid-Atlantic Region. In each of the following subsections, the discussion provides an overview applicable to the broader North Atlantic/Mid-Atlantic Region and integrates information for localized subregions, as available, from north to south. The annotated bibliography consists of all POASI references collected for the BOEMRE Atlantic Data Synthesis database, a subset of which are cited explicitly in the text here.

2.1 WINDS AND THE ATMOSPHERIC BOUNDARY LAYER

The atmospheric surface boundary layer, within which there can be substantial vertical gradients in winds and air properties, can extend up to hundreds of meters above the air-sea interface. Much of our understanding of North Atlantic and Mid-Atlantic winds over the OCS to date pertains to airflow measured within the lowest 15 to 20 m, referred to as surface winds. Informative summaries are given by the BOEMRE (USDOI, MMS 1992; 1999; 2007) and, for the Mid-Atlantic, Lettau et al. (1976). The main source of modern long-term OCS wind measurements is a small number of National Buoy Data Center buoys that have been maintained by NOAA over the past few decades (e.g., USDOC, NOAA 2006) and are typically positioned 50 to 100 kilometers offshore with anemometer heights of less than 10 m.

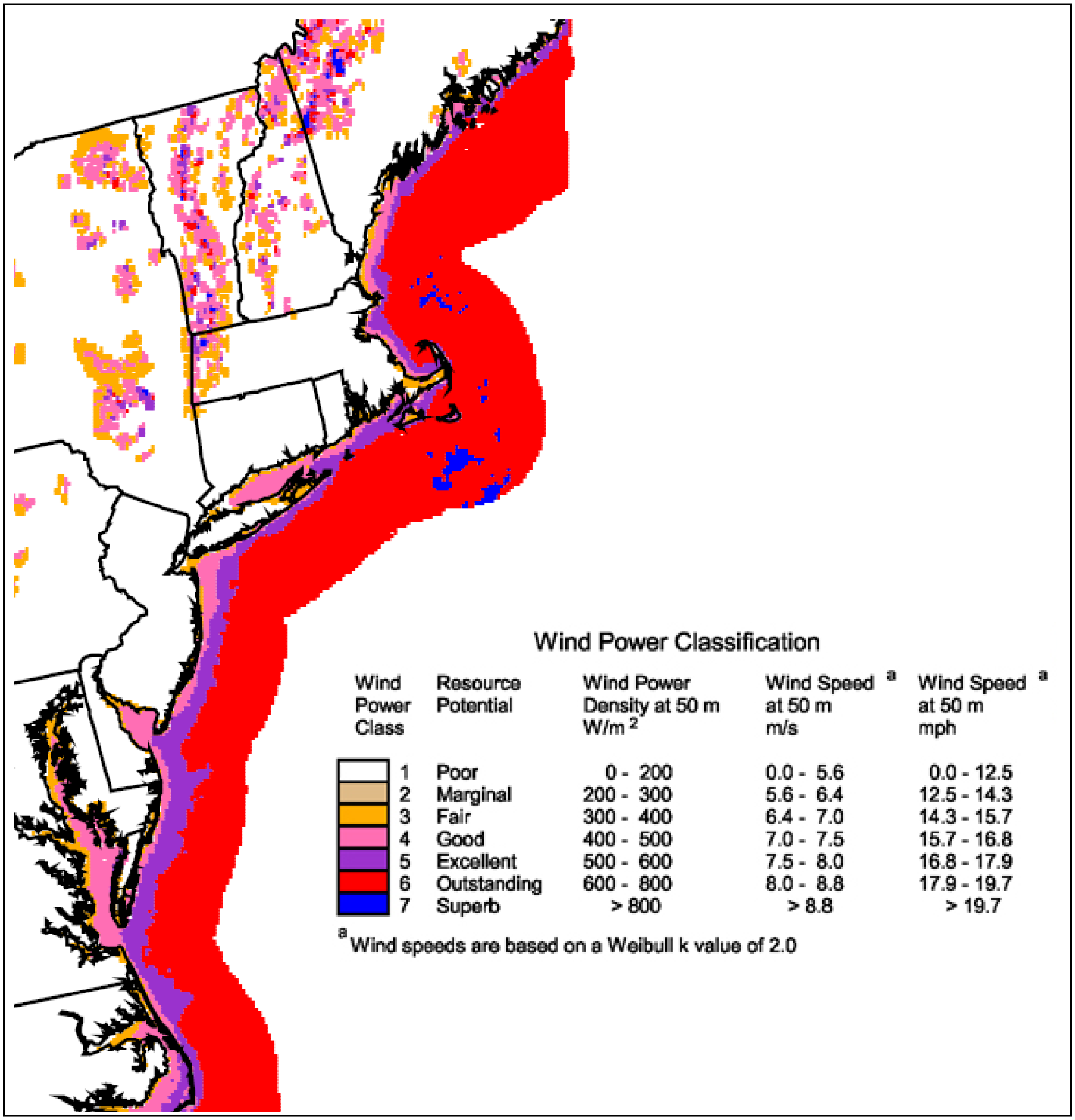
The climatic-mean, large-scale pattern of prevailing surface winds is quite spatially uniform over the North Atlantic and Mid-Atlantic and has a generally eastward component, a consequence of the large-scale North Atlantic Ocean surface pressure pattern dominated by the Icelandic low to the north and the Azores/Bermuda High to the south. Seasonal shifts in this large-scale pressure distribution southward in winter cause winds to be stronger (monthly mean speeds of about 4 to 12 m/s), oriented more southeastward, and more variable (peak speeds range from about 20 to 25 m/s) due to regular passage of extratropical storm systems on timescales of about a week. During summer conditions, winds are weaker (monthly mean speeds of about 2.5 to 7.5 m/s), oriented more northward, and less variable (peaks speeds less than about 15 m/s). A prominent contribution to summertime variability in inshore areas is from diurnal flow driven by the differential in heat capacity of land and sea. During afternoon and evening hours, air over land heats and rises more quickly than does air over water; thus surface winds known as the "sea breeze" are driven onshore during the afternoon. During nighttime and early morning hours the pattern reverses and surface winds known as the "land breeze" are offshore, though generally weaker than the sea breeze.

Extreme winds are associated with two types of intense storms: extratropical nor'easters and hurricanes generated in the tropics. About 20 to 30 nor'easters occur each year, mainly from October to April. They are slower-moving systems up to several hundred kilometers in size characterized by strong southwestward winds that can last up to several days. They usually originate in the south and move northward along the OCS through the Mid-Atlantic as they develop, peaking in strength when they influence the North Atlantic Region. Hurricanes are much less common, on average two to three per year reaching the Mid-Atlantic or North Atlantic at full strength, occurring between June and December and most commonly in September and October. They feature the strongest wind speeds (30 to 70 m/s or more), but have smaller spatial scales and move rapidly, hence affecting particular sites for a shorter duration. They originate in the tropics and their northward tracks can influence all North Atlantic and Mid-Atlantic OCS areas.

The speed and steadiness of the wind both increase sharply with offshore distance across the OCS, in association with reduced turbulence in the boundary layer. As air moves eastward off the rough topographic variations of the continent, where the mixing layer height is highly variable and can reach up to 2,000 m or more, it encounters the relatively flat sea surface, where the mixing height becomes less variable and typically about 500 m due to neutral or slightly unstable conditions maintained by the generally positive ocean to atmosphere heat flux. Very few measurements are available to quantify the rate of speed increase with offshore distance, but Lettau et al. (1976) documented increases of several m/s over a distance of 10s of km from the Long Island and New Jersey coasts; the offshore increase is also demonstrated clearly by observations from Georges Bank (e.g., USDOC, NOAA 2006), the farthest-offshore region of the OCS, which show mean wind speeds up to several meters per second stronger than they are in areas farther inshore. In summertime over the Maine OCS, Angevine et al. (2006) observed that within 10 km of the shore, 30 minutes after moving out over water, the deepest 50 to 100 m had been markedly cooled and stabilized, facilitating marked increases in wind speeds.

Wind speed also increases substantially with vertical distance from the sea surface, due to the lessened influence of turbulence and drag. Little is known, relative to surface winds, about vertical wind profiles over the OCS extending to the 30-to-80-m heights for which WTG are presently being developed. Over land, such vertical profiles have been measured and favorably compared with theoretical formulas, which indicate a wind speed at 50 m height that is twice that at 10 m height. The atmospheric boundary layer over water can be strongly modified by sea surface conditions such as a narrow band of cold water in a nearshore area due to upwelling, for example. in the vicinity of New York Bight apex (Pullen et al. 2007).

A map of estimated wind power density (W/m^2) at 50 m height (Figure 2.1) has been produced for areas that extend over most of the North Atlantic and Mid-Atlantic OCS (USDOE 2009). Wind power levels are grouped with respect to viability for development, with classes 3 to 7 defined by range of average wind speed as Fair (6.4 to 7.0 m/s), Good (7.0 to 7.5 m/s), Excellent (7.5 to 8.0 m/s), Outstanding (8.0 to 8.8 m/s), and Superb (greater than 8.8 m/s), respectively. The estimates were generated (USDOE 1986; Elliott and Schwartz 2006) using available wind observations together with a proprietary meteorological model output wind product (from the private company AWS TrueWind, www.awstruewind.com), on which the structures of the above-mentioned offshore and vertical increases in wind speeds are primarily based. Observations to verify these spatial patterns over the OCS remain to be collected. Despite the likely shortcomings in their quantitative precision for local sites, the estimated patterns are the most detailed available on scales of tens of km or more and are described below.



Wind Power Classification

	Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
⬜	1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
🟫	2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
🟧	3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
▨	4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
🟪	5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
🟥	6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
🟦	7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

Figure 2.1. Annual average wind power estimates at 50 m above the surface, based on a combination of high-resolution and low-resolution datasets from the U.S. Department of Energy National Renewable Energy Laboratory and other organizations. From USDOE/NREL (2009).

Over the northern Maine OCS, speeds are in the range 8.0 to 8.8 m/s (Outstanding), except in a narrow inshore band where they weaken to 7.5 to 8.0 m/s (Excellent). Over the southern Maine and New Hampshire OCS, speeds are 7.5 to 8.0 m/s (Excellent) except in an inshore band, where they are 7.0 to 7.5 m/s (Good), and some narrow offshore bands, where they are 8.0 to 8.8 m/s (Outstanding). Over the Massachusetts OCS, other than some narrow inshore areas with speeds of 7.5 to 8.0 m/s (Excellent), speeds are uniformly in the 8.0 to 8.8 m/s (Outstanding) range, with small areas of speeds in the > 8.8 m/s (Superb) range to the south and east of Nantucket. Not all of Georges Bank was included in the analysis, but the eastern areas omitted would very likely have speeds greater than 8.0 m/s (Outstanding and Superb). For the entire Mid-Atlantic, speeds over the majority of the OCS are 8.0 to 8.8 m/s (Outstanding), weakening in inshore areas to bands of 7.5 to 8.0 m/s (Excellent) and 7.0 to 7.5 m/s (Good). South of Rhode Island and eastern Long Island, the inshore bands with speeds of 7.0 to 8.0 m/s (Excellent and Good) extend about 10 to 15 km offshore, and in areas further south they extend about 20 to 40 km offshore.

2.2 WAVES

Baseline knowledge of observed wave characteristics has developed largely from historical analysis of sparse buoy records (e.g., USDOC, NOAA 2006), with satellite observations (e.g., Woolf et al. 2002) becoming increasingly useful in recent years. Previous reviews include MMS (1992), as well as Godshall (1980) for the North Atlantic, and MMS (1999) and Lettau et al. (1976) for the Mid-Atlantic.

The two dominant factors governing the climate of waves over the North Atlantic and Mid-Atlantic OCS are local meteorological processes, which mainly generate wind waves (with periods less than about 8 s), and arrival of swell (longer periods) generated in deeper offshore regions. Local wave conditions are thus sensitive not only to the relationship between the wind direction and the alongshore direction of the coast, which sets the fetch of local winds, but also to nonlocal offshore swell generation. As a result, wave variability has spatial scales ranging down to the size of small meteorological events (10 to 20 km); timescales range from a few hours, in response to local winds, to more than a week, in response to distant weather systems that generate swell, in particular winter storms in the northeastern Atlantic. Interannual variability and extremes in wave conditions follow the characteristics of the winds they are driven by. The wave climate thus varies significantly from year to year and on decadal timescales, as do meteorological conditions.

The most important wave parameters are the significant wave height, defined as the average crest-to-trough height of the largest one-third of waves, and the direction of wave origin. Seasonal and geographic variability in these parameters across the North Atlantic and Mid-Atlantic OCS regions are demonstrated by summary results (Figure 2.2), over the years 1980 to 1999, of dynamical model hindcast simulations (Tracy et al. 2007; USDOD, ACE 2009) at sites with water depths of approximately 40 to 50 m. This model, from the U.S. Army Corps of Engineers, is representative of modern wave simulation capabilities for the OCS and its results have been shown (Devaliere et al. 2007) to capture well the main features of buoy observations (e.g., USDOC, NOAA 2006).

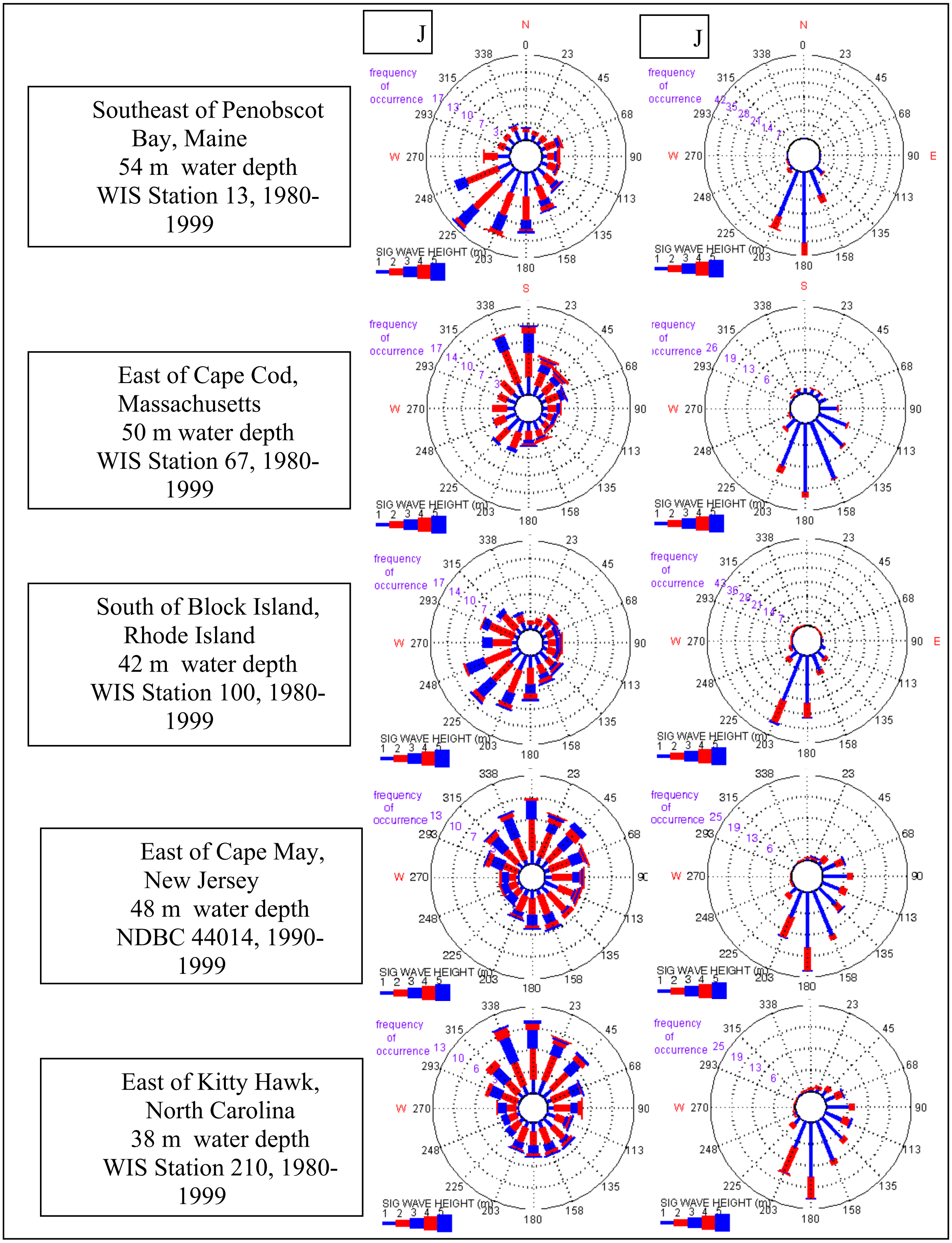


Figure 2.2. Geographic/seasonal variations of wave parameters from hindcast model (Tracy et al. 2007; USDOD, ACE 2009).

A primary characteristic of wave fields is substantial seasonal changes. In winter, significant wave heights are typically in the 3 to 4 m range and reach peak values up to 6 m, and at each station the range of directions is somewhat broad. Off the Maine coast, which is relatively protected by Nova Scotia from swell originating in the northeastern Atlantic, waves are comparatively weak and predominantly from the southwest, which is the direction of the greatest wind fetch. Off Cape Cod, waves are similarly strong, and most often from the north; farther east over Georges Bank (not shown), significant wave heights increase substantially and tend to be from the northwest, the direction with the longest unobstructed fetch. On the southern New England shelf off Rhode Island the significant wave heights are slightly increased relative to the Maine station but directional characteristics are comparable due to the similar coastline orientation of the two stations. Off Delaware, significant wave heights are relatively high and all directions are common, and off North Carolina they are comparably strong but more commonly directed southward. In summer, significant wave heights decrease to 1 to 2 m with maxima of about 3 m, and waves originate almost exclusively from the south central quadrant. These attributes result from the reduced generation of swell offshore due to weaker storm activity, and the increased fetch of the generally northward and eastward prevailing summer airflow.

Although the above portrayal of alongshore variations in average conditions on large spatial scales is useful, it does not convey the importance of pronounced smaller-scale variability. As waves travel, particularly in the across-shelf direction, a range of transformation processes can dramatically increase or decrease their amplitudes and change their directions. These mechanisms including shoaling, directional spread, diffraction, refraction, interaction with currents, and frictional modification (e.g., Komen et al. 1996). Knowledge of such variability in particular geographic areas relies to a large extent on dynamical models for these processes, since relatively few observational programs have achieved the necessary spatial resolution. Observations and modeling of the Virginia-North Carolina shelf have demonstrated the substantial onshore decay of waves to be due more to bottom drag frictional losses than to refraction, diffraction, or shoaling (Maa and Wang 1995; Ardhuin et al. 2003).

Wave energy resources can be characterized in terms of the annual average power per unit length (kW/m) along a coastline, or wave power density. This metric is very crude because it reflects the combined power of all spectral components and thus cannot distinguish the relative importance of wind waves and swell, which varies strongly geographically. Published wave energy distributions based on satellite observations have very coarse spatial resolution (Krogstad and Barstow 1999) but indicate that near the shelf break the North Atlantic and Mid-Atlantic Regions have wave power densities ranging from about 5 to 20 kW/m. To generate a wave power density estimate for a specific region of the OCS, one approach would be to obtain wave information pertinent to the site from a proprietary "wave climate atlas" (e.g., Oceanweather 2009). Such atlases are produced using a hindcast model that incorporates details of the local bathymetry as well as high-quality wind forcing from data-assimilative meteorological models and that has been tuned to a broad range of buoy and satellite wave observations.

2.3 CURRENTS

Currents, broadly defined as flows that persist on timescales of hours or more, are the response of OCS waters to numerous local and nonlocal driving processes and therefore vary on wide ranges spatially (one to hundreds of kilometers) and temporally (hours to decadal). The broad classes of currents treated in the subsections that follow are: long-term mean and low-frequency currents; weather-band motions (synoptic, timescales of days to weeks); tidal flows; and estuarine outflows, currents near canyons, currents due to Gulf Stream ring interactions, and mesoscale currents. Research on circulation in the North and Mid-Atlantic shelf regions, including field observations, has a long history. For background context the reviews of Ingham (1982) and MMS (1992), and for the Mid-Atlantic, Beardsley and Boicourt (1981), are pertinent.

2.3.1 Long-Term Mean and Low-Frequency Currents

On the largest spatial and longest temporal scales the circulation over the North Atlantic and Mid-Atlantic OCS is dominated by a continuous equatorward flow and clockwise movement around Georges Bank, generally oriented parallel to bathymetric contours with speed ranging from a few cm/s up to about 20 cm/s (Figure 2.3). This flow generally weakens with depth but extends to the seafloor, and includes a strong current centered on the outer edge of the continental shelf that weakens with distance inshore and offshore and is therefore often referred to as a jet. This current is associated with the shelf-break front, a boundary between fresher, cooler inshore water and warmer, saltier water offshore. The front is inclined with its shallow portion surfacing farther offshore than where its foot intersects the seafloor. Long-term mean currents in the across-shelf directions are weak (up to a few cm/s) and, inshore of about the 50- or 60-m isobath, tend to form a cell with deeper water directed shoreward and shallower flow moving offshore. Prominent recent analyses of relevance include Pettigrew et al. (2005) for the North Atlantic and Lentz (2008a; 2008b) for the Mid-Atlantic.

The primary driving force for the coastal flow is the alongshore pressure gradient associated with the seasonally modulated movement of Scotian Shelf waters originating from the Labrador Current and moving into the Gulf of Maine along the shores of Nova Scotia. The annual cycle is characterized by strongest flow in the late spring and summer, in association with development of enhanced density contrast across the front. Another important contribution is made by input of surface waters from numerous rivers and estuaries from Maine to Virginia, which are steered southward by the Coriolis force as they enter the OCS. Wind forcing is relatively unimportant to this overall circulation, as evidenced for example by summer currents oriented more or less directly opposite the prevailing wind. However, the offshore tendency of shallow flow appears to be associated with surface Ekman transport to the right of northward-directed winds.

On the Maine OCS the strongest southwestward flow is the Eastern Maine Coastal Current (EMCC), located to the north and east of Penobscot Bay (PB), which generally extends to the seafloor and is strongest (5 to 10 cm/s) over the 100- to 125-m isobaths where the shelf-break front lies. Near PB the current bifurcates and a portion moves offshore, particularly in spring and summer. South of PB, the flow continues, although weaker (3 to 7 cm/s), as the Western Maine Coastal Current (WMCC). In this region a second current (5 to 10 cm/s) occurs farther inshore and is concentrated in the upper water column, in association with riverine inputs mainly from the Penobscot, Kennebec/Androscoggin, Saco, and Merrimack Rivers. This inshore current moves weakly westward (about 2 to 5 cm/s) into Massachusetts Bay south of Cape Ann and then southward to the northern part of Cape Cod Bay before flowing eastward just north of the tip of Cape Cod to rejoin the WMCC. The WMCC continues southward directly from Cape Ann to the shelf east of Cape Cod, where it divides into one portion that flows east and north along the north side of Georges Bank and a second portion that flows southward toward Nantucket Shoals.

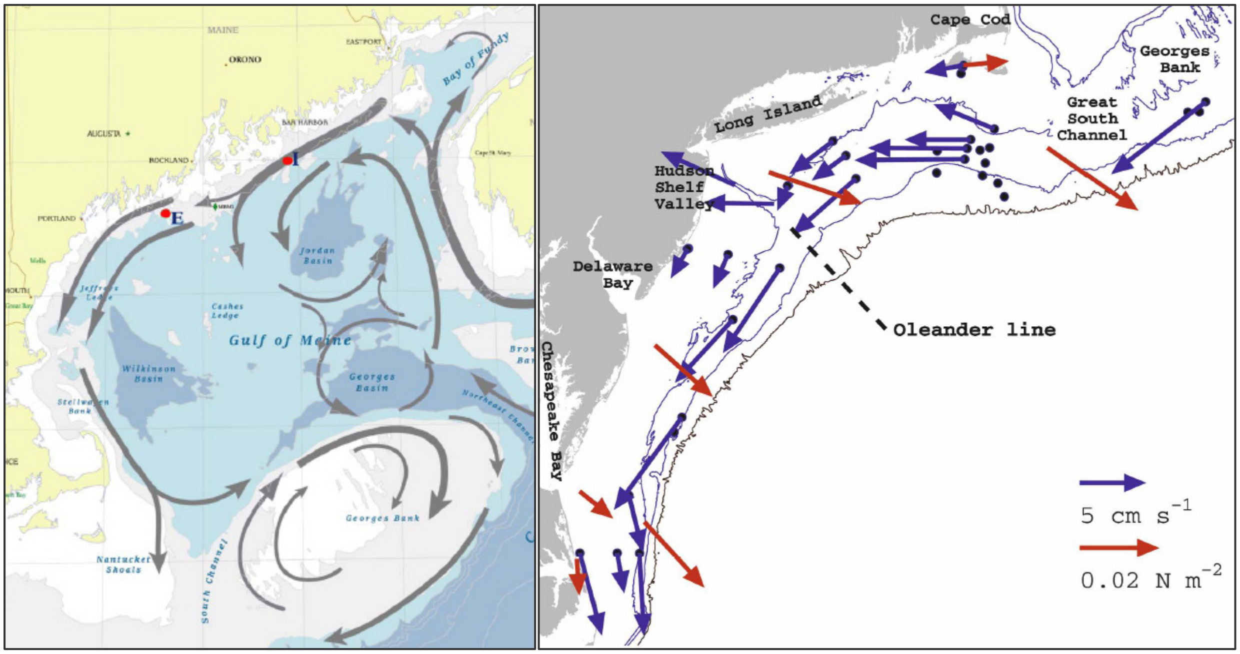


Figure 2.3. Left: schematic low-frequency shallow circulation in North Atlantic Region, summertime only. In winter, currents tend to be more diffuse and variable. From Pettigrew et al. (2005). Right: Mid-Atlantic Region long-term mean depth-averaged currents from selected historical records (blue) and wind stress from selected buoys (red); records from shallow current meters that reveal the inner shelf coastal current system are not included. From Lentz (2008b). Used by permission.

A clockwise current moves around Georges Bank in association with the shelf-slope front roughly at and deeper than the 100-m isobath. In winter, the current is weak and a southward drift is superposed on it. During the summer the flow strengthens to about 20 cm/s, and a portion of the motion westward along the southern flank moves northward along Great South Channel, which can cause a recirculating gyre centered on the bank. Also in summer, another clockwise current around the bank (up to 10 cm/s) forms roughly along the 40- to 60-m isobaths in association with a second boundary, the tidal mixing front, which separates deeper stratified waters from homogenous water continuously mixed by the strong tidal motions atop the bank.

The region from Nantucket Shoals southward to Cape Hatteras has a broader shelf than that to the north. The strong current associated with the shelf-break front continues (about 10 to 15 cm/s), now located farther offshore. Within about 10 to 20 km of shore, and under some conditions extending offshore to the 50-m isobath, there is a system of linked coastal currents flowing southwestward along isobaths and fed by river and estuarine outflows. Prominent sources are Narragansett Bay, Long Island Sound through Block Island Sound, the Hudson River, Delaware Bay, and Chesapeake Bay. Flow strengths range from about 5 to 30 cm/s; they vary with proximity to estuary mouths and with river runoff strength. The vertical extent of this current can be limited to the upper water column or it can reach the seafloor. The nature of this inner shelf flow is poorly known in the areas of Nantucket Shoals and Rhode Island Sound. Outside of Narragansett Bay and Block Island Sound there is evidence that it peaks in strength during the summer.

With respect to development of capabilities for energy conversion from ocean currents, it is important to note that the long-term mean and low-frequency circulation just described is, almost without exception across the North Atlantic and Mid-Atlantic, substantially weaker than flows that vary at weather-band or tidal timescales (described in the two subsequent sections). In addition, meanders in the shelf-break front and jet on timescales of weeks to months are prominent (Linder et al. 2006). Therefore mean and low-frequency currents over the OCS, in contrast to other regions such as the Florida Current (e.g., Finkl and Charlier 2009), are most likely not of primary interest for purposes of estimating extractable energy, nor for purposes of engineering devices to withstand current extremes. However, they do play a central role in the dispersal and ultimate fate of waterborne materials, and thus potential alterations to them are an important consideration for assessing possible impacts of ocean current energy conversion development.

2.3.2 Weather-Band Current Variability

The most prominent feature of current meter records from over the North Atlantic and Mid-Atlantic OCS is variability of current speed and direction in the frequency range, referred to as the weather band, which includes timescales from about 1 to 10 days and is forced by meteorological conditions. Currents typically respond to changes in the wind within hours. Strong winds sustained for a period of a few days, for example due to a storm, commonly drive near-surface currents up to 50 cm/s or stronger. Weather-band currents exhibit a variety of spatial patterns at least as diverse as the driving meteorological conditions, and can be oriented in any direction relative to the wind depending on the setting (shallow or deep, near or far from a coast or topographic feature, stratified or unstratified water column). In addition they can have vertical structure ranging from unsheared, to two layers of opposing flow, to continuous shear in magnitude and direction throughout the water column.

An along-shelf wind with northward component referred to as "upwelling-favorable," drives an offshore current near the surface when it persists for more than about a day, by the mechanism of Ekman transport. The strongest response to such forcing tends to occur in inshore areas where it causes a divergence near the coast and drives water upward in a narrow band near the coast, and, by conservation of mass, onshore at depth. This classic pattern of upwelling, and its counterpart downwelling, in which all motions are essentially reversed, features prominently in weather-band current observations from inshore areas along the Maine coast; the southern New England shelf; and the New Jersey, Delaware, and North Carolina shores (e.g., Scott and Csanady 1976; Yankovsky and Garvine 1998; Rennie et al. 1999; Lentz 2001; Geyer et al. 2004). The onshore-offshore currents are typically 5 to 10 cm/s and can reach 20 to 30 cm/s, particularly in summer during stratified conditions when turbulence, and hence Ekman transport, is concentrated in a surface layer.

In addition to upwelling and downwelling flows there are numerous other current patterns with temporal variability in the weather band. Over offshore portions of the OCS, currents in the along-shelf direction (typically 30 to 40 cm/s) tend to be coherent over distances as long as 500 km or more, and are generally coherent with and aligned along the along-shelf wind, lagged by about 5 to 15 hours (Noble et al. 1983). In deeper or more open OCS regions away from the shoreline, winds due to strong storms such as nor'easters can excite near-inertial internal waves, rotary currents that oscillate with periods corresponding to the local Coriolis frequency (between about 17 and 21 hours from off Cape Hatteras to the northern tip of Maine). In summer, during relatively calm meteorological conditions, sea/land breezes (see Section 2.1) drive diurnal currents (typically about 5 to 10 cm/s but as high as 30 cm/s) in the onshore and offshore directions (Hunter et al. 2007). Finally, the most energetic weather-band currents (reaching 70 cm/s or more) are driven by hurricanes, though they do not necessarily persist for more than about a day (e.g., Mayer et al. 1981; Williams et al. 2001).

2.3.3 Tidal Flows

The tidal regime of the North Atlantic and Mid-Atlantic is semidiurnal and the principal lunar constituent M_2 (period 12.42 hours) dominates. Other prominent semidiurnal constituents are the larger lunar elliptic, N_2, and principal solar, S_2, which are a small fraction as energetic as M_2. The superposition of these three constituents leads to fortnightly or spring-neap variations in tidal currents' amplitudes of about 10 to 30 percent. Tidal current amplitudes vary from a few cm/s over the deeper areas of the broad shelf of Mid-Atlantic OCS to more than 100 cm/s where resonance effects associated with semi-enclosed basins or kinematic flow acceleration due to topographic features is prominent. Except where modified strongly by interactions with the local coastline or bathymetry, the current direction of an individual tidal constituent generally rotates clockwise over time such that the tip of the current vector traces an ellipse clockwise. Moody et al. (1984) provide the foundation of our knowledge on large scales, and Brown (1984) gives a useful early comparison between selected North Atlantic, Georges Bank, and Mid-Atlantic sites.

Along the northern Gulf of Maine OCS, tidal current amplitudes have peak values of about 80 cm/s near the entrance to the M_2-resonant Bay of Fundy and there is a general decrease southward to about 10 cm/s off Massachusetts Bay. Over northeastern Georges Bank, tidal currents reach up to about 100 cm/s and over its flanks and the Nantucket shoals area they are about 40 to 60 cm/s. On Mid-Atlantic OCS amplitudes are about 5 to 10 cm/s except in the New York Bight area, where they reach about 20 cm/s. Within a radius of about 20 km from the mouths of major estuaries (south of Block Island Sound where Long Island Sound outflows; at the apex of the New York Bight for the Hudson River; and outside the entrances to Delaware Bay and Chesapeake Bay), tidal currents become elongated toward the estuary mouth and reach about 60 cm/s (Whitney and Garvine 2008).

The above ranges of amplitude values correspond to near-surface tidal currents. In general, OCS tidal flows weaken with depth due to bottom drag and water-column frictional effects; idealized theoretical expressions for the structure of this decay have been shown to permit reasonably accurate empirical fits to observations in geometrically simple conditions, such as nearly flat areas of the shelf offshore from straight coastlines (Soulsby 1990). However, not only are most observed vertical profiles sensitive to the details of the local bathymetry, but they also vary in time in response to changing water column stratification, shear, and mixing characteristics (Werner et al. 2003), as well as to lateral shear in background currents (Codiga and Rear 2004).

Therefore knowledge of the detailed vertical structure of tidal current amplitudes, which is crucial for planning potential current energy conversion development, generally requires direct observation and analysis of vertical profiles. As a result, assessment of tidal current energy resources is done on a site-by-site basis. The majority of the sites with high potential for development are located inshore of the OCS, near constrictions in the coastline that accelerate the flow.

Internal tides, a form of tidal motion having currents that flow in opposing directions simultaneously at different depths, are energetic at certain sites over the North Atlantic and Mid-Atlantic OCS. They include internal wave motions, referred to as "solitons" or "solibores," which have small spatial scales (wavelengths of the order of hundreds of meters); occur in groups with individual waves separated by fractions of an hour; and can propagate tens of kilometers in a few hours or less. In most cases they are driven by interaction of external tidal currents (the larger-scale, more vertically uniform tidal motions described in the preceding paragraphs) with sharp bathymetric changes such as the shelf break. Such high-energy nonlinear internal waves have been observed, with currents reaching 60 cm/s or more entering Massachusetts Bay from where they originate over Stellwagen Bank (Butman et al. 2006). Similar motions have been observed over Georges Bank (Dale et al. 2003), the New England shelf (Colosi et al. 2001), and the New Jersey shelf (Headrick et al. 2000). They are episodic, they depend on the presence of stratification, and they can be important to onshore transport of suspended materials.

2.3.4 Other Prominent Currents

2.3.4.1 Estuarine Outflows

The long-term mean southward inshore coastal currents along the shelf described above in Section 2.3.1 (e.g., WMCC in North Atlantic) are, to a large extent, the integration of pulses of water delivered to the OCS through the mouths of estuaries. Such buoyant outflows can range in strength from 5 to 50 cm/s or more and are highly variable in time, as they are ultimately driven by river inputs to the estuary. Thus, much as river flows do, OCS currents near the mouths of the major estuaries listed above in Section 2.3.1 fluctuate sharply on the 2-to-3-day timescales of precipitation events, tend to follow a seasonal progression that peaks in spring, and have marked interannual changes. Estuarine outflows typically take the form of plumes extending offshore by tens of kilometers and southward by up to 100 km, distances that vary strongly as a function of riverflow and synoptic wind conditions. Upwelling-favorable winds spread the flow offshore and concentrate it in the upper water column, while effects of downwelling-favorable winds are opposite. Onshore near-bottom flow is strengthened in the vicinity of estuaries, where bi-directional exchange circulation, such as the classic two-layer shallow-outward and deep-inward pattern, is well-developed (Long Island Sound, Delaware Bay, Chesapeake Bay).

2.3.4.2 Currents Near Canyons

Between Georges Bank and Cape Hatteras a series of 20 to 25 canyons, each a few kilometers wide, incise the continental slope by a few km and extend to the 100-m isobath. Over the deeper shelf areas of the OCS in the vicinity of these canyons, there is evidence that mean and weather-band flows, and therefore shelf-slope exchange, are stronger and aligned more along the canyon axis than are currents in the surrounding areas (e.g., Manning et al. 1994). Flow within canyons, generally offshore of the 100-m isobath, has received considerable attention for its sediment transport implications. Fritz (1985) summarized the results of LDGO (1983) and Butman (1986) as follows: peak bottom currents occur on-axis near the canyon head. Mean bottom currents are down-canyon near the head and up-canyon at intermediate depths, causing a convergence zone in-between. Suspension of sediments is primarily by tidal currents as opposed to storms, and is strongest along the axis, with net transport down-canyon.

In contrast to other canyons the Hudson Canyon has an extension, the Hudson Shelf Valley, reaching across nearly the entire continental shelf towards the Hudson River. The Hudson Shelf Valley divides the region into northern and southern sections and impedes communication between them, particularly for deep flow. Wind-driven upwelling and downwelling motions are enhanced, reaching 40 cm/s or more, and aligned along the valley northwestward or southeastward (Harris et al. 2003).

2.3.4.3 Currents Due to Gulf Stream Ring Interactions

Because Gulf Stream rings (GSRs) are characterized by currents ranging from about 60 to 140 cm/s, when they reach close proximity to the shelf break they can substantially modify OCS currents. This typically occurs up to a few times a year, with varying degrees of intensity, as described in the review of their characteristics and interactions with shelf areas by Ingham (1982). They impact the Mid-Atlantic mainly, and the northern Mid-Atlantic most prominently. GSRs cause intrusions of relatively warm, salty water onto the shelf, which strongly influences OCS water properties (see Section 2.4 below). Furthermore, the northern edge of clockwise-rotating warm core rings can reverse the prevailing westward flow along southern Georges Bank and cause strong across-isobath currents that persist for periods of days to weeks (e.g., Ryan et al. 1999).

2.3.4.4 Mesoscale Currents

OCS currents inherently exhibit characteristic variability on timescales of up to a few days and spatial scales of 5 to 25 km. Current speeds associated with these mesoscale motions are commonly in the range of 10 to 30 cm/s (e.g., Garvine 2004). These currents arise from variability and interactions of the responses to the various forcing agents described above (e.g., local winds, estuarine outflows, interactions with bathymetric features, and influences of offshore currents such as eddies and meanders of the shelf-break jet), and can also result from intrinsic fluid-dynamical instabilities (e.g., Yankovsky et al. 2000).

2.4 WATER PROPERTIES AND STRATIFICATION

Temperature, salinity, density fields, and the density stratification, are discussed here; other water attributes (turbidity, dissolved oxygen, nutrients) are discussed with geological oceanography (Chapter 5) and chemical oceanography (Chapter 4). The temperature, salinity, and density fields over the Mid-Atlantic, and to a lesser extent the North Atlantic, have been extensively sampled and analyzed for the past several decades. Comprehensive atlases have been compiled by Godshall (1980) and, for the Mid-Atlantic, Bowman and Wunderlich (1977) and Mountain (2003 and references therein); numerous informative summaries (e.g., Ingham

1982; USDOI, MMS 1999) are available. The description here is brief and highlights a few of the refinements in knowledge over roughly the past decade.

The three main water masses found on or influencing the OCS are the shelf water (SHW), the slope water (SLW), and occasionally Gulf Stream water. SLW is intermediate between SHW and Gulf Stream water in its temperature and salinity, and is considered a product of the exchange in properties across the northern edge of the Gulf Stream over long time scales. SHW is formed by mixing, within the Gulf of Maine, of shallow, cold, and fresh Scotian Shelf Water (SSW) with the warmer and saltier SLW that enters the gulf at depth through the Northeast Channel. Region-wide, SHW is generally the coolest and freshest, and found farthest inshore and nearest the surface. It is subject to modification by estuarine outflows and air-sea interaction as it travels southward along the coastal boundary, and clockwise around the outer portions of Georges Bank. SLW is saltier and warmer and found farther offshore; the boundary between SLW and SHW is the shelf-break front along which the main coastal flow is aligned, as described above in Section 2.3.1. Over northeastern Georges Bank, SSW often arrives directly across the Northeast Channel and exchanges properties with the SHW there. Modification of SHW temperature and salinity toward Gulf Stream water properties occurs when rings interact with Georges Bank and northern Mid-Atlantic shelf waters (e.g., Ryan et al. 1999). Over the Mid-Atlantic OCS, intrusions of SLW shoreward in layers at a range of depths (Churchill et al. 2003) and shallow excursions of SHW (Kumar et al. 2006) both occur, and contribute to complexities in the annual cycle of stratification across the shelf (Castelao et al. 2008).

Region-wide, temperatures follow a predictable seasonal cycle. In the North Atlantic the onset of spring warming is slightly delayed, and winter lows are cooler than in the Mid-Atlantic. Surface temperatures generally peak in August, and in areas that stratify during the summer the bottom temperatures peak in September, since the cooling influence of convective and wind-driven mixing reaches the seafloor later. Over the Mid-Atlantic shelf a winter-formed so-called “cold pool” of water at depth may persist through the summer warming season. Salinity also follows a seasonal cycle, but to a far less predictable extent than temperature. Interannual variability in salinity, driven mainly by changes in river runoff and the formation and movement of SSW, is pronounced and commonly stronger than the seasonal cycle.

These temperature and salinity distributions lead to a density field with a fundamental offshore gradient between less dense inshore waters and denser offshore waters of the shelf-break front. In most areas, density is influenced more by salinity than by temperature. Density stratification is therefore generally strongest inshore due to the freshening influence of shallow coastal outflows. However, temperature contributes importantly to the distinct seasonal cycle that stratification undergoes. In winter, stratification is weak throughout the area due to cooling by air-sea exchange and enhanced vertical mixing by strong winds. In spring and summer, stratification becomes progressively stronger due to surface heating and weaker winds.

Areas shallower than a boundary referred to as the tidal mixing front (TMF) remain unstratified, as a result of turbulence due to tidal currents, which causes sufficient vertical mixing to strongly limit stratification. The location of the TMF can range from about 5 m to 30 m deep, depending on the tidal current speeds and the bathymetric configuration. Generally, along the Maine and Mid-Atlantic OCS the TMF occurs near the 10- to 20-m isobaths (Garrett et al. 1978). In the northern Gulf of Maine where tidal currents are very strong, and over Georges Bank in winter, it may be located farther offshore and effectively merge with the shelf-break front. The TMF is also deeper near Nantucket Shoals due to the enhanced tidal flows there. Water inshore of the TMF tends to be less salty than water offshore of it except in locations where the offshore waters have originated from a very nearby estuarine outflow. Over Georges Bank, tidal currents are strong enough that a TMF encircles the bank along the 40- to 60-m isobaths year round (see Chen et al. 2008).

Local to an estuarine outflow there is a sharp frontal gradient in water properties between the plume and the ambient coastal waters, with the inshore water fresher and typically cooler. Over shelf areas there is evidence for a third type of front that persistently occurs throughout the region, the mid-shelf front (Ullman and Cornillon 2001), located approximately at the 50-m isobath between the shallower TMF and deeper shelf-break front. The mid-shelf front is poorly understood but appears to mark the offshore boundary of cooler fresher water and may be a region-wide integrated result of the collective estuarine outflows.

With respect to potential effects of alternative energy development on OCS water properties, an important concern would be the possible alteration of the geographic distribution of density stratification and its seasonal cycles. The timing and intensity of stratification are known to play central roles in biological processes, such as the annual cycle of primary productivity (e.g., Mann and Lazier 2006) and the decrease in oxygen levels (hypoxia) when stratification isolates deeper water from air-sea interactions. Stratification is sensitive to both horizontal and vertical turbulence and thus potential effects of alternative energy development on these fields should be considered carefully.

2.5 SEA LEVEL

Sea level changes due to surface waves were discussed in Section 2.2. Tidal sea level changes are dominated by the M_2 semidiurnal constituent, whose highest amplitude, about 250 cm, occurs over the northern Maine OCS (Moody et al. 1984). Amplitudes decrease along the southern Maine OCS, to about 125 cm off Massachusetts Bay, and to the 80-to-60-cm range eastward and southward across Georges Bank. In an area including part of the south flank of Georges Bank and Nantucket Shoals, they reach a local minimum of about 30 cm. The remainder of the Mid-Atlantic Region has amplitudes of about 40 cm, except in the New York Bight apex, where they increase to about 60 cm across the inshore half of the shelf. The N_2 constituent has a similar spatial distribution, but with amplitudes about 25 percent as high as those of the M_2 constituent.

Over the OCS the main contributors to nontidal sea level variability on timescales of hours to weeks, referred to as storm surge, are wind set-up and the inverse barometer effect. The influence of wave set-up and wave run-up, of known and prominent importance to storm surge along coastlines (see Pore and Barrientos 1976 regarding the Mid-Atlantic), is generally confined to a narrow band containing the surf zone and hence lies outside the inshore state-waters boundary of the OCS. Wind set-up and set-down are sea level changes due to accumulation or evacuation of water as a result of interaction of wind-stress-driven currents with the coastline, and to some extent with the shelf bathymetry. An example of wind set-up is higher sea level due to an onshore wind that drives water transport downwind against the coast. Wind set-up is thus sensitive to coastline shape, shelf isobath configuration, and the direction of wind-driven currents, which, by the mechanism of Ekman transport, commonly have a component to the right of the wind. Generation of wind set-up is therefore a complex dynamical process with timescales of hours to days, spatial scales influenced by both the regional and local winds, and lags of hours to days relative to the wind. An analysis of coastal sea level in winter (Noble and Butman 1979) indicated North Atlantic wind set-up response (peaks of about 15 to 20 cm) was about half as strong over the North Atlantic compared to the Mid-Atlantic (peaks about 30 to 40 cm), which may be due to the narrower shelf in the North Atlantic. The inverse barometer effect causes sea level to rise by about 10 cm in association with a decrease in atmospheric pressure of 10 hPa (about 10 millibars), and vice versa for pressure increases. Such sea level changes generally respond to atmospheric pressure fluctuations on very short timescales, and share their horizontal scales and durations (hundreds of kilometers and up to a few days). Extreme storm surge is associated with hurricanes and, to a lesser extent but more often, nor'easters.

A numerical simulation of ocean circulation driven by winds and pressures has been shown to hindcast observed coastal storm surge with a good degree of success (Bernier and Thompson 2006) throughout the North Atlantic and northern Mid-Atlantic. Based on the model, OCS storm surge standard deviation undergoes a seasonal cycle between about 10 to 15 cm in winter and about 5 to 10 cm in summer; higher values in these ranges generally occur in the area from the southern Gulf of Maine to Georges Bank, while lowest values lie in the northern Gulf of Maine. The model results indicate that the 40-year return extreme storm surge over the OCS ranged from about 0.4 to 0.6 m over the northern North Atlantic, about 0.8 to 1 m off Massachusetts and over Georges Bank, and about 0.6 to 0.8 m over the northern Mid-Atlantic.

Seasonal and interannual variability in sea level follow climatic changes in winds and atmospheric pressure, as demonstrated by Han (2002) for the North Atlantic, who analyzed satellite altimeter observations and showed that changes on the order of 10 cm occurred on decadal timescales.

2.6 DISPERSION

The highly dynamic circulations over North Atlantic and Mid-Atlantic OCS areas, as described above, cause shear, strain, and turbulence on a broad range of time and space scales. Measuring and understanding the resulting dispersion of waterborne materials is very challenging. Dispersion is commonly quantified in terms of effective eddy diffusivity values, a measure of the rate at which an initial concentration of a passive scalar or dye will spread. Dispersion generally occurs at dramatically higher rates in the horizontal than in the vertical, and analyses of the two directions are usually treated independently.

Vertical dispersion is generally the result of turbulence driven by processes of tidal timescales or shorter, and usually decreases sharply in the presence of density stratification. In shallow areas, turbulence due to tidal currents can prevent stratification, such that materials disperse rapidly through the entire water column. A highly energetic example of these conditions is atop Georges Bank, with diffusivities in the area exceeding 100 cm^2/s (Yoshida and Oakey 1996). In deeper areas, stratification can strongly inhibit mid-depth vertical dispersion, even in the persistence of a highly dispersive near-surface layer made turbulent due to wind stress, or a similar near-bottom layer associated with bottom stress. Examples of such conditions include Massachusetts Bay, where estimated diffusivities are about 0.05 to 0.15 cm^2/s (Geyer and Ledwell 1994), and over the New England shelf, where diffusivities of 0.05 to 10 cm^2/s were inferred (MacKinnon and Gregg 2003; 2005).

Horizontal diffusivities were estimated at depth on the New England shelf by tracking a dye patch, which grew from about 1 to about 50 km^2 over about 100 hours, to be in the range of about 20 to 30 m^2/s (Ledwell et al. 2004). Based on surface drifters, which separate at a rate of about 2 km per day, diffusivities in the range of 100 to 500 m^2/s have been estimated over Georges Bank, the New Jersey Shelf, and outside Delaware Bay (Sanders and Garvine 2001; Manning and Churchill 2006; Spaulding et al. 2006). Measurements of dispersion are very limited, and the few that have been made have shown a remarkable degree of variability. Knowledge of dispersion rates and their vertical, geographic, and temporal variabilities constitutes a major gap in our understanding of OCS physical oceanography, with implications for potential impacts of alternative energy development.

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3. BIOLOGICAL OCEANOGRAPHY

Shelf waters of the northeastern United States are among the best known marine regions of the world; time-series data for some resources span decades, and information sources range from the peer-reviewed literature to government agency reports, books, theses, and websites. This section provides a synthesis of information to characterize the biological resources of the Outer Continental Shelf (OCS) in the North and Central Atlantic Regions of the United States that are most likely to be affected by the development of offshore alternative energy projects. The following research question summarizes the project scope and helped to focus and guide this review:

What are the relevant descriptors of biological resources that could be impacted by the development of alternative energy projects in the North and Central Atlantic Regions of the U.S. OCS?

The specific geographic scope for this effort included waters of the OCS from the U.S./Canadian border to Cape Hatteras, North Carolina. Estuaries were excluded from this scope, and the offshore boundary was defined by the 100-meter isobath. This geographic scope corresponds in large part to boundaries of ecological significance for the western North Atlantic. The U.S. Northeast Shelf Large Marine Ecosystem (Northeast Shelf LME, also called the Northeast U.S. Continental Shelf Ecosystem) extends from the southern edge of the Scotian Shelf (in the Gulf of Maine) to Cape Hatteras, and from the coastline offshore to the shelf break at 100 to 200 m depth (Aquarone and Adams 2009, Sherman et al. 2004, Link et al. 2002). Although the continental slope offshore to the Gulf Stream has sometimes been included in descriptions of this system (Stevenson et al. 2004), the slope is not included in this synthesis, and the terms "Northeast Shelf LME" and "northeast region" will be used to describe the system that largely relates to the basic boundaries for this review of biological resources.

The Northeast Shelf LME is an open oceanic system that was delineated based on ecological criteria including bathymetry, hydrography, productivity, and trophic relationships among populations (Sherman et al. 2004; Link et al. 2002). This system can be subdivided into distinct subareas. The four major subareas that are often identified in the northeast region are: the Gulf of Maine (GOM); Georges Bank; Southern New England; and the Mid-Atlantic Bight (MAB) (e.g., Aquarone and Adams 2009; Link et al. 2002). Southern New England is not treated separately by some authors who include it within Georges Bank and the MAB (Stevenson et al. 2004). Each of the regional systems has unique topographic and hydrographic features. Stevenson et al. (2004) provides a good review of the physical features that characterize the major regional systems within the Northeast Shelf LME. The physical, chemical, and geological attributes that are essential to considering the ecology of the region are also covered in separate sections of this report.

The Northeast Shelf LME is one of the most productive LMEs on Earth (Aquarone and Adams 2009). Biological communities of great ecological and economic importance support valuable commercial and recreational fisheries throughout the northeast region. Living resources in this region also include federally listed endangered species of whales, sea turtles, birds, and fish. The unique habitats and biological communities of the northeast region compose a diverse, complex, and dynamic ecosystem. Not all biological components of this system will be covered in this review; important communities have been omitted based on relevance to the project scope. Intertidal and plankton communities are not considered in this review, since the technologies that are likely to be commercially developed on the OCS in the near future are not expected to result in major impacts to those resources. Conversely, certain groups of animals that are not typically thought of as part of the shelf ecosystem are included in this review based on relevance to the project scope. For example, songbirds and bats that fly along the Atlantic coastline during annual migrations could be impacted by offshore wind projects, and are therefore considered in this review. Hence, this section offers an overview of the status, distribution, and relevant natural history characteristics of the key biological resources that may be affected by offshore alternative energy development in the region. The scope and depth of the information available to characterize those resources are addressed, and the essential functional relationships among components of the Northeast Shelf ecosystem are reviewed. This overview provides guidance and context to help inform the site-specific ecological analyses that are essential to assessing potential environmental impacts of a specific project.

3.1 MARINE MAMMALS

The Northeastern Shelf region provides valuable habitat to marine mammals. Twenty-eight species of cetaceans (whales, dolphins, and porpoise), one sirenian (Florida manatee), and four seals are known to occur in the region. Eight of these species are federally listed as endangered (see Section 3.1.1). Marine mammals rely on habitats in this region for feeding, breeding, nursery grounds, socializing, and migration.

The Cetacean and Turtle Assessment Program (CETAP), conducted from October 1978 to January 1982 by the University of Rhode Island, surveyed the waters from the northern Gulf of Maine to Cape Hatteras, North Carolina, and concluded that the Northeastern Shelf region showed consistently high-density utilization by several cetacean species (Kenney and Winn 1986). Results from this study provide large-scale habitat use information for many cetaceans in the entire study area. The authors concluded that the most intensely used cetacean habitat on the northeast continental shelf was the western margin of the Gulf of Maine (Kenney and Winn 1986). This area was determined to be a major feeding ground for North Atlantic right, fin, and humpback whales, all of which are endangered species (Kenney and Winn 1986).

Within the northeast region, the most intensively utilized habitat was the western edge of the Gulf of Maine, from the Great South Channel to Stellwagen Bank and Jeffreys Ledge (Kenney and Winn 1986). High-use habitats for piscivorous (fish-eating) whales, e.g. fin and humpback whales, were mainly in the western Gulf of Maine and at mid-shelf east of the Chesapeake Bay region. Habitat use for planktivores (plankton-eating whales, e.g. right whales) was highest in the western Gulf of Maine and in the southwestern part of Georges Bank (Kenney and Winn 1986). Within the high-use western Gulf of Maine, North Atlantic right whales were a major component in the southeastern section, in the Great South Channel (Kenney and Winn 1986). The edge of the continental shelf was another high-use cetacean habitat, primarily used by sperm whales (Kenney and Winn 1986). In general, use of these habitats was highest in the spring and summer and lowest in the fall and winter (Kenney and Winn 1986).

Natural history information relevant to understanding potential impacts to marine mammals from offshore alternative energy facilities is synthesized in the following sections. Distribution, diet and feeding, and the major threats confronting these animals are reviewed and discussed. Information regarding hearing and vocalization abilities is also provided for each species when available. This information is emphasized because of the potential impacts to these abilities from anthropogenic noise.

3.1.1 Threatened or Endangered Species

The North and Central Atlantic Ocean is used by eight marine mammal species that are federally listed as endangered: seven whales and the West Indian manatee (Table 3.1). No marine mammals that occur within this region are listed as threatened. The ranges of these endangered marine mammals can be vast, and may vary seasonally from northern to southern regions, as well as from inshore to offshore. Natural history details pertinent to potential offshore alternative energy project activities for each species will be discussed below. Due to their critical status at the population level, particular attention is given to North Atlantic right whale, including hearing and vocalization ranges, and habitat use for feeding and migrating. The North Atlantic right whale is discussed first, and then species are addressed alphabetically within taxonomic grouping.

Table 3.1

Threatened or Endangered Marine Mammal Species Potentially Occurring in the North and Central Atlantic Regions.

Common name	Scientific name	Status
Mysticetes		
North Atlantic Right whale	*Eubalaena glacialis*	E
Blue whale	*Balaenoptera musculus*	E
Fin whale	*Balaenoptera physalus*	E
Humpback whale	*Megaptera novaeangliae*	E
Sei whale	*Balaenoptera borealis*	E
Odontocetes		
Beluga whale	*Delphinapterus leucas*	E
Sperm whale	*Physeter catodon*	E
Sirenia		
West Indian manatee (subspecies Florida manatee)	*Trichechus manatus latirostris*	E

Note: E = Endangered; Source: Waring et al. 2009

3.1.1.1 North Atlantic Right Whale (*Eubalaena glacialis*)

Distribution

North Atlantic right whales are highly endangered with a minimum population size estimated to be 325 individuals in 2003 (Waring et al. 2009). This is a minimum value and does not include individuals sighted from January 2004 to May 2007, as the photo-matching database is not complete (Waring et al. 2009). The fragile state of this population is illustrated by Fujiwara and Caswell (2001), who stated that with current population size, "the prevention of the deaths of only two female right whales per year would increase the growth rate to replacement level."

In 2008, National Marine Fisheries Service (NMFS) listed northern right whales (*Eubalaena* spp.) as two separate endangered species, the North Atlantic right whale (*E. glacialis*) and the North Pacific right whale (*E. japonicas)* (USDOC, NMFS 2008a). Nursery areas and possible mating grounds for North Atlantic right whale are in the shallow, coastal waters of New England (Waring, et al. 2007). Knowlton et al. (2002) found that 94 percent of right whales are found within 30 nautical miles (nm) of the coast, and 64 percent are found within 10 nm of the coast.

Right whales are found throughout the Gulf of Maine from May through July, and in the lower Bay of Fundy and Scotian Shelf from July through October (Mate et al. 1997). One portion of the population can be found to the east of Grand Manan Island, where the majority of summer/autumn sightings of mother/calf pairs occur (Kenney et al. 2001). These whales are found in coastal waters in Cape Cod Bay and Great South Channel from March through May (with peak occurrence in March and April), with numbers of whales remaining through the summer and autumn (Kenney et al. 2001). In recent years, there have been an increased number of sightings (Figure 3.1) in these areas in December and January (M.W. Brown, personal communication to R. Kenney, as cited in Kenney et al. 2001). The New York Bight waters function mainly as a migration pathway, with sightings of cow/calf pairs and solitary individuals occasionally feeding (USDOI, FWS 1997; Knowlton et al. 2002). Calving takes place off Georgia and northern Florida from December through March, with a peak between mid-December and early January. There are insufficient data to support or exclude New York waters as nursery or mating grounds, except the report of a female calf in June 2001 off Long Island (Waring, et al. 2007). Females and calves are seen off Georgia and Florida from November through March (Mate et al. 1997).

There are currently six major habitat areas for North Atlantic right whales: coastal waters off the southeastern United States, the Great South Channel, Georges Bank/Gulf of Maine, Cape Cod and Massachusetts Bay, the Bay of Fundy, and the Scotian Shelf (Waring et al. 2007). Movements within and between habitats may be more extensive than previously known (Mate et al. 1997). Therefore, although right whales can be expected to be in these major habitat areas, they may also be traveling extensively between these areas.

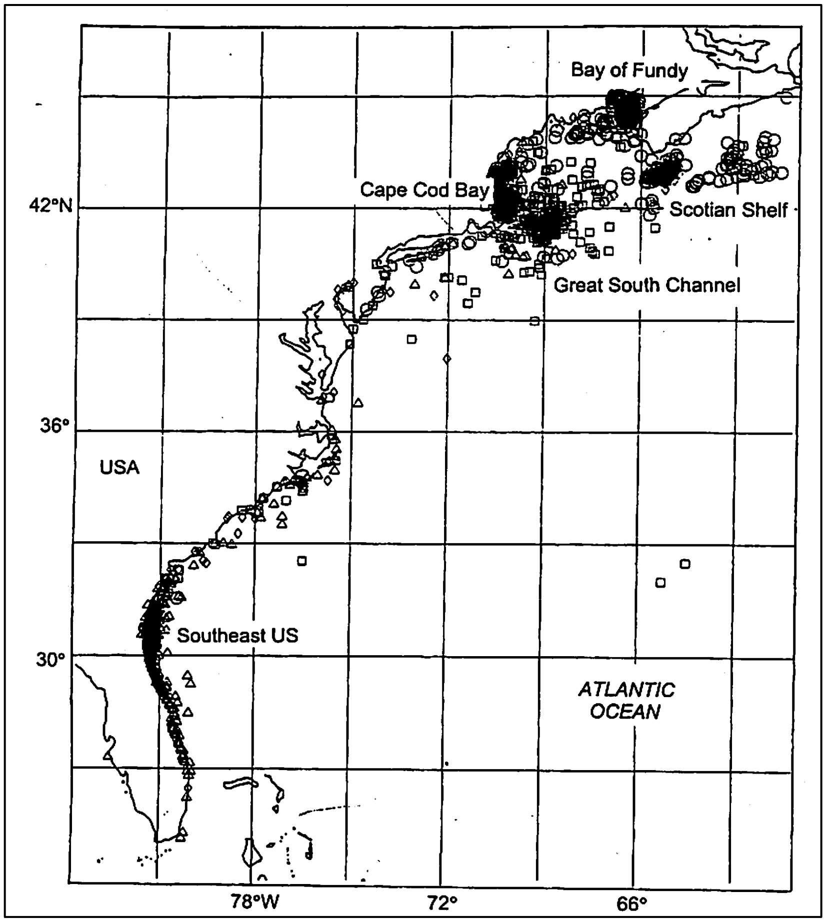

Figure 3.1. Distribution of all western North Atlantic right whale sightings in the main range from Nova Scotia to Florida, historically through the end of 1997 (n = 14,910). Approximate seasons are differentiated by different symbols: Δ = January-March (n = 2,231); □ = April-June (n = 2,137); ○ = July-September (n = 9,346); ◊ = October-December (n = 1,188); (Source: Figure 1 in Kenney et al. 2001). Used by permission.

Right whales have previously been considered to be slow-moving, nearshore animals that tend to occur in restricted areas for well-defined periods of time (USDOC, NMFS 1991). This behavior was not observed in a study using radio-tagged, satellite-monitored right whales in the western North Atlantic (Figure 3.2) (Mate et al. 1997). Overall nine whales, (six females, one pregnant and three with calves, two males, and one juvenile) were radio-tagged and tracked in the Bay of Fundy in 1990 and 1991. Three females with calves and the pregnant female moved 68 km/day, and two individuals each traveled more than 3,000 km (one male and one female with a calf) in six weeks of the study (Mate et al. 1997). All animals tracked more than 12 days left the Bay of Fundy, and several left within a few days of tagging. All tagged whales were, at some time during the survey, located in or near shipping channels in the Bay of Fundy, the deepest portion of the bay (Mate et al. 1997).

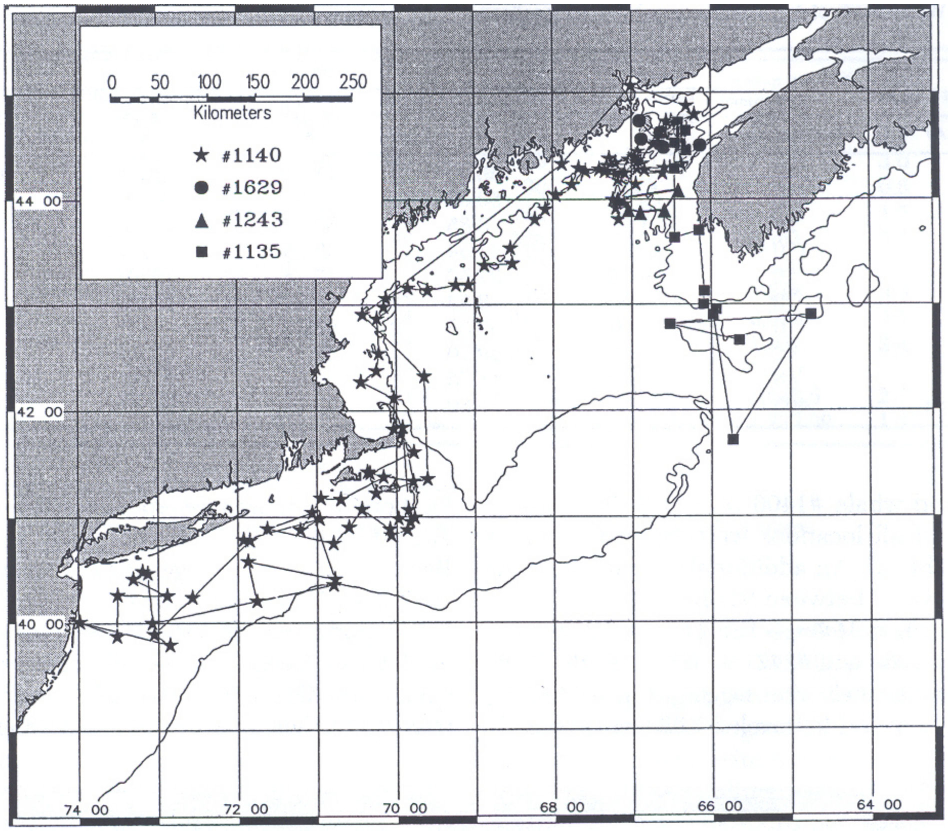

Figure 3.2. Satellite-monitored movements of four right whales radiotagged in the Bay of Fundy, including a pregnant female (#1135) and three females with calves. (Source: Figure 4 in Mate et al. 1997). Used by permission.

From this study it appears that movements in and out of the Bay of Fundy may be routine for many, or even most, right whales, and are likely related to food availability (Mate et al. 1997). This combination of high mobility in a heavily utilized area increases the potential of ship strikes for the whales. In particular, females with calves, critical to the recovery of the species, are known to spend significantly more time than other individuals at the surface (Baumgartner and Mate 2003). This distribution information may be useful for locating offshore alternative energy projects in areas that are not heavily used by right whales.

Diet and Feeding

New England waters, including Cape Cod Bay, Massachusetts Bay, the margins of Georges Bank, the Gulf of Maine, the Bay of Fundy, and the waters over the Scotian Shelf are primary feeding grounds for right whales (Baumgartner et al. 2003). The North Atlantic right whale diet consists primarily of copepods (small planktonic crustaceans), especially *Calanus finmarchicus* (Mayo and Marx 1990 as cited in Waring et al. 2007). The simultaneous seasonal increase in density of the two principal prey species (*Calanus* and *Pseudocalanus*) suggests that the arrival of the whales is timed to coincide with the presence of high densities of these copepods. Conversely, during 1992, right whales were not found in their usual feeding grounds in the Great South Channel, and only a few were seen in Massachusetts Bay (Kenney 2001). The unusually low numbers of whales were attributed to a shift in zooplankton to a high density of an unfavorable species of pteropod caused by significantly reduced water temperature (Kenney 2001).

In a study of right whale habitat in the lower Bay of Fundy and the southwest Scotian Shelf, *C. finmarchicus* was highly abundant in discrete layers over the deepest waters in both regions (Baumgartner et al. 2003). Right whales occurred where the bottom mixed layers forced *C. finmarchicus* into shallower waters, increasing the foraging efficiency for the whales (Baumgartner et al. 2003). Additionally, Woodley and Gaskin (1996) determined that within the lower Bay of Fundy, right and fin whales use two distinctly different habitats and foraging strategies. Right whales typically used the Grand Manan Basin, an area with relatively flat bottom topography and high densities of *C. finmarchicus* (Woodley and Gaskin 1996).

Breeding

Nursery areas and possible mating grounds for North Atlantic right whale are in the shallow, coastal waters of New England (Waring et al. 2007). Right whales are known to congregate in surface active groups (SAG) in which two to forty whales interact at the surface with frequent physical contact (Parks et al. 2007a). SAG have been observed in all habitats (southeastern coastal United States, Cape Cod Bay, Great South Channel, Grand Manan Conservation Area, and Roseway Basin) and in all months (except November due to low survey effort) in which right whales were sighted (Parks et al. 2007a). These groups can encompass both reproductive and non-reproductive behavior including play, breeding practice, and social bonding (Parks and Tyack 2005).

Hearing and Vocalization

Mysticetes are adapted to hear low-frequency noise. The hearing range for North Atlantic right whales is estimated to be 10 hertz (Hz) to 22 kHz with functional ranges probably being between 15 Hz and 18 kHz (Parks et al. 2007b). Right whale vocalizations are mostly concentrated in the lower frequencies. Moans, groans, belches, and pulses have most of their acoustic energy below 500 Hz, with some vocalizations occasionally reaching up to 4 kHz. Right whales use a variety of calls when socializing in a group. In the North Atlantic, calls lasting 0.5 to 2.8 seconds and ranging in frequency from 400 to 3,200 Hz are believed to be produced by the focal female in SAG to attract males. Males produce gunshot-like sounds that might function as a threat display to other males (DOSITS 2008).

In surface active groups, six different call types, which may or may not be related to reproduction, have been recorded. Source levels range from 137 to 162 dB re 1µPa at 1 meter (standard reference for underwater sound is measured in decibels referenced to 1 micropascal, measured at 1 meter from the source) for tonal calls and from 174 to 192 dB re 1µPa at 1 meter for broadband gunshot-type sounds (Parks and Tyack 2005). These source level ranges recorded from calls may be useful for assessing potential masking (i.e. overlapping) impacts of anthropogenic noise from alternative energy project activities.

Threats

The primary threats to North Atlantic right whales are vessel collision causing serious injury, mortality, or entanglement in fishing gear (see Section 8.1.1.1.1.1**)**. From February 2004 to June 2005, the deaths of eight North Atlantic right whales in the Northwest Atlantic, including six adult females (three carrying near-term fetuses), were recorded. Three of these whales were killed by ship strikes and one was probably killed by a ship (Kraus et al. 2005 as cited in Waring et al. 2007). The deaths of these females represent a lost reproductive potential of as many as 21 animals (Kraus et al. 2005 as cited in Waring et al. 2007).

3.1.1.2 Blue Whale (Balaenoptera musculus)

Distribution

Blue whale distribution in the western North Atlantic extends from the Arctic to the tropics (Wenzel 1988). Blue whales are known to occur singly or in pairs; individuals are difficult to identify at a distance, especially when associated with groups of fin whales. They are most frequently sighted in the waters off eastern Canada and the Gulf of St. Lawrence in the spring, summer, and fall, where 308 recognizable individuals have been catalogued (Sears et al. 1987 as cited in Waring et al. 2009; COSEWIC 2002). According to the Blue Whale Recovery Plan (USDOC, NMFS 1998), “the U.S. east coast does not appear to be a region of importance to blue whales; only occasional sightings and strandings are reported there.”

In the Gulf of Maine from 1995 through 2007, five blue whales have been observed in the Bay of Fundy; four of the five were seen near Long Island, Nova Scotia (one in 1995; two in 1996 and in 2002), and one (in 2002) was seen 41 mi west-southwest of Long Island, Nova Scotia (Right Whale Consortium 2008).

Within the Mid-Atlantic Region, blue whales are rarely sighted in the New York Bight waters. Okeanos Foundation has documented fewer than a dozen sightings in the New York Bight in the past 15 years. The sightings have occurred at least 40.2 km (25 mi) south of Montauk Point in waters deeper than 30 m (USDOI, FWS 1997).

Diet and Feeding

Blue whales mainly feed on krill, but will also feed on copepods and fish (USDOC, NMFS 1998). Waters of the Northeast Shelf region are not thought to be an important feeding ground for blue whales (USDOC, NMFS 1998).

Hearing and Vocalization

Blue whale sounds are low frequency and are known to travel thousands of miles in the deeper oceans. Blue whales’ vocalizations are long, multi-part sounds including long pulses, buzzes, and rasps typically ranging from 15 to 40 Hz (Mellinger and Clark 2003). Blue whales produce two types of high frequency clicks. The first are in the 6-to-8 kHz frequency range, with two source levels recorded 130 and 159 dB re 1µPa at 1 meter. The second type of click ranges from 21 to 31 kHz with a dominant frequency of 25 kHz (Richardson et al. 1995). Blue whales produce moans at a frequency of 12 to 390 Hz, with a dominant frequency of 16 to 25 Hz and a source level of 188 dB re 1µPa at 1 meter (Richardson et al. 1995). The seasonality and structure of the sounds suggest that these are male song displays for attracting females and/or competing with other males.

In a field experiment on the effects of loud, low-frequency noise on foraging blue and fin whales, the estimated received levels exceeded 140 dB re 1µPa at 1 meter (Croll et al. 2001). The foraging whales did not significantly alter their behavior during sound pulses, but some of their vocal behavior was significantly different between experimental and nonexperimental periods. The most serious potential impact of anthropogenic low-frequency noise is a long-term change in habit use and behavior.

Threats

There has been a noticeable decrease in the number of sightings of blue whales in the eastern North Atlantic. It is not known if these changes are a result of a change from the historic distribution and migratory pattern or if it is due to a crash in population size (USDOC, NMFS 1998). Recent threats include entanglement in fishing gear, vessel strikes, impact from low-frequency noise, and loss of feeding habitat due to habitat degradation (USDOC, NMFS 1998). Blue whales have occasionally been killed or injured after colliding with ships. In 1998, a deceased juvenile blue whale was found on the bow of a tanker coming into Narragansett Bay, Rhode Island (Laist et al. 2001). It is not known where the collision took place. Increased vessel traffic is more of a concern for impacting this species than any other human impact.

3.1.1.3 Fin Whale (Balaenoptera physalus)

Distribution

Among cetaceans of the Northeast Shelf region, the fin whale has the largest standing stock (31 to 47 percent of cetaceans), the largest food requirements (annual prey consumption of 646,000 tons), and the largest impact on the ecosystem; "Not only are fin whales dominant, they are strongly dominant" (Hain et al. 1992). The most important habitat for fin whales in this region appears to be from the Great South Channel, along the 50-m isobath past Cape Cod and over Stellwagen Bank, and northeast past Cape Ann and over Jeffreys Ledge (Hain et al. 1992). The minimum population estimate for fin whales in the western North Atlantic is 1,678 (Waring et al. 2009). This estimate is extremely conservative due to the incomplete coverage of this species' known habitat and the whales' movements between surveyed and unsurveyed areas (Waring et al. 2009). Fin whale abundance in this area is highest in the spring and summer. The whales are thought to migrate to the south and/or offshore in the winter. Walker et al. (1992) examined the association between geomagnetic field intensity and gradient, and fin whale sighting positions during migration. The authors indicated that fin whales recognize geomagnetic fields, and that their seasonal migration is associated with geomagnetic fields (Walker et al. 1992).

Within the Mid-Atlantic, fin whales are present in Long Island waters year round, although there are seasonal distribution differences. During April through August fin whales are usually found within 30 mi of land, where intensive feeding activity usually occurs. During September through early December the whales usually move offshore along the continental shelf near the 200-meter contour. Based on neonate stranding data, calving is thought to occur from October to January in the U.S. Mid-Atlantic waters (Hain et al. 1992). However, in the waters off of New York, calves are observed year round, with newborns observed mainly in early July (USDOI, FWS 1997). Fin whales are likely the most abundant large whale in the waters off Virginia, and are often found stranded on Virginia beaches (Blaylock 1985).

Diet and Feeding

During the summer, fin whales feed on krill, small schooling fish (e.g. herring, capelin, and sand lance), and squid. Fin whales are found in shallower waters on the continental shelf with topographical variability and relatively high densities of euphausids and herring (Woodley and Gaskin 1996). This species fasts in the winter, during their migration to warmer waters (USDOC, NMFS 2008b). However, in January through March some whales can be found feeding again within 1 mi of the eastern shores of Long Island, New York, apparently feeding on the high densities of herring and mackerel that occur there at this time of year. During the summer, feeding groups often involve aggregations of 20 or more animals (USDOI, FWS 1997).

Hearing and Vocalization

Fin whales vocalize at low frequencies, with the most common sound at 20 Hz, but may also produce sounds at frequencies up to 200 Hz (Richardson et al. 1995). Most of the 20-Hz sounds have source levels of roughly 180 to 190 dB re 1 µPa at 1 m, with an overall range of 140-200 dB, but fin whales also produce low source-level sounds ranging from 155 to 165 dB (Charife et al. 2002; Croll et al. 2001). These sounds are emitted during their reproductive season from autumn to early spring and are believed to be acoustic displays associated with reproduction. Calls have been detected 15.5 mi away in deeper waters and 5 to 6 mi in shallow water (i.e. the Outer Continental Shelf waters).

Threats

The biggest threats to fin whales are entanglement in gillnets and ship strikes (Waring et al. 2007).

3.1.1.4 Humpback Whale (*Megaptera novaeangliae*)

Distribution

Humpback whales are found in all of the oceans of the world and are known to feed in the summer months in high-latitude areas (USDOC, NMFS 1991). Summer ranges are close to shore, including major coastal embayments and channels (USDOC, NMFS 1991). Humpbacks can be seen feeding with calves present during June through November in the northern Gulf of Maine and the Bay of Fundy (Right Whale Consortium 2008), and during all months except October and November in the Mid-Atlantic (USDOI, FWS 1997). These whales can be seen in the winter off Virginia and North Carolina during their southward migration (Blaylock 1985). In the winter, most whales appear to migrate south (latitude 10˚ to 35˚) to the West Indies to mate and calve (Waring et al. 2007). However, not all whales migrate south in the winter, and recently (since the 1980s) a relatively large number of animals has been found in mid- and high-latitude waters, specifically off Chesapeake Bay area and Delaware (Waring et al. 2007).

An increased number of sightings and strandings were reported in Mid-Atlantic and southern states from 1985 to 1992 (Waring et al. 2007). Wiley and Asmutis (1995) reported 38 humpback whales stranded in these waters, particularly along the Virginia and North Carolina coasts. Strandings occurred with the highest frequency in April, followed by February, March, and October (Wiley and Asmutis 1995). Barco et al. (2002 as cited in Waring et al. 2007) reported that between 1990 and 2000, 52 known humpback mortalities occurred in the Mid-Atlantic. Of these animals, 81.2 percent were first-year animals, and 14.6 percent were immature (dependent or newly independent and sexually immature). Wiley and Asmutis (1995) concluded that these areas are becoming increasingly important habitat for juvenile humpbacks. The authors also suggest that the most likely explanation for the increased number of mortalities appears to be a combination of the increased use of the area by juvenile humpbacks, which are then exposed to "larger, faster, deeper draft vessels pos[ing] a greater danger than the slower, shallower draft vessels of the past."

Diet and Feeding

Feeding is the primary activity in the waters of New England, and humpback whales' distribution is largely correlated to their prey species and abundance (Payne et al. 1990 as cited in Waring et al. 2007). Humpbacks are known to feed on herring (*Clupea harengus*), sand lance (*Ammodytes* spp.), and other small fish. In the northern Gulf of Maine, euphausids are an important food item (Paquet et al. 1997 as cited in Waring et al. 2007). The greatest abundance of humpback whales in the New York Bight occurs as they feed on concentrations of small schooling fish from June through September, and again in December and January. According to Barco et al. (2002 as cited in Waring et al. 2007) the Mid-Atlantic Region is likely a supplemental feeding ground, used primarily in winter, but also used at other times of the year. Humpbacks are often found in shallow water and have been observed along western Long Island, in New York Harbor, and within Long Island Sound, Block Island Sound, and Gardiner's Bay, New York, for periods exceeding a week (USDOI, FWS 1997).

Hearing and Vocalization

Due to the lack of data, auditory sensitivity information for humpback whales has been estimated mathematically (Houser et al. 2001). The results show the typical U-shaped audiogram with sensitivity to frequencies from 700 Hz to 10 kHz, with maximum sensitivity between 2 and 6 kHz. Humpback whales have been observed reacting to low-frequency industrial noises at estimated received levels of 115 to 124 dB (Malme et al. 1985 as cited in Richardson et al. 1995). Humpback whales have been shown to elicit reactions from conspecifics up to 5.6 mi (4.9 nm) away (Tyack and Whitehead 1983). Humpbacks have also been observed to react to nonspecific calls at received levels as low as 102 dB (Frankel et al. 1995). Increase in ambient noise levels and boat presence has had an impact on humpbacks' utilization of habitats. Humpback whales have demonstrated a short-term avoidance of areas with increased whale-watching activity (Corkeron 1995). These hearing data are relevant for determining the possible impacts of noise from offshore alternative energy project activities.

Threats

The biggest threats to humpback whales are gear entanglements and ship strikes. Glass et al. (2008) reported six mortalities and nine serious injuries from entanglements of humpback whales along the U.S. eastern seaboard from 2002 to 2006. This total of 15 observed entanglements was higher than for any other whale species along the U.S. Atlantic and Gulf of Mexico coasts.

Three unusual mortality events (UME) have been recorded along the eastern U.S. coast. In 1987 through 1989, at least 14 humpbacks in Cape Cod Bay and Nantucket Sound died after feeding on mackerel containing a dinoflagellate saxitoxin (Geraci et al. 1989 as cited in Waring et al. 2007). In 2003, 12 to 15 whales died offshore in the Northeast Peak of Georges Bank, and 21 dead humpback whales were found in New England between July and December of 2006. No definitive cause of death has been determined for these events (Waring et al. 2009).

3.1.1.5 Sei Whale (Balaenoptera borealis)

Distribution

The Nova Scotia stock of sei whales is distributed from the U.S. coast to Cape Breton, Nova Scotia, and east to longitude 42˚. Populations of sei whales may seasonally migrate toward the lower latitudes during the winter and higher latitudes during the summer.

The distribution and movement patterns of this species are not well known. This species may unpredictably and randomly occur in a specific area, sometimes in large numbers. These events may occur suddenly and then not occur again for long periods of time (USDOC, NMFS 2009). Though generally considered an offshore species, sei whales occasionally travel into more shallow and inshore waters (Great South Channel and Stellwagen Bank) in years when there is an abundance of copepods (Waring et al. 2007). Sei whales are commonly found in the Gulf of Maine and on Georges Bank and Stellwagen Bank during the spring and summer (Waring et al. 2007).

Within the Mid-Atlantic Region, this species is infrequently sighted in the New York Bight; however, they have been found occasionally in association with finback whale aggregations, principally in the months of July and August. They are generally sighted north of 40°N latitude, on the outer edge of Georges Bank east of the New York Bight.

Diet and Feeding

Sei whales are known to feed primarily on copepods, euphausids, and a variety of small schooling fishes (Waring et al. 2002). Foraging activity has been reported as far south as the New York Bight (USDOI, FWS 1997).

Hearing and Vocalization

Very little is known about sei whale vocalizations. The only recordings were made off eastern Canada; sounds consisted of sweeps in the 1.5-to-3.5 kHz range (Richardson et al. 1995).

Threats

According to Waring et al. (2007), the biggest threat to sei whales is ship strikes. From 2002 to 2006, three mortalities that resulted from ship strikes were recorded along the U.S. eastern seaboard, off Virginia, Maryland, and Jeffreys Ledge (Glass et al. 2008). The carcass of a 13-m female was recovered in May 2001 in New York Harbor after it slid off the bow of an arriving ship. Freshness of the carcass and hemorrhaging indicated that the strike was pre-mortem (Waring et al. 2007).

3.1.1.6 Beluga Whale (Delphinapterus leucas)

Beluga whales are found in Arctic and subarctic regions, and the Gulf of St. Lawrence Estuary. The St. Lawrence population is considered to be separate from other beluga populations (DOSITS 2008). These whales enter the St. Lawrence Estuary when the ice breaks up, usually late March or April (DOSITS 2008). Belugas occur seasonally (mainly in summer) in shallow coastal waters; however, they often move into deep, offshore waters in the other seasons. Although various species of fish are considered to be the primary prey items, belugas also feed on a wide variety of mollusks and benthic invertebrates. Based on stomach contents, belugas are thought to feed mostly on or near the bottom (USDOC, NMFS 2008b).

Occurrence of beluga whales in the North and Mid-Atlantic Regions would be rare or accidental. A single beluga, ranging from Boston Harbor to the mid-coast of Maine, was sighted 150 times during 2003 and 2004. This beluga was found dead in Maine in November 2004 (NEFSC 2004). Within the Bay of Fundy waters from 1998 through 2007, there was one beluga whale seen 12 mi east off Grand Manan Island in August of 2003 (Right Whale Consortium 2008). Beluga whale vocalizations range in frequency from 0.26 to 20 Hz, with dominant frequencies for various calls from 2 to 5.9 Hz and 1 to 8.3 Hz. Source levels range from 40 to 60, and 100 to 120, with echolocation source levels ranging from 206 to 225 dB re 1μPa at 1 meter (Richardson et al. 1995).

3.1.1.7 Sperm Whale (Physeter macrocephalus)

Distribution

Sperm whales are found in all oceans of the world and seasonally within the Northeast Shelf region. In the winter, sperm whales are concentrated east and northeast of Cape Hatteras, and northward to the east of Delaware and Virginia. In the spring, they are widespread throughout the central Mid-Atlantic bight and southern Georges Bank (Scott and Sadove 1997). In the summer, the distribution is similar, but also includes the waters east and north of Georges Bank and the Northeast Channel, as well as on the continental shelf inshore of the 100-m isobath south of New England (Waring et al. 2007). In the fall, sperm whales can be found south of New England on the continental shelf and shelf edge.

Sperm whales are known to have various social groups, including nursery schools, harem or mixed schools, juvenile or immature schools, bachelor schools, bull schools or pairs, and solitary bulls (Whitehead et al. 1991 as cited in Waring et al. 2007). Geographic distribution may be linked to their social structure, with females and juveniles generally found in tropical and subtropical waters, and males ranging more widely (Waring et al. 2007).

The New York Bight offers an anomalous habitat for sperm whales. Sperm whales have been regularly and repeatedly sighted in the shallow coastal waters off Long Island, NY, in autumn, winter, and late spring, and occasionally during early summer (Scott and Sadove 1997). No direct observations of feeding have been made, and it is still a mystery as to what the whales are doing there, although Scott and Sadove (1997) speculate that "the whales [may be] using this channel (27 km SSE of Montauk Point, between Block Island Sound and Block Canyon) to follow prey inshore during the late spring and early summer. More than 36 species of cephalopods have been recorded off the east coast of North America, including several squids which migrate inshore during the spring to spawn."

The Okeanos Foundation of New York reports that they regularly see sperm whales in one location south of Montauk Point, Long Island, in less than 18 m of water from late May through June and again in October (Riverhead Foundation 2009). Scott and Sadove (1997) report that it is not known whether the same individuals return to this location each year, but upon arrival, the whales appear to take up a short-term residence in the area as opposed to making transient visits. Breeding season in the Northern Hemisphere extends from January to August, with a peak from March through June. Observations and sightings indicate that the distribution of young whales, both calves and juveniles, resembles that of the adults, and cows and calves are regularly sighted in the New York Bight (USDOI, FWS 1997).

Diet and Feeding

Sperm whales' diet consists mainly of large squid, but also may include large demersal and mesopelagic sharks, skates, and fish (USDOC, NMFS 2009). Sperm whales are known to dive to great depths to find food. Foraging dives last about 30 to 40 minutes and descend to depths from 300 to 1,245 m (Wahlberg 2002). Sperm whales may have the longest and deepest dives of any marine mammal, with recorded dives of over two hours to depths of 3,000 m (Watkins et al. 1985 as cited in Waring et al. 2007).

Hearing and Vocalization

Sperm whales' dominant vocalizations are clicks produced at a frequency range of 0.1 to 30 kHz, with dominant frequencies of 2 to 4 kHz and 10 to 16 kHz, and a source level of 160 to 236 dB re 1 μPa at 1m (Richardson et al. 1995, Mohl et al. 2003). Regular click trains and creaks have been recorded from foraging sperm whales and may be used for echolocation (Madsen et al. 2002). Audiograms measured from a sperm whale calf exhibited an auditory range of 2.5 to 60 kHz, with the most sensitivity between 5 and 20 kHz (Ridgway and Harrison 1999). A stereotyped series of clicks, or "codas," have been associated with social interactions and are thought to play a role in communication (Weilgart and Whitehead 1993).

Threats

Threats to sperm whale populations include entanglement in fishing gear, ship strikes, and pollution (Waring et al. 2007). Along the U.S. Atlantic coast and Puerto Rico from 2001 to 2005, 15 sperm whale strandings were reported (Waring et al. 2009). From 2001 to 2005, there was one confirmed sperm whale ship strike in May 2000 in Block Canyon (on the continental shelf off New York and New Jersey; Waring et al. 2009). Block Canyon is an important pathway in the spring for sperm whales entering the southern New England continental shelf waters pursuing migrating squid (Scott and Sadove 1997).

3.1.1.8 West Indian Manatee, Subspecies Florida Manatee (Trichechus manatus latirostris)

The Florida manatee, a subspecies of the West Indian manatee, can be found throughout the southeastern United States, although this region is the northern limit of their range (USDOC, NMFS 2009). This is a subtropical species with a low tolerance for cold. During warmer months, they may disperse great distances throughout coastal waters, and have been sighted as far north as Massachusetts. They are known to occupy different habitats during various times of year, with the focus on warm-water sites in the winter, including fresh, brackish, and marine waters. Manatees feed on submerged, floating, and emergent aquatic vegetation.

West Indian manatee's hearing sensitivity ranges from 15 to 46 kHz, with best sensitivity at 6 to 20 kHz, with source levels ranging from 45-50 dB re 1μPa (Richardson et al. 1995). Manatees are more sensitive below 3 kHz than any other marine mammal studied to date, and hearing extended down into the infrasonic range (15 Hz; Richardson et al. 1995). Sensitivity at 10 to 32 kHz was also unexpectedly good. (Manatee calls are below 10-12 kHz.)

3.1.2 Non-Endangered Species

The North and Central Atlantic waters are inhabited by 21 cetaceans and 4 seals that are not federally listed as threatened or endangered but are protected under the Marine Mammal Protection Act (Table 3.2). Marine mammals recorded in these waters include many commonly seen animals like minke whales, pilot whales, several dolphin species, and harbor seals. These waters also include marine mammals that are rare or rarely sighted in the northeastern regional waters such as killer whales and hooded and harp seals. Additionally, species of whales that are rarely seen due to their lifestyle and offshore distribution have been recorded in these waters. These species include pygmy sperm whales and beaked whales.

These marine mammals use the Northeastern Shelf waters for many purposes, including migration, feeding, and seasonal habitation. A brief natural history and distribution of each species are presented below for the purpose of describing how each species utilizes these waters and how each may be affected by offshore alternative energy projects.

3.1.2.1 Cetaceans

This section presents brief species profiles for non-endangered cetacean species in the northeast region. Natural history information relevant to potential impacts from offshore alternative energy facilities is provided. Since anthropogenic noise is a key concern for marine mammals, cetacean hearing and vocalization are reviewed briefly below.

In general, odontoceti communicate at moderate-to-high frequencies (i.e. 1-2 kHz), and many species also have highly developed echolocation systems operating at high and very high frequencies (i.e. 20-150 kHz). Baleen whales are apparently sensitive mainly to low- and moderate- frequency sounds (i.e. 12Hz to 8 kHz). Since species within the North and Central Atlantic Regions use both inshore and offshore waters, it should be noted that acoustic transmission in deep water is different from transmission of the same sound in shallow water. "Marine mammals create sound to communicate about presence of danger, food, conspecifics or other animals, their own position, identity, and territorial or reproductive status. Additionally, Odontoceti use echolocation sound to detect, localize and characterize underwater objects; including obstacles, prey, and one another" (Richardson et al. 1995).

Table 3.2

Marine Mammals of the North and Central Atlantic Regions that are not Federally Listed

Common Name	**Scientific Name**
CETACEA	
Mysticetes	
Minke whale	*Balaenoptera acutorostrata*
Odontocetes: whales	
Antillean (Gervais') beaked whale	*Mesoplodon europeaus*
Dense-beaked (Blainville's) whale	*Mesoplodon densirostris*
Sowerby's beaked whale	*Mesoplodon bidens*
True's beaked whale	*Mesoplodon mirus*
Goose/ Cuvier's beaked whale	*Ziphius cavirostris*
Dwarf sperm whale	*Kogia sima*
Pygmy sperm whale	*Kogia breviceps*
Odontocetes: dolphins	
Atlantic/long-finned pilot whale	*Globicephala melaena*
Short-finned pilot whale	*Globicephala macrorhynchus*
Atlantic spotted dolphin	*Stenella frontalis*
Pantropical spotted dolphin	*Stenella attenuata*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Bottlenose dolphin	*Tursiops truncatus*
Clymene dolphin	*Stenella clymene*
Common dolphin	*Delphinus delphis*
Grampus (Risso's dolphin)	*Grampus griseus*
Killer whale	*Orcinus orca*
Striped dolphin	*Stenella coeruleoalba*
White-beaked dolphin	*Lagenorhynchus albirostris*
Odontocetes: porpoise	
Harbor porpoise	*Phocoena phocoena*
PINNIPEDIA	
Gray seal	*Halichoerus grypus*
Harbor seal	*Phoca vitulina*
Harp seal	*Phoca groenlandica*
Hooded seal	*Cystophora cristata*

Source: Waring et al. 2009

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales inhabit the waters from eastern Davis Strait (45˚W) to the Gulf of Mexico, and are common and widely distributed within the Northeastern Shelf region (Waring et al. 2007). They are known to occupy the continental shelf proper, rather than the shelf edge, and their distribution in these waters is strongly seasonal. Minke whales are most abundantly found in

New England waters in the spring and summer, with fewer present in the fall, and are for the most part absent in the winter. During the summer, minkes segregate into different groups depending on sex and age. Males migrate farther north in open seas, while females stay in more southern and coastal areas. Minke whales typically feed on various fish and plankton species, including sand lance, salmon, mackerel, cod, herring, euphausiids, and copepods. Minke whale vocalizations range from 60 to 140 Hz and 850 Hz to 20 kHz, with sound pressure levels ranging from 151 to 175 dB re 1 µPa at 1 m (Richardson et al. 1995).

Threats relevant to minke whales in the northeast region include entanglement in gear, vessel collision, and underwater noise. From 2001 to 2006, eleven mortalities caused by entanglement in fishing gear were reported from Rhode Island to Maine (Waring et al. 2007, Waring et al. 2009). From 2002 to 2006, two mortalities from ship strikes were recorded, one in Massachusetts and the other in New Jersey, in June and May respectively (Waring et al. 2009).

Beaked Whales (*Mesplodon* spp.)

Four beaked whale species from the genus *Mesoplodon* can be found in the northwest Atlantic: True's beaked whale (*M. mirus),* Gervais' beaked whale (*M. europaeus*), Blainville's beaked whale (*M. densirostris*), and Sowerby's beaked whale *(M. bidens)* (Waring et al. 2007*).* These species are difficult to identify to the species level at sea, and are often reported as *Mesoplodon* spp. Most beaked whale sightings are along the continental shelf edge in spring and late summer (sightings biased by survey effort in these seasons). The most common *Mesoplodon* species in the northwest Atlantic is Gervais' beaked whale. This species is oceanic in habitat and can be found from Cape Cod Bay to Florida (Waring et al. 2007). True's beaked whales have been reported from Nova Scotia to the Bahamas, Blainville's beaked whales can be seen from Nova Scotia to Florida, and Sowerby's beaked whales have been reported from New England north to the pack ice. Blainville's beaked whale vocalizations range in frequency from less than 1 to 6 Hz (Richardson et al. 1995).

From 1992 to 2000, a total of 53 beaked whales stranded along the U.S. Atlantic coast between Florida and Massachusetts (USDOC, NMFS unpublished data as cited in Waring et al. 2007). Additionally, several unusual mass strandings of beaked whales in the North Atlantic have been associated with naval activities. During the 1980s, multiple mass strandings of beaked whales occurred in the Canary Islands (Simmonds and Lopez-Jurado 1991 as cited in Waring et al. 2007). Twelve Cuvier's beaked whales that lived stranded and subsequently died in the Mediterranean Sea in 1996 were associated with low-frequency acoustic sonar tests conducted by the North Atlantic Treaty Organization (Frantiz 1998 as cited in Waring et al. 2007). In March 2000, 14 beaked whales live stranded in the Bahamas. Six of these whales subsequently died and were examined. Necropsy of the six whales revealed evidence of tissue trauma associated with an acoustic or impulse injury that caused the animals to strand (Cox et al. 2006). The authors underscore the need for future research in distribution, abundance, and habitat preference of beaked whales (Cox et al. 2006).

Cuvier’s Beaked Whales (*Ziphius cavirostris*)

The other beaked whale that may occur in the North and Central Atlantic is Cuvier’s beaked whale. Sightings of this species occur mostly along the continental shelf edge in the Mid-Atlantic Region off New York, New Jersey, and Maryland (Waring et al. 2007).

Pygmy Sperm whale (*Kogia breviceps*) and Dwarf Sperm Whale (*Kogia sima*)

Pygmy sperm whales, *Kogia breviceps,* and dwarf sperm whales, *Kogia sima*, are very difficult to differentiate, and sightings of each are often referred to as *Kogia sp*. Almost nothing is known of the behavior and ecology of this species. Pygmy sperm whales are distributed worldwide in temperate to tropical waters. They are particularly common near the continental slope (Caldwell and Caldwell 1989 as cited in Waring et al. 2007). Most sightings of pygmy sperm whales are of small groups, usually less than five or six individuals. According to Caldwell and Caldwell (1989 as cited in Waring et al. 2007), this species can be difficult to spot at sea because they usually appear slow and sluggish, and often float at the surface with no visible blow. *Kogia* sp. vocalization frequencies range from 60 to 200 Hz, with a dominant frequency of 120 Hz (Richardson et al. 1995).

One *Kogia* sp. whale was sighted in the New York Bight in July, 1995 (Right Whale Consortium 2008). From 1990 to 1998, 21 pygmy sperm whale strandings occurred in the northeastern United States (Delaware, New Jersey, New York, and Virginia) (Waring et al. 2007). Although pygmy sperm whales are rarely sighted in the waters off Virginia, they are the most frequently live-stranded cetacean in the area (Blaylock 1985). In 1985, one dwarf sperm whale mother and calf live-stranded on a Virginia Beach (Blaylock 1985). From 2001 to 2005, a relatively high number of pygmy and dwarf sperm whales stranded in North Carolina (11 *K. sima*, 10 *K. breviceps*, and 2 *Kogia* sp.) compared to 1 *K. breviceps* in Massachusetts and 1 *K. sima* in New Jersey within the same time frame (Waring et al. 2007). Potential threats for *Kogia* sp. include vessel strikes and anthropogenic noise.

Long-finned/Atlantic Pilot Whale (*Globicephala melaena*) and Short-finned Pilot Whale (*Globicephala macrorhynchus*)

Two species of pilot whales inhabit the Western Atlantic, the long-finned (Atlantic) pilot whale, *Globicephala melaena*, and the short-finned pilot whale, *G. macrorhynchus*. The species boundary is considered to be in the New Jersey to Cape Hatteras area. Sightings north of this area are likely *G. melaena* (year round from the Mid-Atlantic Bight to Georges Bank, Abend and Smith 1999), while sightings in more southern waters are likely *G. macrorhynchus*. However, these species are difficult to differentiate at sea and therefore some of the descriptions below refer generally to pilot whales, *Globicephala* sp. (Waring et al. 2007). Sightings of pilot whales are likely to occur in oceanic waters and along the continental shelf and slope. Pilot whales are highly social and are typically found in pods of about 20 to 100, but pod sizes can reach over 1,000. Pilot whales’ vocalizations range in frequency from 1 to 18 Hz with dominant frequencies ranging from 1.6 to 6.7 Hz (Richardson et al. 1995).

Potential threats to pilot whales include noise, vessel strikes, and mass stranding. The cause of mass stranding in pilot whales is not known. From 2002 to 2006, pilot whales mass-stranded throughout their range, however, the numbers of stranded animals was relatively higher in Massachusetts and North Carolina (95 and 45 respectively of 217 total animals stranded; Waring et al. 2009).

Atlantic Spotted Dolphin (*Stenella frontalis*) and Pantropical Spotted Dolphin (*Stenella attenuata*)

There are two species of spotted dolphin in the Atlantic Ocean, the Atlantic spotted dolphin, *Stenella frontalis*, and the pantropical spotted dolphin, *S. attenuata* (Perrin et al. 1987). Atlantic spotted dolphins appear to be inshore, inhabiting the continental shelf usually inside or near the 200-meter isobath, but sometimes come in very close to shore. Off Virginia, spotted dolphins are most frequently found feeding within the 200-meter line. They are common in continental shelf waters, and may be seen as far north as New Jersey, but are much more common from Cape Hatteras south (Blaylock 1985). Pantropical spotted dolphins seem to be found more offshore than Atlantic spotted dolphins, on the continental shelf edge and deeper, with sightings from off New York to off North Carolina (Waring et al. 2007). The two species are difficult to differentiate where they co-occur. Their diet consists of a wide variety of epi- and mesopelagic fishes and squids, as well as benthic invertebrates (Waring et al. 2007). From 1999 to 2003, 17 Atlantic spotted dolphins were stranded between Massachusetts and Florida (USDOC, NMFS unpublished data as cited in Waring et al. 2007). Atlantic spotted dolphin vocalizations of various types range in frequency from 0.1 to 19.8 Hz (i.e. squawks, barks, and growls = 0.1-3 Hz; clicks = 1-8 Hz; chirps = 4-8 Hz; and whistles = 5-19.8 Hz) (Richardson et al. 1995).

Atlantic White-Sided Dolphin (*Lagenorhynchus acutus*)

Within the northwestern Atlantic, white-sided dolphins can be found in continental shelf waters from western Greenland to North Carolina. From January to May, low numbers of this species are found off New Hampshire and south of Georges Bank. From June to September, large numbers are found from Georges Bank to the lower Bay of Fundy, and from October to December, white-sided dolphins occur at intermediate densities from southern Georges Bank to southern Gulf of Maine. Virginia and North Carolina appear to be the southern limit of white-sided dolphins (Waring et al. 2007). Sightings south of Georges Bank, particularly around Hudson Canyon, have been reported at all times of the year but at low densities (Waring et al. 2007). Atlantic white-sided dolphin vocalizations range in frequency from 6 to 15 Hz (Richardson et al. 1995). Mass strandings are common for this species, with some episodes reaching to over 100 animals. From 1999 to 2003, 249 white-sided dolphins stranded along the east coast of the United States and Canada (Waring et al. 2007).

Bottlenose Dolphin (*Tursiops truncatus*)

The U.S. Atlantic coast provides habitat for two morphologically and genetically distinct groupings of bottlenose dolphins: the offshore and nearshore morphotypes (Mead and Potter 1995 as cited in Waring et al. 2007). The coastal morphotype tends to concentrate in waters less than 25 m deep, while the offshore type is found in waters deeper than 40 m, although overlap of the two morphotypes does occur (Kenney 1990 as cited in Waring et al. 2007). Sightings have occurred along the continental shelf break from Georges Bank to Cape Hatteras during spring and summer (Kenney 1990 as cited in Waring et al. 2007).

The coastal morphotype is the most abundant marine mammal along the Virginia and North Carolina coasts just outside the surf line in the summer (Blaylock 1985). The coastal morphotype is found along the entire Virginia coast within 1 mi of shore, and in the Chesapeake Bay from late spring to winter (Blaylock 1985). From 1997 to 2003, 2,379 bottlenose dolphins were reported stranded along the Atlantic coast from New York to Florida (Waring et al. 2007). Bottlenose dolphin vocalizations range in frequency from 0.8 to 24 Hz, with dominant frequencies of various sounds from 0.3 to 0.9 and 3.5 to 14.5 Hz and source levels ranging from 125 to 173 dB re 1 µPa at 1 m. Echolocation frequency levels range from 110 to 130 Hz with source levels from 218 to 228 dB re 1 µPa at 1 m (Richardson et al. 1995).

Clymene Dolphin (*Stenella clymene*)

Clymene dolphins are distributed in tropical and subtropical waters of the Atlantic. They are routinely sighted in the western North Atlantic in small numbers. Two years in a row, 1998 and 1999, clymene dolphins were sighted in the same general area off Cape Hatteras (Waring et al. 2007).

Common Dolphin (*Delphinus delphis*)

Common dolphins are distributed along the continental slope and occur from Cape Hatteras northeast to Georges Bank and occasionally in the Gulf of Maine from mid-January to May. Then during the summer through the fall, these dolphins move onto Georges Bank and the Scotian Shelf (Waring et al. 2007). Groups of more than 3,000 dolphins have been recorded on Georges Bank in the fall (Waring et al. 2007). From 1999 to 2003, a total of 202 common dolphins stranded along the U.S. Atlantic coast (Waring et al. 2007). Common dolphin vocalizations for various sounds range from less than 0.5 to 3 Hz and 2 to 18 Hz, and echolocation frequencies range from 23 to 67 Hz (Richardson et al. 1995).

Grampus/Risso's Dolphin (*Grampus griseus*)

Off the northeast U.S. coast, Risso's dolphins are typically seen along the continental shelf edge from Cape Hatteras northward to Georges Bank in the spring, summer, and fall (Payne et al. 1984). Strandings of Risso's dolphins are rare in Virginia, but not uncommon in North Carolina (Blaylock 1985). In winter, Risso's dolphins are found in the Mid-Atlantic Bight and further offshore (Waring et al. 2007). Risso's dolphins feed on crustaceans and cephalopods, but seem to prefer squid. From 1999 to 2003, 20 Risso's dolphins were found stranded along the U.S. Atlantic coast (USDOC, NMFS unpublished data from Waring et al. 2007). Risso's dolphin vocalizations range in frequency from 0.1 to 8 Hz, with dominant frequencies ranging from 2 to 5 Hz. The frequency for echolocation is 65 Hz with source levels of approximately 120 dB re 1 µPa at 1 m (Richardson et al. 1995).

Killer Whale (*Orcinus orca*)

These whales are uncommon or rare in Northeast Shelf waters (Waring et al. 2009). Killer whales are usually found in small groups; however, a group of 40 killer whales was reported in the southern Gulf of Maine in 1979, and a group of 29 was reported in Massachusetts Bay in August of 1986 (Waring et al. 2009). Though best known for their habits of preying on warm-blooded animals (killer whales are known to have attacked marine mammals of all groups, from sea otters to blue whales, except river dolphins and manatees), killer whales often eat various species of fish and cephalopods. Killer whales also occasionally eat seabirds and marine turtles. It is thought that different pods of killer whales specialize in different types of prey (Simila et al. 1996). Vocalization frequencies for various sounds (i.e. whistles, clicks, creaks, etc.) range from 0.5 to 25 Hz, with dominant frequencies ranging from 1 to 12 Hz with a source level of 160 dB re 1 µPa at 1 m (Richardson et al. 1995). Echolocation frequencies range from 12 to 25 Hz with a source level of 180 dB re 1 µPa at 1 m (Richardson et al. 1995).

Striped Dolphin (*Stenella coeruleoalba*)

In the northeast coastal waters, striped dolphins are distributed along the continental shelf edge from Cape Hatteras to the southern margin of Georges Bank, and also offshore over the slope and rise in the Mid-Atlantic Region (Mullin and Fulling 2003). Their diet consists mainly of small, mid-water squid and fish, especially lanternfish (Perrin et al. 1994 as cited in Waring et al. 2007). From 1995 to 2003, 50 striped dolphins were stranded between Massachusetts and Florida (USDOC, NMFS unpublished data as cited in Waring et al. 2007). Striped dolphin vocalization frequencies ranged from 6 to 24 Hz, with dominant frequencies ranging from 8 to 12.5 Hz (Richardson et al. 1995).

White-Beaked Dolphin (*Lagenorhychus albirostris*)

White-beaked dolphins can be found in the waters from southern New England to southern Greenland. Within the Northeast Shelf region, sightings of this species are concentrated in the western Gulf of Maine and around Cape Cod, Massachusetts (Waring et al. 2007). In late March, a group of 18 white-beaked dolphins was seen about 60 nm east of Provincetown, Massachusetts (USDOC, NMFS unpublished data as cited in Waring et al. 2007). From 2001 to 2005, there were strandings of white-beaked dolphins in Maine (two), Massachusetts (two), and New York (one). The cause of death was not possible to determine in any of these strandings (Waring et al. 2007).

Harbor Porpoise (*Phocoena phocoena*)

Harbor porpoise are abundant in U.S. and Canadian waters of the western North Atlantic. From July through September, they are concentrated in the northern Gulf of Maine and southern Bay of Fundy, mostly over the continental shelf and in waters less than 50 m. In the spring (April to June) and fall (October to December), this species can be found from New Jersey to Maine. Harbor porpoise do not seem to migrate seasonally from the Bay of Fundy (Read and Westgate 1997). Harbor porpoise vocalization frequency is at 2 Hz with the source level of 100 dB re 1 µPa at 1 m. Echolocation frequency levels ranged from 110 to 150 Hz with source levels ranging from 135 to 177 dB re 1 µPa at 1 m (Richardson et al. 1995).

3.1.2.2 Pinnipeds

This section presents brief profiles for pinniped species that occur in the Northeast Shelf region (i.e., seals). Natural history information relevant to potential impacts from offshore alternative energy facilities is provided. Since anthropogenic noise is a key concern for marine mammals, pinniped hearing and vocalization are reviewed briefly below.

Similar to whales and dolphins, seals produce and receive many different sounds at different frequencies and source levels. Unlike cetaceans, seals use sound to communicate in air as well. Pinnipeds that mate in the water (hooded and harbor seals) are often very vocal during the breeding season. Underwater vocalizations of these seals range from less than 1 to 10 kHz, with source levels ranging from approximately 95 to 193 dB re 1 µPa at 1 m (Richardson et al. 1995). Pinnipeds that mate on land or ice (gray and harp seals) typically use airborne calls as well as visual displays. Underwater vocalizations of these seals appear to be limited to barks and clicks at frequencies ranging from less than 1 to 4 kHz (Richardson et al. 1995). Seal hearing, communication, and behavior will be relevant to the discussion of noise produced by alternative energy project activities.

Gray Seals (*Halichoerus grypus*)

The western Atlantic population of gray seals occurs from New England to Labrador (Lesage and Hammill 2001 as cited in Waring et al. 2007). Small numbers of seals and pupping have been recorded on islands of coastal Maine, and in Nantucket and Vineyard Sound, Massachusetts. Resident colonies have been recorded in Maine since 1994, and since the late 1900s, a year-round breeding population was documented on outer Cape Cod and Muskeget, Massachusetts (Waring et al. 2007). In 1999, no gray seals were recorded at haul-out sites between Newport, Rhode Island and Montauk Point, New York (Barlas 1999), although more recently small numbers of gray seals have been recorded in this region (R. DiGiovanni, personal communication, Riverhead Foundation, Riverhead, NY).

Gray seals are known to dive up to 300 m but typically dive 60 m or less. They feed on a wide variety of benthic and demersal prey in coastal areas. They also feed on schooling fish in the water column, and occasionally take seabirds, and a variety of molluskan invertebrates, including cephalopods (Murie and Lavigne 1992).

Gray seals are polygynous, with the males competing for females using vocalizations, threat gestures, and occasional fighting. Pupping and breeding typically occurs on rocky shores (Bonner 1981 as cited in Waring et al. 2007) between late September and early March, depending on location. From 2002 to 2006, 213 gray seals strandings were recorded from Maine to North Carolina, with the highest numbers in Massachusetts (Waring et al. 2009). Gray seal vocalizations from various sounds range in frequency from 0 to 40 Hz, with dominant frequencies ranging from 0.1 to 10 Hz (Richardson et al. 1995).

Harbor Seals (*Phoca vitulina*)

Harbor seals are nonmigratory and mainly found in the coastal waters of the continental shelf and slope, in bays, rivers, estuaries, and intertidal areas. Most harbor seal haul-out sites are used daily, based on tidal cycles, although foraging trips can last for several days (Bigg 1981). In the western North Atlantic, harbor seals are distributed from the eastern Canadian Arctic and Greenland south to southern New England and New York (Barlas 1999). Harbor seals occur seasonally along the southern New England and New York coasts from September through late May (Schneider and Payne as cited in Waring et al. 2007). In recent years, harbor seals' seasonal interval along the southern New England to New Jersey coasts has increased (deHart 2002). Their distribution is sparse in the Mid-Atlantic, but they are occasionally found hauled out on Virginia Beach in the spring and summer (Blaylock 1985). In the fall and early winter, there is a general southward movement from the Bay of Fundy to southern New England, and from mid-May to June when pupping occurs, there is movement northward to southern New England to Maine (Waring et al. 2007).

In the northeast region, harbor seals typically breed and pup in waters north of the New Hampshire/Maine border, but breeding may occur as far south as Cape Cod, Massachusetts (Waring et al. 2007). Harbor seal vocalizations range from 0.5 to 3.5 and 8 to 150 Hz, with the dominant frequency ranging from 12 to 40 Hz (Richardson et al. 1995). From 2002 to 2006, 2,160 harbor seal stranding mortalities were reported for all states from Maine to North Carolina (Waring et al. 2009).

Harp Seals (*Phoca groenlandica*)

Harp seals in the western North Atlantic are found off the coast of Newfoundland and Labrador. In recent years, however, numbers of sightings and strandings have been increasing off the east coast of the United States from Maine to New Jersey (Lacoste and Stenson 2000 as cited in Waring et al. 2007). These appearances usually occur in January to May (Harris et al. 2002). Harp seals are highly migratory, and in late September, after feeding all summer, nearly all adults and some juveniles migrate southward, extending into the Atlantic Exclusive Economic Zone (EEZ; from a state's coast out to 200 nautical miles) in the winter and spring (Waring et al. 2007). They are known to feed on a wide variety of crustaceans and fishes (Harris et al. 2002).

From 2002 to 2006, 456 strandings were reported from Maine to North Carolina (Waring et al. 2009). Harp seal vocalizations range in frequency from less than 0.1 to 16 Hz, with dominant frequencies ranging from 0.1 to 3 Hz, and source levels from 130 to 140 dB re 1 μPa at 1 m (Richardson et al. 1995).

Hooded Seals (*Cystophora cristata*)

Hooded seals can be found off the coast of Newfoundland and Labrador, preferring deeper water and occurring farther offshore than harp seals. This species is highly migratory and sightings from Maine to Florida have been increasing, usually from January to May in New England, and in the summer and fall in the southeastern Atlantic (Waring et al. 2007).

Hooded seals typically fast during breeding and molting, but actively feed during much of the rest of the year. Their diet is not well-known, but most likely includes squids and fish such as Greenland halibut, Atlantic and Arctic cod, several redfish species, herring, and capelin (Reeves and Ling 1981). From 2001 to 2005, 138 hooded seal stranding mortalities were reported in all states from Maine to North Carolina (Waring et al. 2009). Hooded seal vocalizations range in frequency from 0.1 to 6 Hz, with dominant frequencies ranging from 0.1 to 1.2 Hz (Richardson et al. 1995).

3.2 MARINE BIRDS, COASTAL BIRDS, AND BATS

The Northeast Shelf LME contains a diversity of habitats used by a wide array of bird species. Marine and coastal bird population patterns reflect habitat needs for both nesting and reproduction and for food sources (Veit and Petersen 1993). Coastal habitats can also provide overwintering and temporary feeding and resting habitat for migratory species. Patterns of habitat use by marine and coastal birds are highly dependent on food availability. The distribution and abundance of avian prey items such as invertebrates and fish can be influenced by substrate, depth, and seasonal, annual, and decadal changes in water temperature (USDOC, NOAA 1993). The fish and invertebrate resources that provide essential food sources to birds in the region are discussed in Sections 3.4 and 3.5. The physical environment of the Northeast Shelf is also critical to the ecology of birds in the region. Oceanic environments are dynamic; daily, seasonal and long-term changes in conditions occur along with periodic disturbances due to large-scale weather events such as hurricanes and northeasters. The birds utilizing the variety of marine habitats in the Northeast Shelf region are efficient at adapting to changes in their physical and chemical environment (MAS 2008).

A list of marine and coastal birds that occur in the Northeast Shelf LME is provided in Table 3.3. Several systematic bird references, including *Birds of Massachusetts* (Veit and Petersen 1993) and the *Encyclopedia of North American Birds* published by the Audubon Society (Terres 1995), give detailed accounts of bird habitats, distributions, and life cycles for the species listed in Table 3.3. In addition, the American Ornithologists' Union has an online "Check-list of North American Birds," seventh edition (AOU 2008), the Patuxent Wildlife Research Center has developed the online Patuxent Bird Identification Infocenter (Gough et al. 1998), and the Cornell Lab of Ornithology has developed The Birds of North America Online (CLO 2008); all of these sources include detailed bird species accounts and information on birds' habitats and ecology.

A number of comprehensive management and conservation plans or reviews exist of marine and coastal birds, including species that occur in the Northeast Shelf region, and have been reviewed for information relevant to development of offshore renewable energy projects in the Central and North Atlantic study area. For example, Erwin (1996) wrote an ecological profile and management plan for waterbirds and shorebirds in shallow-water habitats of the Mid-Atlantic coast. The Center for Conservation Biology created a Bird Conservation Plan for the Mid-Atlantic Coastal Plain (Watts 1999), including conservation measures and objectives along with species accounts. Also, the Manomet Center for Conservation Sciences created the National Shorebird Conservation Assessment in 2000 (Brown et al. 2000), and the Fish and Wildlife Service (FWS) wrote the U.S. Shorebird Conservation Plan (USDOI, FWS 2004) detailing those species that are considered imperiled or of high conservation concern; in addition the USFWS maintains web pages for the U.S. and Regional Shorebird Conservation Plans (USDOI, FWS 2008a). Andres (2008) summarized relevant literature for the U.S. Shorebird Conservation Plan and its goals, including species accounts and ecology. USFWS also recently issued the Mid-Atlantic/New England Maritimes Waterbird Conservation Plan (Johnston and Parsons 2008).

The North American Waterbird Conservation Plan (Kushlan et al. 2002) provides management and conservation guides for 210 species of waterbirds, seabirds, and coastal birds; this plan also has an updated website of information. The Sea Duck Joint Venture (SDJV) was formed as part of the North American Waterfowl Management Plan, and SDJV reports detail populations of 20 species of seaducks (2003). The Atlantic Seaduck Project is a website coordinating data and research between the U.S. Geological Survey (USGS), USFWS, Canadian Wildlife Service and SDJV (Perry et al. 2004). The Atlantic Coast Joint Venture (2005) created a Waterfowl

Implementation Plan with a focus area of the Mid-Atlantic including species accounts and conservation goals for waterfowl.

Table 3.3

Birds Potentially Using the Northeast Shelf LME

Common Name	Scientific Name
Gaviformes (Loons)	
Common Loon	*Gavia immer*
Red-throated Loon	*G. stellata*
Podicipediformes (Grebes)	
Horned Grebe	*Podiceps auritus*
Red-necked Grebe	*P. grisegena*
Procellariiformes (Tube-nosed swimmers)	
Northern Fulmar	*Fulmarus glacialis*
Cory's Shearwater	*Calonectris diomedea*
Greater Shearwater	*Puffinus gravis*
Sooty Shearwater	*P. griseus*
Manx Shearwater	*P. puffinus*
Wilson's Storm petrel	*Oceanites oceanicus*
Leach's Storm petrel	*Oceanodroma leucorhoa*
Pelecaniiformes (Pelicans, Gannets and Boobies)	
Northern Gannet	*Sula bassanus*
Great Cormorant	*Phalacrocorax carbo*
Double-crested Cormorant	*P. auritus*
Anseriformes (Ducks, Geese, Swans)	
Long-tailed Duck/Oldsquaw	*Clangula hyemalis*
Brant	*Branta bernicla*
White-winged Scoter	*Melanitta fusca*
Black Scoter	*M. nigra*
Surf Scoter	*M. perspicillata*
Red-breasted Merganser	*Mergus serrator*
Falconiformes (Ospreys, Hawks, Falcons)	
Osprey	*Pandion haliaetus*
Sharp-shinned Hawk	*Accipiter striatus*
Peregrine Falcon	*Falco peregrinus*
Charadriiformes (Gulls, Terns, Alcids and Shorebirds)	
Piping Plover	*Charadrius melodus*
Red Phalarope	*Phalaropus fulicaria*
Northern Phalarope	*P. lobatus*
Parasitic Jaeger	*Stercorarius parasiticus*
Pomarine Jaeger	*S. pomarinus*
Great Skua	*Catharacta skua*
Herring Gull	*Larus argentatus*
Great black-backed Gull	*L. marinus*
Glaucous Gull	*L. hyperboreus*
Iceland Gull	*L. glaucoides*
Laughing Gull	*L. atricilla*
Ring-billed Gull	*L. delawarensis*

Table 3.3. Birds Potentially Using the Northeast Shelf LME (continued).

Common Name	Scientific Name
Bonaparte's Gull	*L. philadelphia*
Sabine's Gull	*Xema sabini*
Black-legged Kittiwake	*Rissa tridactyla*
Roseate Tern	*Sterna dougallii*
Royal Tern	*S. maxima*
Sandwich Tern	*S. sandivicensis*
Sooty Tern	*S. fuscata*
Bridled Tern	*S. anaethetus*
Forster's Tern	*S. forsteri*
Arctic Tern	*S. paradisaea*
Common Tern	*S. hirundo*
Least Tern	*S. antillarum*
Black Tern	*Childonias niger*
Razorbill	*Alca torda*
Thin-billed Murre	*Uria aalge*
Thick-billed Murre	*U. lomvia*
Dovekie	*Alle alle*
Black Guillemot	*Cepphus grylle*

Sources: USDOC, NOAA 1995; USDOC, NOAA 1993; Veit and Petersen 1993; AOU 2008; ESS Group 2003

3.2.1 Threatened and Endangered Bird Species

Two species of federally endangered or threatened birds occur in the Northeast Shelf LME during at least part of their life cycle. The northeastern population of the roseate tern (*Sterna dougallii*) is listed as an endangered species, while populations of the roseate tern from other than northeastern U.S. coastal waters are listed as threatened. The piping plover (*Charadrius melodus*) is also federally listed as a threatened species. The red knot (*Calidris canutus rufa*) has been designated as a candidate for Endangered Species Act protection since 2006. A natural history profile of each of these species is provided below.

For both of the listed species, roseate tern and piping plover, increasing human disturbance and development are significant threats to their increased population. Threats include human disturbance from pedestrian and vehicular traffic; predation by animals including gulls, crows, foxes, feral dogs and cats; habitat loss or degradation; oil spills; and beach stabilization, which prevents natural coastal processes (such as overwash and breaching) that create and maintain favorable nesting habitat (Haig 1992). The suitability of feeding and brood-rearing habitat may be important in nest site selection, and storm-maintained habitats such as open vegetation, ephemeral pools, breaches, and overwash fans are especially important as brood-rearing habitat. Conservation and management actions used by state and Federal agencies include using predator exclosures, reducing disturbance from pedestrians and off-road vehicles through fencing and public outreach, and allowing for storm-maintained, open, sandy habitat (USDOI, FWS 1997).

Roseate Tern (*Sterna dougallii)*

The northeastern breeding population of roseate tern was designated as endangered on November 2, 1987, and a Recovery Plan for this population was approved in 1989, with an updated Recovery Plan issued in 1998 (USDOI, FWS 1998). Nisbet and Spendelow (1999) reviewed and summarized the twelve-year period of management and recovery of this species. Information below is taken from the updated Recovery Plan (USDOI, FWS 1998) unless otherwise cited.

The roseate tern is a medium-sized oceanic tern that is exclusively marine and breeds on either small islands or sand dunes at the end of barrier beaches. Roseate terns are usually found nesting with common terns (*S. hirundo*), although they typically select more protected areas for nesting such as dense grass clumps, or even under shelter objects such as boulders, driftwood or rip-rap. The nest may be only a depression in sand, shell or gravel, and may be lined with bits of grass and other debris. They may adopt artificial nest sites such as erosion control structures and nest boxes. One brood per season is typical, although two broods are sometimes produced.

Roseate terns feed primarily on American sand lance (*Ammodytes* spp.), a small marine fish. Roseate terns prefer to feed in clearer and deeper water than common terns and rarely feed close to the shore or in marshy inlets; however, during breeding terns forage over shallow coastal waters, relatively close to the colonies. Colony locations therefore tend to center around areas where prey fish are close to the surface such as shallow bays, tidal inlets, channels and sandbars. Most roseate terns dive from a height of less than 15 m (Spendelow 1995).

A marine coastal species that can be found worldwide, the roseate tern breeds along the coasts of the Atlantic, Pacific, and Indian oceans on salt marsh islands and beaches with sparse vegetation. In eastern North America, it breeds from the Canadian Maritime Provinces south to Long Island, although their historic breeding range extends to Virginia.

There is little information available concerning the winter distribution of this species but the North American population's winter range is believed to be from the northern coast of South America southward to eastern Brazil. The northeastern Atlantic breeding population begins its northern migration in April, returning to breeding grounds in late April or early May. Nesting begins one month later. This migration occurs offshore and not along the coastline, and birds arrive at night, circling hundreds of feet in the air before alighting in early dawn (Spendelow 1995).

Most of the northeastern Atlantic population congregates in the Nantucket Sound area in late April before individuals continue on to breeding colonies. Although information is lacking on how long individuals use the Sound before moving on, it is thought to be a period of several weeks (Spendelow 1995). Approximately 10 to 12 percent of this breeding population travels north of Nantucket Sound, nesting at various colony sites around the Gulf of Maine off the coasts of New Hampshire, Maine, and Canada (Spendelow 1995). Fall migration begins typically in September, and, reversing the spring migration, the terns fly offshore to the Caribbean and South America (Spendelow 1995).

Productivity can be limited by reductions in food availability, storm events and a suggested imbalanced sex ratio. Sex ratios among breeding roseate terns are female-biased due to differential loss of male chicks (Szczys et al. 2005). Spendelow et al. (2008) reviewed 19 years of mark-recapture/resighting data collected on 11,020 birds from 1988-2006 at five colony sites in Massachusetts, New York, and Connecticut, to examine the temporal variation in survival rates of adult roseate terns during periods of overall population increase (1988-2000) and decline (2000-2006); this review was unable to correlate the recent population decline to significant weather events or known environmental contamination spills.

Piping Plover (*Charadrius melodus*)

The Atlantic Coast population of the piping plover was listed as threatened in January 1986, at the same time that the Northern Great Plains population was listed as threatened and the Great Lakes population was listed as endangered; a recovery plan for the Atlantic coast population was completed in 1988 and revised as the *Piping Plover Atlantic Coast Population Revised Recovery Plan* (USDOI, FWS 1996). Information below is taken from the revised Recovery Plan unless otherwise cited.

The piping plover is a small shorebird that breeds only in North America, in three geographic regions (USDOI, FWS 2008b). The Atlantic Coast population breeds on sandy beaches along the east coast of North America, from Newfoundland to South Carolina. Piping plovers return to their breeding areas within the Northeast Shelf region in late March to early April, where they nest on sand and cobble coastal beaches above the high tide line, often in association with least terns (*Sterna antillarum*). Plovers feed on a variety of invertebrates in the intertidal zone, wrack line, sand and mudflats, ephemeral pools, and open vegetation. Plover chicks can forage relatively undisturbed from human activities behind the primary dune in ephemeral pools containing high prey abundance (USDOI, FWS 1997). After chicks fledge between early July and the end of August, plovers migrate south along the coast to wintering grounds from North Carolina to Mexico and into the Bahamas and West Indies (USDOI, FWS 1997).

Each year from early spring to late summer, natural resource managers from numerous local, state, Federal, and nonprofit organizations collect data on piping plovers throughout the bird's Atlantic Coast nesting range. Information is collected on the number of birds during a late spring "window census," and for the nesting season as a whole. Data are also collected on nesting "productivity," expressed as number of chicks that survive to fledging per nesting pair of adult birds. The information is compiled by state wildlife agencies and consolidated into an annual status report prepared by the Northeast Region of the U.S. Fish and Wildlife Service (USDOI, FWS 2008c). Comparison of the abundance and productivity estimates from 2006, 2007, and 2008 indicates a slight increase in the number of nesting pairs and productivity in the New England region.

Red Knot (*Calidris canutus rufa*)

The red knot is the largest of the "peeps," or sandpipers, in North America, and one of the most colorful. It makes one of the longest yearly migrations of any bird, traveling 15,000 km (9,300 mi) from its Arctic breeding grounds to Tierra del Fuego in southern South America, on wingspans of only 20 in, from south to north every spring and repeating the trip in reverse every autumn (CLO 2008).

Red knot depends for its success and the species' survival on certain conditions, one of the most important being the continued availability of billions of horseshoe crab eggs at major North

Atlantic staging areas, notably the Delaware Bay and Cape May peninsula. The increase in taking of horseshoe crabs for bait in commercial fisheries that occurred in the 1990s has been a major factor in the decline in red knots. Another condition important for red knots' survival is the continued existence of middle- and high-arctic habitat for breeding; red knots could be particularly affected by global climate change, which may be greatest at the latitudes where this species breeds and winters (CLO 2008).

Although currently the USFW acknowledges the need to protect the red knot, they have not proposed the bird for protection under the Act due to the strong conservation actions initiated by the states of New Jersey and Delaware, which have reduced threats to red knots at their migratory stopover in Delaware Bay. Red knot populations recorded at their migratory stopovers and at their South American wintering grounds have remained stable since 2005 (USDOI, FWS 2006).

3.2.2 Non-Endangered Bird Species

In discussing seabirds, most literature divides these birds into two broad categories, coastal birds and marine birds, based on the habitat they use for the majority of their life cycles, although references may vary on some of the genus groupings. Coastal birds use the coastal and nearshore habitats such as beaches, sand and mud flats, and vegetated tidal marshes. For the purposes of this literature review and synthesis, “coastal birds” includes both resident species, which spend their full life cycle within the region, and transitory species, which migrate along the coastline on a seasonal basis. Birds that spend their entire lives in areas that are traditionally associated with coastal zones such as wetlands and upper estuaries but are above the high tide line are not included in this study; this includes wading birds such as herons and egrets and most passerine species. Morrison et al. (2006) developed population estimates for most species of North American shorebirds in 75 taxa. “Marine birds” are those birds that spend most of their lives on the open water of the ocean, coming to land only to breed or avoid severe environmental conditions (AOU 2008; Schreiber and Burger 2001). Marine birds often concentrate in nutrient-rich upwelling areas such as the western edge of the Gulf Stream off Cape Hatteras, North Carolina (USDOI, FWS 1997). This group is composed of members of several different bird families, and may be broadly lumped into two subgroups based upon distribution: a nearshore group, which is common within about 3 mi of land and which includes the sea ducks, loons, grebes, gulls and terns, although species within this subgroup may be found in offshore waters on occasion (Veit and Petersen 1993); and a pelagic or oceanic group that generally occurs farther offshore, out of sight of land, and includes such species as petrels, shearwaters, fulmars, gannets, phalaropes, skuas, kittiwakes, jaegers and auks (AOU 2008; CLO 2008).

Coastal Birds

Coastal birds are those species that are migratory and use estuaries and freshwater habitats for breeding, summering, and wintering (Howe et al. 2000). The Massachusetts Audubon Society (MAS) Coastal Waterbird Program has a detailed website with information on coastal birds of New England that includes most species expected to be found within the Northeast Shelf LME (MAS 2008). Plovers (Family Charadriidae), sandpipers (Family Scolopacidae), avocets (Family Recurvirostridae) and oystercatchers (Family Haematopodidae) are common shorebirds. Depending on food preferences, species use a variety of habitats including mudflats, marshes, sandy, pebbly or cobbly beaches, and the rocky coast. Species richness and abundance are typically highest at low tide during late summer to early fall, corresponding to the overlap between the summer and year-round residents and the autumn migration of birds that winter along the shores. Coastal bird diets consist mainly of polychaetes, amphipods and mollusks obtained from tidal flats, intertidal rocks, and shallow subtidal bottoms (Veit and Petersen 1993).

Marine Birds

Approximately 30 species of marine birds (see Table 3.3) can be found within the Northeast LME belonging to the following families: Procellariidae (Shearwaters, Fulmars, Petrels); Sulidae (Gannets and Boobies); Hydrobatidae (Storm-Petrels); Laridae (Gulls, Terns, Skuas and Jaegers); Alcidae (Auks, Murres, Guillemots, Murrelets, and Puffins); Gaviidae (Loons); Phalaropodidae (Phalaropes); Phalacrocoracidae (Cormorants); and Podicipedidae (Grebes). Many of the species that are more commonly observed in offshore waters may also occur within waters landward, and similarly there are several species that are considered common in coastal areas that may occasionally be found in offshore waters, such as scoters and long-tailed duck (USDOC, NOAA 1993; USDOI, MMS 2009).

Marine birds are not evenly distributed in space or time, and concentration areas, species composition, and densities of nonbreeding birds shift seasonally, depending upon the distribution of migration habitats and food resources.

Nearshore Marine Birds

Loons, cormorants, grebes, gulls, and terns, although typically grouped as marine birds due to their limited use of coastal habitat, can also be found nearshore. With the exception of gulls and terns, these birds are usually not found during the summer but they range from rare to locally common during the winter (Veit and Petersen 1993). Species including common loon (*Gavia immer*), red-throated loon (*G. stellata*), horned grebe (*Podiceps auritus*) and red-necked grebe (*P. grisegena*) (Veit and Petersen 1993; USDOI, MMS 2009) feed on fish they catch while diving in open waters in either nearshore (littoral) or offshore zones. Double-crested cormorants (*Phalacrocorax auritus*) and great cormorants (*P. carbo*) can be present throughout the year but the former are most abundant in the summer and the latter are most abundant in the winter. Gulls can include herring (*Larus argentatus*), great black-backed (*L. marinus*), glaucous (*L. hyperboreus*), Iceland (*L. glaucoides*), laughing (*L. atricilla*), ring-billed (*L. delawarensis*), Bonaparte's (*L. philadelphia*) and Sabine's gulls (*Xema sabini*); and common (*Sterna hirundo*), Arctic (*S. paradisaea*), roseate (*S. dougallii*) and least terns (*S. antillarum*; USDOC, NOAA 1995).

Pelagic Birds

Pelagic birds include those typically referred to as marine or seabirds (USDOC, NOAA 1995). Such species can include loons, shearwaters, fulmars and storm petrels, kittiwakes, gannets, phalaropes, alcids and jaegers, skuas, and terns (USDOI, MMS 2009). These species spend most of their lives on the open oceanic waters and come to land for breeding only. Foraging habitat for marine birds can be widespread and diffuse. Due to the large expanse of shallow coastal shelf in the northeast region, divers and surface feeders may disperse over a great distance. Nearshore birds may cross waters far off the coast to feed, while typically offshore species can roam close to the coast to do the same. Typically, pelagic species feed primarily on fish and marine invertebrates, which may be picked off the water surface or obtained by diving and plunging. They can spend up to 90 percent of their lives at sea and typically migrate to follow the seasonal abundance of a distinct group of prey. They are necessarily tied to land to reproduce but can travel significant distances to do so. The distribution and abundance of pelagic birds are variable and can be loosely associated with the availability of food items (USDOC, NOAA 1995).

Seasonality and Abundance

In the summer, when many species of coastal and marine birds are on their breeding grounds, relatively low densities and species diversity would be observed within the waters of the Northeast Shelf LME. Nonetheless, localized concentrations of birds can be found foraging on coastal fish and invertebrates throughout the summer season. Shearwaters and storm-petrels are the most abundant pelagic birds in the northeast region during summer, with species such as the greater shearwater (*Puffinus gravis*), sooty shearwater (*P. griseus*), and Wilson's storm-petrel (*Oceanites oceanicus*) breeding in the southern hemisphere and spending much of their nonbreeding period in the North Atlantic (USDOC, NOAA 1993; USDOC, NOAA 1995). Other pelagic birds such as the Manx shearwater (*P. puffinus*) and Leach's storm-petrel (*Oceanodroma leucorhoa*) breed in the North Atlantic and migrate through the Northeast Shelf region in the summer and fall (USDOI, MMS 2009). Gulls and terns that nest on beaches and islands within the region feed on fish and marine invertebrates in the nearshore and offshore waters as well as bays and estuaries.

The most common coastal and marine birds migrating through the Northeast Shelf LME in the fall and spring include shearwaters, petrels, gannets, phalaropes, and jaegers. Substantial numbers of waterfowl, especially sea ducks, also move into and migrate through the region in the fall (USDOC, NOAA 1993). During the winter months, moderate densities of birds are observed dispersed over the entire continental shelf. Species such as kittiwakes, skuas, gannets, and auks occur in the offshore waters of the northeast region, while coastal waters are dominated by gulls, sea ducks, loons, and grebes (these species may also occur in offshore waters, but at lesser densities). The black-legged kittiwake (*Rissa tridactyla*) is one of the more common pelagic birds in the open waters during the fall, winter, and spring, while three species of alcids or auks, including the razorbill (*Alca torda*), dovekie (*Alle alle*), and thick-billed murre (*Uria lomvia*), are regularly observed at low densities during the winter. Two species of loons, common loon (*Gavia immer*) and red-throated loon (*G. stellata*), migrate through and winter in the northeast region. Sea ducks, including the black, white-winged, and surf scoters (*Melanitta nigra*, *M. fusca*, and *M. perspicillata*), as well as the long-tailed duck (*Clangula hyemalis*) are widely distributed in low numbers in the coastal and offshore waters. Two species of gulls, the herring gull (*Larus argentatus*) and great black-back Gull (*L. marinus*) are abundant in winter in the bays, coastal waters, and offshore waters (USDOC, NOAA 1993).

The highest densities of seabirds in the Northeast Shelf region occur in the spring on the Outer Continental Shelf near the shelf break. During the late winter and spring, these waters are well-mixed and fish and invertebrates associated with the upwelling of nutrient-rich waters along the shelf break provide an abundant food source for pelagic birds. Pelagic birds migrating through in the spring may include many of the same species that migrate in the fall, such as fulmars, skuas, gannets, petrels, phalaropes, and jaegers (USDOI, MMS 2009).

Specific Study Area Information

The transient and transitory nature of many species of marine and coastal birds makes it difficult to study their life in entirety, and in fact many species have little available data on their life history, populations, and historical trends. However, there are several regions of the Northeast Shelf LME that provide significant sources of bird data. For example, locations of proposed offshore projects like the waters off the coast of Cape Cod, Massachusetts, have received site-specific attention. Also, areas of Federal or state protection such as the Stellwagen Bank National Marine Sanctuary, and regions with natural boundaries for study such as the New York Bight or the Gulf of Maine, have also received special attention from researchers.

Stellwagen Bank and the adjacent Stellwagen Basin are included in the Stellwagen Bank National Marine Sanctuary (SBNMS), which is protected via Federal regulations. Stellwagen Bank is approximately 118 square mi and contains a strong upwelling zone along the edge of the bank that provides a zone of high productivity in an otherwise nutrient-limited region of the Gulf of Maine. The SBNMS Site Characterization Report (USDOC, NOAA 1995), the SBNMS Management Plan (USDOC, NOAA 1993) and the SBNMS Draft Management Plan and Environmental Assessment (USDOC, NOAA 2008) each provides a list of offshore birds that may potentially be found in the region and highlights potential threats to the populations it describes. Species that would be affected by potential offshore alternative energy projects are thought to constitute a subset of this list.

The Cape Wind Energy Project (CWEP) has been proposed for Horseshoe Shoal in Nantucket Sound, south of Cape Cod. The Draft Environmental Impact Statement and all of its associated appendices and attachments can be found online (USDOI, MMS 2009). In association with this proposed project, Cape Wind Associates conducted several aerial and boat surveys of Nantucket Sound, Cape Cod, and Horseshoe Shoal (Perkins et al. 2003); these surveys were compared to data from Massachusetts Department of Environmental Management – Division of Wildlife (MassWildlife)/U.S. Fish and Wildlife Service (USFWS) winter waterfowl inventory and the National Audubon Society Christmas Bird Count (CBC) data over a 13-year period (USDOI, MMS 2009; ESS Group 2003).

Additionally, the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service (NMFS) in coordination with Manomet Bird Observatory (currently the Manomet Center for Conservation Sciences) conducted a Cetacean and Seabird Assessment Program (CSAP) in shelf and shelf-edge waters of the northeastern United States from 1980 to 1987. Observations were made from research vessels conducting standardized surveys (MBO 1987).

Erickson and Meegan (2007) and Erickson et al. (2007) reported on overwintering waterfowl and then summarized data collection efforts to provide a regional view of waterfowl populations within the Atlantic flyway and Northeast North Carolina as a supplement to an EIS for the U.S. Navy Outlying Landing Field (OLF). Geo-Marine (2006) conducted initial avian radar monitoring at the proposed location of the project.

3.2.3 Use of Atlantic Coast Habitats by Migratory Birds

A majority of the Northeast Shelf region is located within the Atlantic flyway. The Atlantic flyway extends from the offshore waters of the Atlantic Coast west to the Allegheny Mountains where, curving northwestward across northern West Virginia and northeastern Ohio, it continues across the Canadian prairie provinces and the Northwest Territories to the Arctic Coast of Alaska (Figures 3.3 and 3.4). The coastal route of the Atlantic flyway, which in general follows the shoreline, has its northern origin in the eastern Arctic islands and the coast of Greenland. The coastal islands and shores contained within the region are important migratory stopovers for coastal birds, seabirds, raptors, and passerines traveling along the Atlantic coast between northern habitats in New England, Canada, and the Arctic and southern habitats in tropical and subtropical areas of the Americas (Figures 3.3 and 3.4) (USDOI, MMS 2009). Approximately 50 different species of landbirds that breed in New England follow coastal routes during southern migrations in the fall (AOU 2008). During spring and fall migrations the varied habitats provided in the North and Central Atlantic are used for resting and foraging. In addition to landbirds, species migration can include marine or coastal birds migrating from summer breeding habitats, in the northern latitudes, to overwintering habitats in tropical or subtropical regions. Other migration routes are due to overwintering of inland birds, such as those species that come from the Great Plains to utilize the warmer waters off the Atlantic coast.

Several comprehensive books and websites cover the ecology and life history accounts of the land, coastal, and marine birds that may migrate through the Northeast Region. These include: *Birds of Massachusetts* (Veit and Petersen 1993); the *Encyclopedia of North American Birds* published by the Audubon Society (Terres 1995); the American Ornithologists' Union online Check-list of North American Birds, Seventh edition (AOU 2008); the online Patuxent Wildlife Research Center Bird Identification Infocenter (Gough et al. 1998); and the Cornell Lab of Ornithology's *The Birds of North America Online* (CLO 2008). Berthold et al. (2001) wrote *Bird Migration,* providing a comprehensive and scholarly approach to bird migration. Also, the South Atlantic Migratory Bird Initiative Implementation Plan (Watson and Malloy 2006) discusses protection of birds from all habitats and includes species information in relation to migrating birds and their patterns of flight.

Waterfowl

The flyway embraces several primary migration routes important to waterfowl, some being branches from primary routes of other flyways. The Atlantic flyway route from the northwest is of great importance to migratory waterfowl such as canvasbacks, redheads and lesser scaups that winter on the waters and marshes south of Delaware Bay (Watson and Malloy 2006). The coastal section of the flyway passes directly over the Atlantic Ocean from Labrador and Nova Scotia to southern regions as far as the mainland of South America. This flyway is used by thousands of water birds and shorebirds of several species, such as Canada geese (*Branta canadensis*), tundra swan (*Cygnus columbianus*), loons, and sandpipers. In the autumn, some of

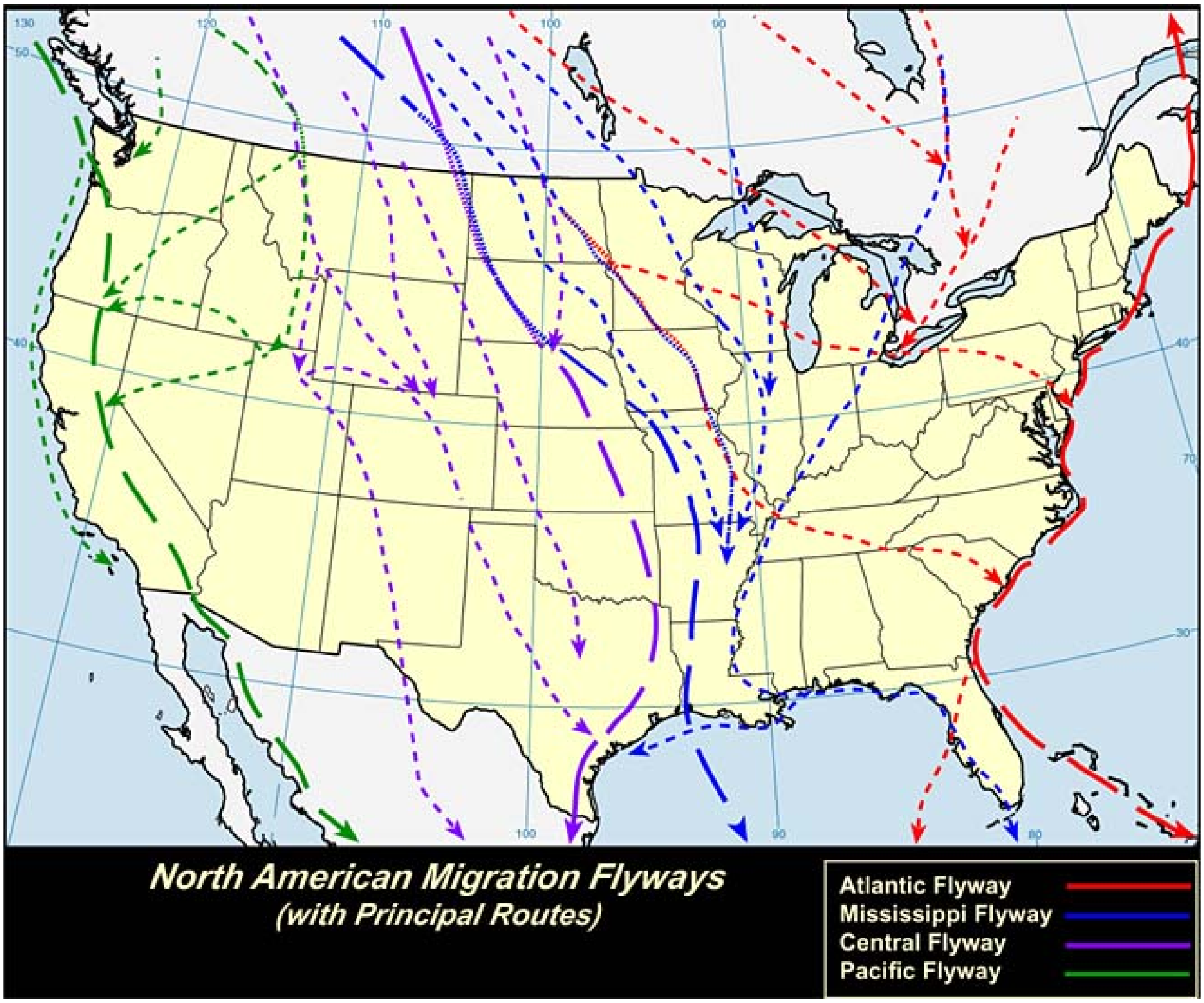

Figure 3.3. North American migration flyways showing the Atlantic flyway within the northeast region. (Source: Birdnature 2009). Used by permission.

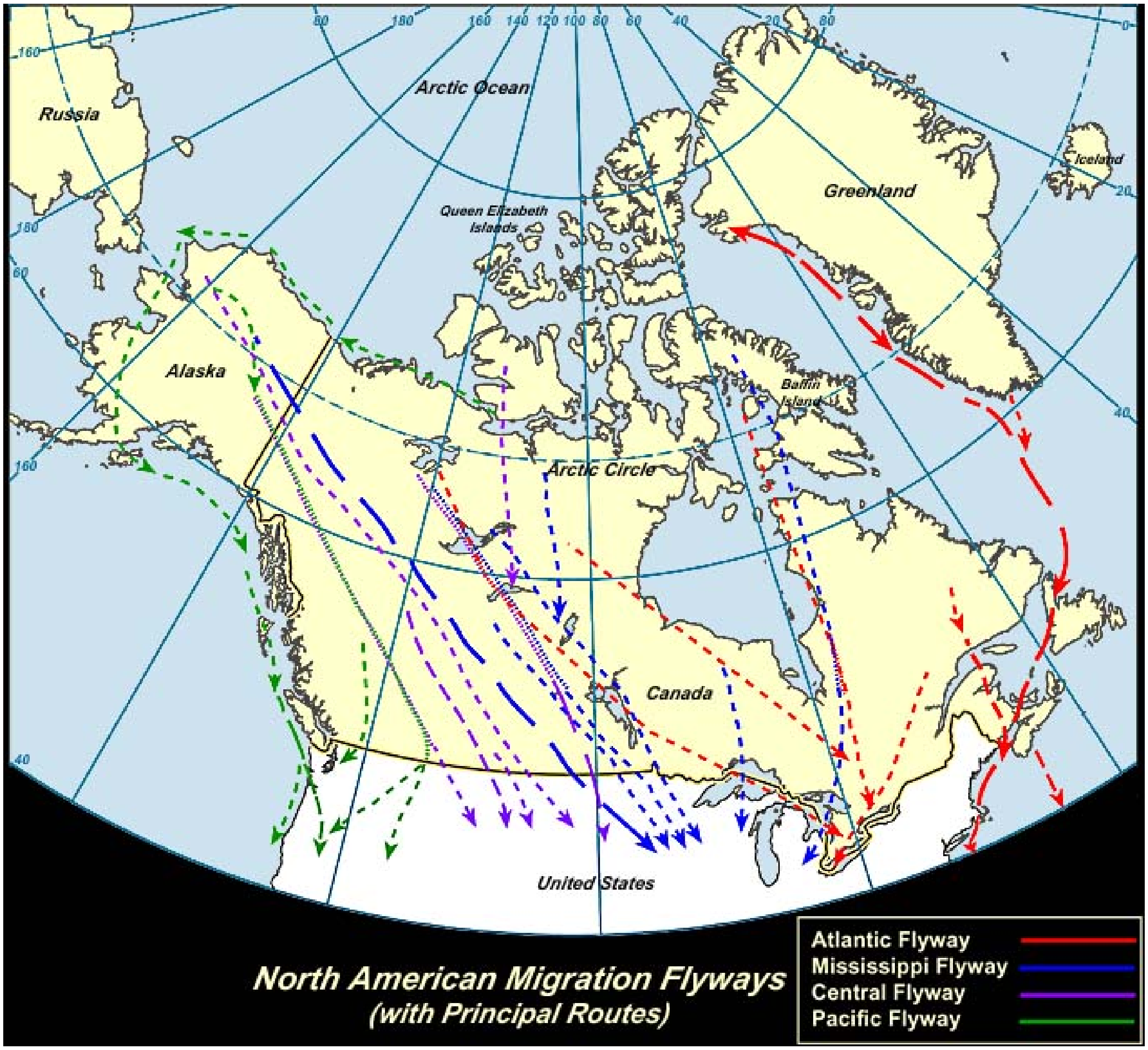

Figure 3.4. North American Migration Flyways, Northern View, showing the Atlantic Flyway within the Northeast Region. (Source: Birdnature 2009). Used by permission.

the shorebirds that nest on the Arctic tundra of Mackenzie and Alaska (e.g., American golden-plover, *Pluvialis dominica*) fly southeastward across Canada to the Atlantic coast and finally follow this oceanic course to the mainland of South America. The Allegheny Mountain/Plateau system, originating in New York and extending southwest to Virginia, includes a number of parallel ridges that provide a migratory barrier for birds along the U.S. east coast. These mountain ridges form the dividing line between the Atlantic and Mississippi flyways such that migratory waterfowl that breed east of this system utilize the Atlantic flyway (AOU 2008).

Species that overwinter or migrate through the North Atlantic states are recorded annually by the Division of Migratory Bird Management (USDOI, FWS 2008d). Species observed during the 2007-2008 Waterfowl Mid-Winter Survey include a variety of dabblers (mallards, black ducks), divers (redheads, canvasbacks, scaup, goldeneye, bufflehead), sea ducks (eiders, scoters), ducks (mergansers), and geese (brant, Canada geese).

Passerines

A substantial portion of the land bird population of North America consists of neotropical and regional passerines that migrate annually. Many of these songbirds migrate at night when collision with wind turbines may be more likely due to lower visibility. Examples of nocturnal migrating passerines that have been killed during collision with on-land wind facilities include warblers, vireos, swallows and thrushes (Erickson et al. 2001). The extent to which migrating passerines fly over open waters of the Northeast Shelf region is not well known (USDOI, MMS 2009). Only three birds (two swallows and one American goldfinch) were observed during boat-based surveys for the Cape Wind project in Nantucket Sound (USDOI, MMS 2009). Evidence that migrating songbirds concentrate in coastal areas during migration and stopover is largely anecdotal; little information exists to support this concept and there is little existing data on the numbers of migrating passerines along the Atlantic Coast (USDOI, MMS 2009). Nonetheless, some Neotropical migrant species, such as wood warblers (family Paurlidae) may make substantial water crossings during nocturnal migration, while other species that migrate in coastal areas may be blown offshore during weather events (USDOI, MMS 2009).

The highest concentrations of migrating birds in the northeast region have been noted to occur during fall and spring (September through October and April through May). They are known to travel over a broad front, as opposed to narrow streams, and can be seen at varying altitudes. Birds that have been noted migrating south or west-southwest across the northeast coastal region include such nocturnal bird migrants as thrushes, cuckoos, swallows, wood warblers, and sparrows (Tingley 2003). Estimates vary in the number of individuals, but radar studies conducted during analysis for the Cape Wind project placed the numbers as high as a few million (USDOI, MMS 2009). Although these studies were targeted at the Cape Cod area, there are few other sources of information on offshore migration; thus the results of these studies offer some trends that should be noted: Median flight heights observed during the day were lower than those observed at night across all seasons and years; a greater percentage of individuals were flying at altitudes lower than that of the proposed maximum wind turbine height during the day than during the night; the majority of nocturnal migrants are Neotropical songbirds whose flight heights over land are typically at higher altitudes than are those of waterbirds that typically migrate during the day; and visual and aerial observations within the Cape Cod area noted very few songbirds or similar passerines during visual and aerial surveys, as was expected since most songbirds migrate at night (USDOI, MMS 2009).

Raptors

With the exception of foraging or migrating osprey (*Pandion haliaetus*) or peregrine falcons (*Falco peregrinus*), raptors do not utilize offshore habitat (USDOI, MMS 2009). The Hawk Migration Association of North America (HMANA) provides data online on migration and life history of 33 North American raptor species (HMANA 2008). The group also organizes migration surveys and counts that are conducted by volunteers. According to observation data from this website, both osprey and peregrine falcons can be seen migrating along the Atlantic coast. Osprey nest in coastal areas on trees or anthropogenic structures such as electrical towers and telephone poles. This species feeds primarily on live fish and can forage offshore (CLO 2008). Peregrine falcons have one of the longest migrations of any North American bird, with some birds flying from Alaska to Argentina, a round trip of 15,000 mi; these falcons are observed migrating along topographic ridges mostly in late September and early October, returning north in late February and March. However, migration patterns for this species vary since southern birds migrate only short distances and some may not migrate at all. Peregrine falcons nest in cliffs or high dwellings such as tall city buildings (CLO 2008).

3.2.4 Bats

The migratory behavior of some bat species may place them at risk of colliding with offshore structures, such as boats or wind towers (Johnson 2004; Johnson and Arnet 2004; USDOI, MMS 2009). However, for the Northeast Shelf region, there is little information to confirm or refute this. Limited information exists on the use of offshore aerial habitat by bats. The Cape Wind FEIS (USDOI, MMS 2009) details the limited scope of such information and provides the few citations listing those records of bat sitings in offshore waters. To date, no studies have been conducted with the goal of obtaining a visual, auditory, or physical observation of bats in offshore waters, and no studies have occurred that track migrating patterns of bats along the East Coast (USDOI, MMS 2009).

Although considerable variation exists in migratory behavior, North American migratory bats can be categorized into two general groups: long-distance and short-distance migrants. Regardless of migration strategy, individuals undergo such movements twice per year: once when leaving wintering ground for summering areas, and again for the return trip from summer to wintering grounds. Most species of North American temperate bats migrate relatively short distances (less than 1,000 km) between summer habitat areas and regional caves, mines, and other suitable structures that serve as hibernation sites during late fall through early spring. Species such as little brown bat (*Myotis lucifugus*), northern long eared bat (*M. septentrionalis*), and big brown bat *(Eptesicus fuscus)* are short-distance migrants. Long-distance migratory bats, primarily ‘tree bats,’ such as the eastern red bat (*Lasiurus borealis*), hoary bat (*L. cinereus*), eastern pipistrelle (*Perimyotis subflavus*), and the silver-haired bat (*Lasionycteris noctivagans),* can migrate up to 1,300 km between winter and summer habitat areas and can migrate in waves across a landscape within a relatively short time period (Cryan 2003). Historic museum records of migratory bats in North America suggest some tendency of tree bats to migrate along the Atlantic coast, especially during the fall; however, these records should be viewed in light of the historic decline in overall bat populations (USDOI, MMS 2009; Cryan 2003). Eastern red bats in the northern United States and Canada migrate in the fall southward and have been observed flying over the Atlantic Ocean (TPWD 2009).

Although most bat species do not migrate over the coast or open waters of the North Atlantic, some migrating bats that follow the coastline may take shortcuts over water and can occasionally be blown out to sea. A report on translocation of bats (Constantine 2003) noted North American migrant bats such as hoary bats, eastern red bats, Seminole bats *(L. seminolus*), and silver-haired bats have been found in Bermuda, 1,046 km east of North Carolina, United States, during fall and spring migrations, having been blown there by wind along with waves of migratory birds. Hoary bats are occasionally found in Iceland, also possibly blown there by the wind. A hoary bat was captured in the Orkney Islands, off the coast of Scotland. This report also included data describing exhausted bats flying over the ocean, both individually and in flocks, that have been reported to land on ships and be carried to unintended destinations. Records from the North Atlantic Ocean include eastern red bats and silver-haired bats. In addition, bats can roost in or on ships in port and may be transported as a consequence. Silver-haired bats have been discovered hibernating in hulls of ships and yachts in New York. Little brown bats roosted aboard a ship that frequently traveled from Canada to Europe, flying ashore after arrival in the Netherlands and England (Constantine 2003).

Concern has developed over reports of higher-than-expected numbers of bat collisions with onshore wind turbines. Johnson and Arnet (2004) wrote an important annotated bibliography of bat interactions with onshore wind turbines which includes information on habitat and migration of many bat species. The American Wind Energy Association and The American Bird Conservancy issued several reports reviewing bat impacts at wind parks (Johnson 2004; Kunz 2004) including site data from several wind parks; within these reports is information, albeit limited, about the species of bats that were impacted and their migrating behavior. A review of bat migration and behavior is provided by Kunz et al. (2007) and Bat Conservation International, a group that manages a website with detailed species accounts and migration patterns where known.

Threatened or Endangered Bat Species

Three species of federally endangered bats have the potential to use the terrestrial habitats that border the Northeast Shelf LME during at least part of their life cycle: the gray bat (*Myotis grisescens*), the Indiana bat (*M. sodalis*) and the Virginia big-eared bat (*Plecotus townsendii virginianus*); there are no federally threatened bat species that utilize habitat along the Atlantic coast (USDOI, FWS 2008e). It is unlikely that any of these species would use aerial habitat in offshore waters.

3.3 SEA TURTLES

Sea turtles are highly migratory marine reptiles that have a wide geographic range in tropical, subtropical, and temperate waters. Sea turtles often migrate for long distances to feeding, mating, and nesting grounds (Miller 1997). Marine turtles utilize the whole water column, floating for short periods on the sea surface to rest after feeding at depth (Thompson 1988). They spend most of their lives in the water, except when females go ashore to nest, digging holes in sandy beaches, where they lay tens to hundreds of eggs (Miller 1997). Information on feeding, migration, and hatchlings leaving the nesting beach is provided because it is during these activities and life stage that sea turtles are most likely to be impacted by offshore energy project activities.

There are five species of sea turtles that may occur in the waters of the North and Central Atlantic Region: loggerhead, Kemp's ridley, green, hawksbill, and leatherback. All five species are federally listed as threatened or endangered (Table 3.4). A natural history profile for each of these species is provided in the following sections.

Table 3.4

Federal Status of Sea Turtles in the North and Central Atlantic

Common name	Scientific name	Status
Green	*Chelonia mydas*	T
Hawksbill	*Eretmochelys imbricata*	E
Kemp's ridley	*Lepidochelys kempii*	E
Leatherback	*Dermochelys coriacea*	E
Loggerhead	*Caretta caretta*	T

T = Threatened, E = Endangered

3.3.1 Green Sea Turtle (*Chelonia mydas*)

Distribution

Green turtles are globally distributed, occurring throughout tropical, subtropical, and to a lesser extent, temperate waters (USDOC, NMFS 2008). Although information for this species is limited, they are known to use three habitat types: oceanic beaches for nesting, convergence zones in the open ocean for juvenile development, and benthic feeding grounds in coastal areas. Their preferred habitats in coastal areas are inlets, bays, and estuaries (Carr 1986).

Information on juveniles during the oceanic phase (where they occur and for how long) is lacking; the juvenile oceanic phase is one of the most poorly understood aspects of green turtle life history. Green turtles are very slow growing (less than 1 cm to more than 5 cm per year), and take the longest of any sea turtle species to reach maturity (ranging from less than 20 to 40 years or more; USDOC, NMFS and USDOI, FWS 1991). Subadult green turtles migrate northward from Florida in the spring to the Mid-Atlantic, where they are occasionally observed feeding in the late summer on seagrass beds in Chesapeake Bay and along the shores of Long Island. In the fall, they return to Florida waters. Nesting on beaches can occur as far north as North Carolina (Thompson 1988).

Although green turtles are extremely rare in northern waters, a confirmed sighting of a live green turtle was made in Chedabucto Bay, Nova Scotia, in August 1999, and a highly unusual confirmed hybrid green and loggerhead turtle was observed in St. Margarets Bay, Nova Scotia, in October 2001 (James et al. 2005). James et al. (2005) questioned whether the above-recorded reports represent accidental occurrences of green sea turtles in Nova Scotian waters or observations of small numbers of this species that regularly forage along the Scotian Shelf in summer and early fall.

Diet and Feeding

Post-hatchling, pelagic-stage green turtles are omnivorous until they enter the benthic feeding grounds, at which time they become herbivores. Green turtles are the only herbivorous marine turtle (Bjorndal 1997). Green turtles may venture as far north as the New York Bight and New England in small numbers during the summer, where some become cold-stunned each year by falling water temperatures in the fall and winter. The USDOI, FWS (1997) estimates that each year during summer months at least 100 green sea turtles use the New York Bight region for foraging. These turtles range widely in size, indicating a variety of age classes. Their distribution is related to available submerged aquatic vegetation food sources such as *Ulva* and *Codium* spp. (USDOI, FWS 1997).

Threats

Potential threats to green turtles include bycatch in trawls, dredging, ingestion of marine debris or oil, ship and propeller strikes, and underwater noise (USDOC, NMFS 2008). Additionally, the accumulation of oil, Styrofoam, and other plastic debris within floating rafts of the brown algae *Sargassum* spp. may also impact these turtles (NYDEC 2008).

3.3.2 Hawksbill Sea Turtle *(Eretmochelys imbricata)*

Distribution

Hawksbill turtles typically occur in tropical and subtropical waters. They can be found along the eastern seaboard from Florida to Massachusetts, but sightings north of Florida are rare (USDOC, NMFS and USDOI, FWS 1993). Within the Mid-Atlantic waters, there are few records to indicate that this species is anything but a rare or anomalous visitor to the New York Bight area (USDOI, FWS 1997). Hawksbill turtles prefer habitats consisting of warm, coastal shoal water less than 15 m deep with abundant submerged vegetation and coral reefs, lagoons, inlets, and bays.

Diet and Feeding

When they enter shallow coastal waters and begin feeding on the bottom, hawksbill turtles are omnivorous, eating primarily sponges, but also algae, sea grasses, soft corals, crustaceans, mollusks, jellyfish, and sea urchins (USDOC, NMFS and USDOI, FWS 1993). As subadults and adults, they have been observed eating various species of sponges, using their pointed beaks to extract invertebrate prey from reef crevices and rock outcroppings (Bjorndal 1997).

Threats

Potential anthropogenic impacts to the hawksbill turtle include bycatch in trawls, dredging, ingestion of marine debris or oil, ship and propeller strikes (especially when cold-stunned), and underwater noise (USDOC, NMFS and USDOI, FWS 1993; USDOC, NMFS 2008).

3.3.3 Kemp's or Atlantic Ridley Sea Turtle *(Lepidochelys kempii)*

Distribution

The Kemp's ridley turtle, which can be found from the Gulf of Mexico north to New England waters, is the most endangered sea turtle in the western North Atlantic (Thompson 1988). They can be found in North Carolina and Virginia in April and May respectively (Morreale and Standora 2005). In the summer and early fall, they come into New York and New England bays and estuaries (Morreale and Standora 2005). They are known to forage as far north as the Gulf of Maine during the summer, returning to Florida in the fall and winter. Kemp's ridley turtles annually strand along the northeast U.S. coast in significant numbers in the late fall (Thompson 1988). Juveniles prefer shallow, sheltered, sandy, and muddy areas along the coast and are found in bays, coastal lagoons, and river mouths (USDOC, NMFS and USDOI, FWS 1992).

In a recent study, the Kemp's ridley was found to be the most abundant species of sea turtle along the shores of New York (CTDEP 2008), where a significant number of the estimated surviving population of 100 to 300 individuals use the New York Bight annually in their development cycle. In 1993, the New York State Department of Environmental Conservation identified Long Island Sound as critical habitat for immature Kemp's ridley turtles, providing important habitat for development during the early stages of life (2 to 5 years; NYDEC 2008). These juveniles are commonly found in the eastern part of New York Bight from June to October.

Diet and Feeding

In waters of the Northeastern Shelf, Kemp's ridleys feed primarily on green crab (*Carcinas maenas*) and spider crabs (*Libinia* spp.), consuming large quantities and doubling their weight in less than five months.

Threats

Threats to Kemp's ridley turtles include bycatch in trawls, anthropogenic noise, propeller or vessel strike, oil spills, ingestion of marine debris, incidental take during dredging activities, degrading water quality/clarity, and altered current flow (USDOC, NMFS 2008).

3.3.4 Leatherback Sea Turtle *(Dermochelys coriacea)*

Distribution

In the western Atlantic, leatherback turtles range from Newfoundland to Argentina, occupying both nearshore and offshore waters (USDOC, NMFS 2008; James et al. 2005). Leatherbacks are known to nest on beaches in the tropics and subtropics, and to forage in higher latitude waters.

A tagging study of 38 leatherbacks off Nova Scotia during 1999 through 2003 found that some of these turtles' movements were concentrated in the waters off eastern Canada and the northeast United States in June through December, although most turtles leave the area for the southward migration during October (James et al. 2005). Leatherback turtles can be found from Nantucket out to the 200-mile limit north to Canadian waters (James et al. 2006; Thompson 1988). The leatherback is a common species in the New York Bight from May through November, where adult and large juveniles can be found feeding in near-coastal areas, but rarely in the bays or lagoons.

Diet and Feeding

Leatherbacks are pelagic feeders, foraging throughout the water column on gelatinous organisms such as jellyfish, tunicates, comb jellies, and salps. Feeding has been directly observed at the surface, but evidence of feeding at depth comes from nematocysts from deepwater jellyfish (siphonophores) that have been found during the examination of stomach contents (USDOC, NMFS 2008). Grant et al. (1996 as cited in USDOC, NMFS 2008) found a correlation between jellyfish and leatherback presence in the nearshore waters off North Carolina.

Threats

Anthropogenic threats to leatherback populations include bycatch in trawls; underwater noise; collisions with vessels and injuries from their propellers; entanglement at sea with ropes and cables deployed in a variety of activities; and ingestion of marine debris, especially plastic bags, plastic and styrofoam pieces, and tar balls (USDOC, NMFS 2008).

3.3.5 Loggerhead Sea Turtle (*Caretta caretta*)

Distribution

Loggerhead sea turtles are the most abundant sea turtles occurring in U.S. waters and are highly migratory, ranging from Newfoundland to Argentina (USDOC, NMFS and USDOI, FWS 1991). Loggerheads are widely distributed within their range and may be found hundreds of miles offshore as well as inshore in bays, lagoons, creeks, ship channels, and mouths of large rivers (USDOC, NMFS and USDOI, FWS 1991). In the spring, these turtles are found in high concentrations along the Florida coast (Thompson 1988). Loggerheads then migrate northward along the coastal United States in the summer and early fall, moving as far north as the Gulf of Maine and as far east as Georges Bank. In the late fall and winter, they return to more southern waters in the southeastern United States and Gulf of Mexico. Migration routes between foraging grounds and nesting grounds for a portion of the population are restricted to the continental shelf.

Significant nesting assemblages can be found as far north as North Carolina. During the nesting season, females come ashore and lay several times, in several nests during a single season; the eggs will incubate for approximately two months. In mid-May to mid-August, juvenile loggerheads will hatch and leave the nest and may linger for months in the waters just off the nesting beach, or become transported by ocean currents within the western North Atlantic (USDOC, NMFS 2008). Once offshore, they can live among Sargassum rafts in the North Atlantic gyre for as long as 10 to 12 years. Juveniles between 7 and 12 years of age migrate to nearshore coastal areas, where they feed on benthic organisms. Juvenile loggerheads occupy coastal feeding grounds for a decade or more before becoming mature and making their first reproductive migration (USDOC, NMFS and USDOI, FWS 1991). The predominant foraging areas for adult loggerheads in the western North Atlantic are within the relatively shallow U.S. continental shelf waters (USDOC, NMFS 2008).

While sea turtles spend the majority of time below the surface, they sometimes spend as much as 19 to 26 percent of their time at the surface, engaged in surface basking, feeding, orientation, and mating (Lutcavage and Lutz 1997), as well as making brief visits to the surface to breathe.

Diet and Feeding

Pelagic stage juvenile loggerheads are carnivorous, feeding opportunistically on small prey living within the Sargassum weeds. More than 75 percent of the diet of subadult loggerheads feeding in Long Island waters during summer was found to consist of crabs, particularly spider crabs (*Libinia* spp.) and Atlantic rock crabs (*Cancer irroratus*) (CRESLI 2008). Jellyfish (coelenterates and ctenophores), small crustaceans, hydrozoans, insects, gastropods, and pieces of Sargassum have been found in stomach contents of juvenile turtles.

Threats

Anthropogenic threats to loggerhead populations include bycatch in trawls; underwater noise; dredging of feeding areas; ingesting marine debris, oil, or tar; and strikes by ships or propellers. Vessel strikes are particularly problematic for turtles that are cold-stunned (USDOC, NMFS 2008). Loggerheads also frequently strand due to cold-stunning (hypothermia) between November and January each year along the north shore of Long Island Sound, the bays of eastern Long Island (Burke et al. 1991), and north to Massachusetts in Cape Cod Bay. Cold-stunned turtles, having lost their swimming abilities, tend to float on the surface, and eventually may be brought ashore with the tide and currents.

3.4 FISH RESOURCES AND ESSENTIAL FISH HABITAT

Fish resources in the Northeast Shelf LME are well-studied in comparison to most regions of the world. The historic and continued importance of commercial fisheries in the region has provided the impetus for intense study of the resource. Much of this research has been conducted by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS or NOAA Fisheries). NMFS is responsible for the conservation and management of living marine resources in the United States. Its responsibilities include management of threatened or endangered marine species (see Section 3.4.1), basic ecological research to support responsible stewardship (see Section 3.4.2), and consultation with Federal agencies to protect essential fish habitat (see Section 3.4.3). The management of Northeast fisheries is complex and involves a number of stakeholders in addition to NMFS, including the New England Fisheries Management Council, the Mid-Atlantic Fishery Management Council, the Atlantic States Marine Fisheries Commission (ASMFC), individual states, and Canada. Commercial fish resources are generally managed through fishery management plans (FMPs), whose development is mandated to the councils, the ASMFC, and NMFS. Federally listed threatened or endangered fish species are managed under recovery plans (see Section 3.4.1). NMFS regulates fisheries in offshore waters (3-200 nm offshore), while the coastal states and the ASMFC have management jurisdiction in the territorial sea (0-3 nm offshore). NMFS periodically produces Our Living Oceans, an overview of the status of U.S. living marine resources, which discusses the FMPs and fisheries management in the United States (USDOC, NMFS 1999).

The Northeast Fisheries Science Center (NEFSC) is the research arm of NMFS in the region extending from Cape Hatteras through the Gulf of Maine. The NEFSC conducts basic and applied research on living resources of the shelf ecosystem. Data are collected through a range of different programs including surveys of commercial catch and effort ("fishery-dependent" data) and long-term ecological monitoring through various programs ("fishery-independent" data). Among the most important datasets for groundfish resources in the northeast region are those from seasonal bottom-trawl surveys that have been conducted by the NEFSC since the early 1960s. Data from these surveys have been reported in technical reports and peer-reviewed journals, on topics ranging from stock status assessments to biogeography, habitat associations, and trophic ecology (e.g., NEFSC 2008; Gabriel 1992; Methratta and Link 2006a, Methratta and Link 2007a, Bowman et al. 2000). In addition to the data and literature produced by NMFS, information describing fish resources of the Northeast Shelf has also come from other government agencies (Federal and state) and from academic research.

3.4.1 Threatened or Endangered Fish Species

The Endangered Species Act (ESA) establishes a national program for the conservation of threatened or endangered species (T&E species) of fish, wildlife, and plants, and the ecosystems upon which they depend. Under the ESA, "endangered" means that a species is in danger of extinction throughout all or a significant portion of its range, and "threatened" means that a species is likely to become endangered. Such species are protected under Federal law. NMFS and the U.S. Fish and Wildlife Service (USFWS) share responsibility for implementing the ESA. In general, NMFS is responsible for marine and anadromous species, while USFWS is responsible for terrestrial and freshwater species.

Section 7 of the ESA requires Federal agencies to consult with NMFS or USFWS to ensure that any actions that they authorize, fund, or carry out will not jeopardize listed species or destroy or adversely modify the critical habitat of a listed species. Informal consultations are conducted to determine: (1) whether listed species and critical habitat are in the area affected by the action, (2) whether they may be affected and, if so, how the action could be modified to avoid adverse effects, and (3) whether a formal consultation is required. If necessary, formal consultations provide a threshold examination and a biological opinion on the likelihood that the proposed activity will jeopardize the continued existence of the resource and on the effect of the proposed activity on the endangered species. NMFS or USFWS may require the Federal agency to provide additional information or conduct appropriate biological studies if there is insufficient information to conclude that the proposed activity is not likely to jeopardize the species or its habitat.

NMFS provides on their website the current listing of all T&E species under their jurisdiction (USDOC, NMFS 2008). "Species of concern" are also listed, including information for "candidate species" and "proposed species." Species of concern are those species that NMFS has identified as potentially at risk, but insufficient information is available to warrant listing the species under the ESA. Although species of concern are not protected under the ESA, these species are identified and listed by NMFS to elicit proactive attention and conservation action. Candidate species are those that are actively being considered for listing as endangered or threatened, or are undergoing an ESA status review. "Proposed species" are those that have been found to warrant listing as either threatened or endangered and were officially proposed as such in a Federal Register notice. Allowing for a period of public comment, NMFS generally has one year to make a final determination whether to list a proposed species as threatened or endangered. Delisted species, which were formerly listed as threatened or endangered, are also catalogued on the NMFS website.

NMFS produces technical reports including Recovery Plans for T&E species, Status Reviews for candidate species, and profiles for species of concern (see USDOC, NMFS 2008). These documents provide information on species distribution, life history, population levels, and analysis of conservation status and stressors such as human impacts that affect each species. Additional information for these species is available through a variety of sources including other NMFS technical reports, books, and species profiles produced by the ASMFC (e.g., Cargnelli et al. 1999a; Packer et al. 2003a; Packer et al. 2003b; Collette and Klein-MacPhee 2002; ASMFC 2008).

Shortnose sturgeon and Atlantic salmon are currently the only two fish species in the Northeast Shelf region that are federally listed as endangered species. These fish rely primarily on critical riverine and estuarine habitat, which are outside the scope of this review. Hence, only a brief description of each species is provided below. The smalltooth sawfish (*Pristis pectinata*) is a third federally listed endangered species, which historically occurred as far north as Cape Hatteras, but is not currently found north of Florida. Table 3.5 lists the 17 fish species that occur in the Northeast Shelf region and that are currently listed as species of concern. Atlantic sturgeon, Atlantic wolffish, and cusk are candidate species that are being considered for Federal listing.

Shortnose Sturgeon (*Acipenser brevirostrum*)

The Recovery Plan for shortnose sturgeon offers a detailed species profile (USDOC, NMFS 1998). Shortnose sturgeon occur in their natal rivers and estuaries along the east coast of North America from New Brunswick, Canada, to Florida. These fish are amphidromous, spending most of their lives in freshwater, but periodically entering estuarine and marine waters. Habitat use varies among populations of the species, with southern populations considered estuarine anadromous, while northern populations have been reported to use marine habitats in addition to estuaries and rivers. Fish collected in the ocean have typically been taken in nearshore, coastal waters. In estuarine and presumably coastal waters, shortnose sturgeon feed opportunistically on benthic invertebrates including mollusks, shrimps, and polychaete worms (Collette and Klein-MacPhee 2002).

Table 3.5

Fish Species of Concern in the Northeast Shelf Region

Common Name	Scientific Name	Range	Comments
Alewife	*Alosa pseudoharengus*	Atlantic-Newfoundland to North Carolina	
Atlantic halibut	*Hippoglossus hippoglossus*	Atlantic-Labrador to southern New England	
Atlantic salmon	*Salmo salar*	Atlantic-Gulf of Maine (other populations in streams and rivers in Maine outside the range of the listed Gulf of Maine DPS); anadromous	Proposed endangered as of 09/03/2008
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*	North America, Atlantic coastal waters	Candidate species as of 10/17/2006
Atlantic wolffish	*Anarhichas lupus*	Atlantic-Georges Bank and western Gulf of Maine	Candidate species as of 10/01/2008
Barndoor skate	*Dipturus laevis*	Atlantic-Newfoundland, Canada to Cape Hatteras, NC.	NMFS reviewed the status of this species and determined that ESA listing was not warranted, but retained the species on the species of concern list.
Blueback herring	*Alosa aestivalis*	Atlantic-Cape Breton, Nova Scotia, to St. John's River, FL	
Cusk	*Brosme brosme*	Atlantic-Gulf of Maine	Candidate species as of 03/09/2007
Dusky shark	*Carcharhinus obscurus*	Atlantic; Gulf of Mexico; Pacific	
Nassau grouper	*Epinephelus striatus*	Atlantic-NC southward to Gulf of Mexico	
Night shark	*Carcharinus signatus*	Atlantic; Gulf of Mexico	
Porbeagle	*Lamna nasus*	Atlantic, Newfoundland, Canada to New Jersey	
rainbow smelt	*Osmerus mordax*	Atlantic-Labrador to NJ; anadromous	
Sand tiger	*Carcharias taurus*	Atlantic; Gulf of Mexico	
Speckled hind	*Epinephelus drummondhayi*	Atlantic-NC to Gulf of Mexico	
Thorny skate	*Amblyraja radiata*	Atlantic-West Greenland to NY	
Warsaw grouper	*Epinephelus nigritus*	Atlantic-MA southward to Gulf of Mexico	

Source: USDOC, NMFS 2008

Atlantic Salmon (*Salmo salar*)

The Gulf of Maine (GOM) distinct population segment (DPS) of Atlantic salmon includes remnant populations of naturally reproducing anadromous Atlantic salmon from the mouth of the St. Croix River at the Maine/New Brunswick (Canada) border, southward to portions of the Kennebec River in Maine (USDOC, NMFS 2008). This DPS was listed as endangered on December 17, 2000. Certain populations within the range of the GOM DPS were initially excluded from listing due to insufficient data. As of September 3, 2008, these populations have now been proposed for listing as endangered. The Recovery Plan for Atlantic salmon provides a detailed profile for this species (USDOC, NMFS and USDOI, FWS 2005). Atlantic salmon is an anadromous species that reproduces in coastal rivers then undertakes extensive feeding migrations in the open ocean. In North America this species historically ranged from northern Quebec to Long Island Sound, with spawning runs occurring in nearly every major coastal river north of the Hudson River in the United States. Wild populations no longer exist in rivers south of Maine, although restoration efforts have been under way in several rivers for the past thirty years. Atlantic salmon have a complex life cycle, spending 1 to 3 years in their natal rivers before entering the sea. Salmon from U.S. rivers migrate north to feeding grounds off of Newfoundland, Labrador and Greenland. Adult Atlantic salmon feed on fish including Atlantic herring, alewife, rainbow smelt, capelin, mummichog, haddock, small sculpins, small Atlantic mackerel, sand lance, and flatfishes (Collette and Klein-MacPhee 2002). Adults in U.S. waters typically spend 2 years in the ocean before returning to their natal rivers. While there is currently no designated critical habitat for the Atlantic salmon, there is a proposed revision to its recovery plan that includes proposed critical habitat.

3.4.2 Other Fish Species

Fish communities of the Northeast Shelf LME are both ecologically and economically important to the region. These communities support valuable commercial and recreational fisheries and provide an essential food source for marine mammals and birds. Fish comprise a diverse component of the complex and productive ecosystem in the Northeast Shelf region. Table 3.6 provides a listing with scientific names for fish species that are discussed in this section.

Fish species are commonly categorized by life habits or preferred habitat associations. "Demersal fish" (groundfish) are those species that live on or near the ocean bottom for at least a portion of their life cycle. Examples of groundfish in the northeast region include Atlantic cod, haddock, red hake, white hake, silver hake, pollock, flounders, monkfish, dogfish, skates, Atlantic halibut, and black sea bass. "Pelagic" fish species live within the water column; examples from the region include Atlantic mackerel, herrings (Atlantic, round, and blueback herrings and alewife), bluefish, and butterfish. "Diadromous" species are fish that migrate between freshwater and marine environments. This group can be further classified into "anadromous" or "catadromous" species. Anadromous species such as river herrings (alewife and blueback herring), American shad, striped bass, sturgeon (Atlantic and shortnose), and Atlantic salmon spawn in freshwater but spend much of their life at sea. Catadromous species such as American eel spawn in marine waters but spend much of their life in freshwater. Highly migratory species such as billfish, tunas, and certain sharks carry out extensive migrations and can occur both within the waters of the Northeast Shelf region and outside the region on the high seas.

Table 3.6

Scientific Names of Fish Species

Common name	**Scientific name**	**Common name (continued)**	**Scientific name (continued)**
Acadian redfish	*Sebastes fasciatus*	Longfin hake	*Urophycis chesteri*
Alewife	*Alosa pseudoharengus*	Longhorn sculpin	*Myoxocephalus octodecemspinosis*
American eel	*Anguilla rostrata*	Northern sand lance	*Ammodytes dubius*
American plaice	*Hippoglossoides platessoides*	Northern sea robin	*Prionotus carolinus*
American shad	*Alosa sapidissima*	Ocean pout	*Marcozoarces americanus*
Armored sea robin	*Perestedion miniatum*	Offshore hake	*Merluccius albidus*
Atlantic cod	*Gadus morhua*	Pollock	*Pollachius virens*
Atlantic croaker	*Micropogonias undulatus*	Red hake	*Urophycis chuss*
Atlantic halibut	*Hippoglossus hippoglossus*	Scup	*Stenotomus chrysops*
Atlantic herring	*Clupea harengus*	Sea raven	*Hemitripterus americanus*
Atlantic mackerel	*Scomber scombrus*	Sheepshead	*Archosargus probatocephalus*
Atlantic salmon	*Salmo salar*	Common name	Scientific name
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*	Silver hake (whiting)	*Merluccius bilinearis*
Black drum	*Pogonias cromis*	Spiny dogfish	*Squalus acanthias*
Black sea bass	*Centropristis striata*	Spot	*Leiostomus xanthurus*
Blackbelly rosefish	*Helicolinus dactylopterus*	Spotted hake	*Urophycis regia*
Blueback herring	*Alosa aestivalis*	Striped bass	*Morone saxitilus*
Bluefish	*Pomatomus saltatrix*	Summer flounder	*Paralichthys dentatus*
Butterfish	*Peprilus triacanthus*	Tautog	*Tautoga onitis*
Conger eel	*Conger oceanicus*	Thorny skate	*Amblyraja radiata*
Cunner	*Tautogolabrus adspersus*	Tilefish	*Lopholatilus chamaeleonticeps*
Fawn cusk-eel	*Lepophidium profundorum*	Weakfish	*Cynoscion regalis*
Fourspot flounder	*Paralichthys oblongus*	White hake	*Urophycis tenuis*
Gag grouper	*Mycteroperca microlepis*	Windowpane	*Scophthalmus aquosus*
Goosefish (monkfish)	*Lophius americanus*	Winter flounder	*Pseudopleuronectes americanus*
Gray triggerfish	*Balistes capriscus*	Winter skate	*Raja ocellata*
Gulf Stream flounder	*Citharichthys arctifrons*	Witch flounder	*Glyptocephalus cynoglossus*
Haddock	*Melanogrammus aeglefinus*	Yellowtail flounder	*Limanda ferruginea*
Little skate	*Raja erinacea*		

Note: Nomenclature follows Nelson 2004.

A gradient of increasing species diversity from northern to southern latitudes is a well-known macroecological pattern in the overall biodiversity of fishes in the western North Atlantic (Love and Chase 2007). Reasons for this pattern are not thoroughly understood, but explanations include differences in habitat complexity and temperature differences with thermal refugia found in more southern waters (Love and Chase 2007). A small fraction of fish species that occur in the Northeast Shelf LME dominate assemblages in terms of abundance or biomass. Many of these dominant species are targeted by commercial or recreational fisheries. Other numerical dominants represent important prey species in the diets of larger fish and other marine animals. Hence these dominant fishes are often both economically and ecologically important, and they are typically well-studied in comparison to some of the less common fishes. Commercially important species are especially well-studied (Link 2007). Many of the less common species are at the limits of their range, with centers of abundance outside the northeast region. Other species are likely underrepresented in the reported data. For example, the catchability of different species varies based on the sampling gear types used, resulting in some fishes likely being underreported (Gabriel 1992). Much less is reported about many of the uncommon species that occur within the Northeast Shelf region. Nonetheless, information ranging from occurrence reports to details of life history is available in sources such as the primary scientific literature, technical reports, and books. In the classic reference *Bigelow and Schroeder's Fishes of the Gulf of Maine* (Collette and Klein-MacPhee 2002), 252 fish species from 118 families are profiled. The distributions of many of these species extend beyond the GOM to more southerly reaches of the Northeast Shelf system.

3.4.2.1 Distribution and Habitat Associations

The distribution of fish species and community composition vary with latitude, depth, temperature, bottom substrate, habitat complexity, and unique topographic and hydrographic features. Species distribution can vary over temporal scales ranging from diel periods (daily), to seasonal migrations and movements, to long-term changes or shifts that can be related to changing oceanographic conditions or fluctuating population levels. In addition, distribution will usually vary during the life cycle of a given species (ontogenetic variation), such that specific life stages are associated with particular habitats. Much of the best broadscale information about fish distribution in the northeast region comes from surveys conducted by the NEFSC. Seasonal bottom-trawl surveys that have been conducted since the 1960s provide data that have been used to assess fish distribution and habitat associations focusing on a range of spatial and temporal scales. This program also provides data from gut-content analyses that have been used to assess the feeding ecology of fishes in the Northeast Shelf region.

Biogeography of Fish Assemblages

At a biogeographical scale, fishes of the Northeast Shelf have been identified with several distinct assemblages associated with geography and water depth (Stevenson et al. 2004; Mahon et al. 1998; Gabriel 1992). Gabriel (1992), using data collected by NEFSC autumn trawl surveys from 1967 to 1988, identified demersal fish assemblages in the waters between Cape Hatteras and Nova Scotia. The following six major assemblages, with their associated dominant species, were identified: (1) deepwater Gulf of Maine/Georges Bank – thorny skate, American plaice, white hake, redfish and witch flounder; (2) Gulf of Maine/Georges Bank transition zone – Atlantic cod, haddock, and pollock; (3) shallow water Georges Bank/Southern New England – winter skate, little skate, windowpane, winter flounder, yellowtail flounder and longhorn sculpin; (4) Northern Mid-Atlantic Bight – spotted hake, fourspot flounder and butterfish; (5) Southern Mid-Atlantic Bight – summer flounder, scup, northern sea robin, black sea bass, and a distinct inshore group including Atlantic croaker, spot, and weakfish; and (6) deepwater (slope depths throughout the region) – offshore hake, blackbelly rosefish, longfin hake, armored sea robin, Gulf Stream flounder and fawn cusk-eel. Affiliations of several important species such as silver hake, red hake, goosefish, and spiny dogfish shifted over time among the Northern MAB, Georges Bank, and GOM region assemblages. Additional analysis of site groupings based on fish assemblages resulted in groupings that essentially corresponded to the four major subregions of the Northeast Shelf LME (the GOM, Georges Bank, Southern New England, and the MAB). In addition, Gabriel (1992) found that the spatial distribution of northern assemblages was consistent from year to year whereas geographic boundaries of southern assemblages shifted. This change over time in the boundaries for southern assemblages was attributed to oceanographic conditions that varied interannually. The species composition of all assemblages was found to be highly persistent over time, although impacts of commercial fishing pressure were evident in the data.

Habitat Associations

At more local spatial scales, habitat associations for both individual species and fish assemblages have recently been assessed by a number of researchers. Investigations and reviews of habitat use for multiple species were conducted by Methratta and Link (2006a) and Steimle and Zetlin (2000). Methratta and Link (2006a) looked at local-scale relationships between fish and soft-bottom habitats using data collected between 1998 and 2002 by the NEFSC seasonal bottom-trawl survey program. They analyzed associations between sediment grain size and 58 demersal fish species using multivariate analyses. Relationships between substrate type and species distribution and abundances were identified for 12 out of the 58 species analyzed. Atlantic cod, winter flounder, longhorn sculpin, and sea raven were found to be associated with larger grain sizes, whereas white hake, red hake, silver hake, goosefish, spiny dogfish, and American plaice were associated with fine-grained substrates. Steimle and Zetlin (2000) reviewed available information about reef habitats and associated communities in the MAB. Sea bottom in the MAB is characterized as being predominantly soft sediments with only isolated occurrences of natural reef in the form of sand or gravel ridges, clay or sandstone formations, and some glacially exposed rock along the southern New England coast. Hence, the majority of reef habitat in the Bight comes from man-made structures such as shipwrecks, lost cargos, and artificial reefs. Steimle and Zetlin (2000) summarized available information on the abundance and distribution of reef habitat in the MAB, and discussed trends in the use of artificial reefs to manage marine resources. The authors note that reefs can provide fish refuge from trawls and can influence the distribution and abundance of reef-associated species. Fish that are commonly found on reef habitats in the MAB include Atlantic cod, red hake, ocean pout, scup, black sea bass, tautog, American eel, conger eel, pollock, striped bass, gag grouper, spot, sheepshead, Atlantic croaker, black drum, tilefish, cunner, and gray triggerfish (Steimle and Zetlin 2000).

Methratta and Link (2006b) investigated seasonal variation in habitat associations for 24 demersal fish species in the GOM and Georges Bank regions. Data collected between 1968 and 2002 by the NEFSC seasonal bottom trawl survey program was used for the analyses. Species-specific relationships were identified between abundance and bottom temperature, bottom depth, bottom substrate, and season. During both spring and fall, distribution patterns were more strongly related to depth and temperature than to substrate. Associations between species and substrate type, which have been reported at local spatial scales, were less clear at the broader spatial scales analyzed for their study. Ontogenetic variation in habitat associations was also investigated by Methratta and Link (2007a; 2007b) using NEFSC bottom trawl survey data. In two separate papers the authors reported on how size classes of four flatfishes (Methratta and Link 2007a; American plaice, winter flounder, yellowtail flounder and fourspot flounder) and four other key groundfish (Methratta and Link 2007b; Atlantic cod, haddock, spiny dogfish and silver hake) are related to habitat parameters including depth, temperature, substrate, and season. Depth had the strongest association with fish distribution and abundance, and fish size was found to increase with depth in most cases. For example, larger Atlantic cod size classes were found in deeper water during both spring and fall. Larger haddock were also found in deeper water during fall, but the trend was reversed during spring. Seasonal associations with habitat features and the relevant ecological factors such as spawning migrations, and thermal preferences are also discussed.

Lathrop et al. (2006) developed a habitat classification scheme for identifying associations between fish and habitat in the New York Bight. Silver hake and summer flounder habitat preferences were assessed using a classification scheme that included side scan sonar imagery, image classification, and GIS techniques. Although strong associations were not identified, the authors presented a noteworthy approach to habitat classification. Other researchers have also investigated habitat use by silver hake. Auster et al. (1997) looked at the distribution of juvenile silver hake in response to small-scale habitat variability. Juvenile silver hake were found to occur on silt-sand bottoms where amphipod tubes were present. Auster et al. (2003a) reported on the use of sand wave habitats on Stellwagen Bank and Georges Bank by silver hake. Based on the results of video surveys the authors reported that there was a positive correlation between sand wave period and fish length, and that silver hake use the seafloor more during the daytime than at night. Other assessments of associations between fish and bottom substrate also focused on individual species. Auster et al. (2003b) reported that juvenile Acadian redfish on Stellwagen Bank were associated with polar reef and surrounding patches of cerianthid anemones, while Able et al. (2007) reported broad distribution of young-of-year goosefish in the MAB, Georges Bank, and portions of the GOM.

3.4.2.2 Trophic Ecology

The feeding ecology of fishes in the region has also been examined using data from fish collected during NEFSC bottom-trawl surveys and in other independent studies. Understanding trophic interrelationships among fishes is essential to determining the role of predation in ecosystem structure. Such knowledge can be used to assess the potential indirect impacts to a predator species in light of expected impacts to important prey. Bowman et al. (2000) provided a reference document of prey items eaten by fishes (and two common species of squids) in the Northeastern Shelf region. The stomach contents of 180 species (31,567 individuals), primarily collected by NEFSC bottom-trawl surveys or by longline, were analyzed to provide data for this reference. In addition to reporting species-specific diet composition by size class and geographic area, the authors provided a summary of the most important prey items in the region. Relatively few species were found to provide a substantial portion of the food consumed by fishes of the Northeast Shelf region. Northern sand lance was identified as the primary fish prey throughout the region, while herrings, silver hake, other gadids, scup, and sculpin were also mentioned as important fish prey. Important invertebrate prey items included squids, decapod crustaceans, other crustaceans (such as copepods, amphipods, euphausiids, mysids, and stomatopods), echinoderms, and gastropod and bivalve mollusks.

Trophic guilds are groups of species within a community that use similar prey resources. Identification of these ecologically similar functional units provides a useful framework to simplify complex ecosystems. Garrison and Link (2000a) evaluated trophic guild structure of the fish community in the Northeast Shelf ecosystem. Data from the NEFSC bottom-trawl surveys were used to analyze an assemblage of 40 fish species based on size class to account for ontogenetic diet shifts. The following six major predator groups were identified: crab eaters, planktivores, amphipod/shrimp eaters, shrimp/small fish eaters, benthivores, and piscivores. Fourteen significant trophic guilds, which separated predator groups based on prey size and position within the water column, were also identified by the study. Typically, fewer than five prey species accounted for more than fifty percent of the diet within each trophic guild. Trophic guilds in the northeast region illustrate the typical resource partitioning patterns that have been identified for fish communities worldwide. The two major defining aspects are vertical distribution, ranging from benthic to pelagic to surface-oriented feeding; and a prey size gradient that corresponds to morphological constraints in predator species such as mouth size, body size, and swimming speed (Garrison and Link 2000a). Garrison and Link (2000b) also analyzed food habits of five hake species (offshore hake, silver hake, white hake, red hake, and spotted hake) in the northeast region using NEFSC bottom-trawl survey data. Spatial and temporal variation in diet composition was analyzed and compared among species. Since hakes are among the most abundant predators in the Northeast Shelf LME, they play an important role in ecosystem dynamics. Garrison and Link (2000b) reported that hakes prey on pelagic fish and invertebrates (e.g., euphausiids and other shrimps) with increasing piscivory in larger size classes. Hake predation may represent a primary source of mortality for economically important pelagic fish species. Several other species-specific accounts of food habits are also available. Link and Garrison (2002) looked specifically at the diet of Atlantic cod, while Buckel et al. (1999) reported on bluefish diet, and Able et al. (2007) reported on young-of-year goosefish.

3.4.2.3 Additional Information Sources

Additional information on the life history and ecology of individual species including distribution, habitat associations, and feeding ecology for various life stages and seasons has been reviewed and summarized in a variety of sources. Among these, the NMFS Essential Fish Habitat source documents (see Section 3.4.3, Table 3.7) and *Bigelow and Schroeder's Fishes of the Gulf of Maine* (Collette and Klein-MacPhee 2002) provide excellent sources, and the ASFMC species profiles are another useful reference (ASFMC 2008).

Site-specific information for fishes in the northeast region is spotty and where available may be outdated. Nonetheless, information for certain locations may be found in the peer-reviewed literature from academic research, or in state or Federal government agency reports (e.g., compliance reports, technical reports and NEPA documents). Reports related to sand and gravel mining are an example of agency reports that provide site-specific data for fish in the Northeastern region. The U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) is responsible for issuing leases for sand and gravel mining in Federal waters on the OCS. The BOEMRE has conducted a number of environmental surveys to support responsible decisionmaking in its offshore leasing programs. Technical reports that characterize biological communities in potential offshore borrow areas are available for several areas in the MAB. These reports provide site-specific information on fish communities in areas offshore North Carolina (Byrnes et al. 2003), Virginia (TLB Group 1999), Maryland (Cutter et al. 2000; TLB Group 1999), Delaware (Cutter et al. 2000; TLB Group 1999), New Jersey (Byrnes et al. 2004; Byrnes et al. 2000; TLB Group 1999) and New York (Byrnes et al. 2004).

3.4.3 Essential Fish Habitat

The Magnuson-Stevens Act of 1976 was established to promote conservation of marine fishery (shellfish and finfish) resources. This included the establishment of eight regional fishery management councils (FMCs) that develop fishery management plans (FMPs) to properly manage resources within their jurisdictional waters. The 1986 and 1996 amendments to the Magnuson Act, renamed the Sustainable Fisheries Act (Public Law 104-297), recognized that many fisheries are dependent on nearshore and estuarine habitats for at least part of their life cycles and included evaluation of habitat loss and protection of critical habitat. The marine environments important to marine fisheries are referred to as essential fish habitat (EFH) and are defined to include "those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity." "Waters" includes aquatic areas and their associated physical, chemical, and biological properties that are used by fish. "Substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities. "Necessary" means the habitat that is required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle. Councils may also designate "habitat areas of particular concern" (HAPC), which identify subsets of EFH that have particularly high ecological value, or that are especially vulnerable to degradation. Designation of an area as HAPC does not confer additional protection, but can help prioritize conservation efforts.

The Sustainable Fisheries Act further mandates NMFS to coordinate with other Federal agencies to avoid, minimize, or otherwise offset adverse effects on EFH that could result from proposed activities. An EFH consultation is required to provide an opportunity for NMFS to recommend ways for Federal agencies to avoid or minimize the effects of their actions on habitat that supports federally managed commercial and recreational fisheries. The consultation provisions require: (1) Federal agencies to notify NMFS regarding a proposed action that may adversely affect EFH; (2) Federal agencies to consult with NMFS if they determine their actions may adversely affect EFH for federally managed species of fish; (3) NMFS to provide EFH conservation recommendations for any Federal or State agency action that would adversely affect EFH; and (4) Federal action agencies to respond to those recommendations in writing; if the action agency disagrees with NMFS advice, it must explain why.

EFH has been identified for a total of 65 species in U.S. waters of the North or Central Atlantic. These species are managed within 14 fishery management plans (FMPs), under the auspices of the New England Fishery Management Council (NEFMC), the Mid-Atlantic Fishery Management Council (MAFMC), and the South Atlantic Fishery Management Council (SAFMC) or NMFS. The FMPs describe EFH designations for each species, and NMFS maintains a website that provides maps and other documentation to assist in identifying EFH designations throughout the region (see USDOC, NMFS 2009).

Table 3.7 presents EFH parameters with additional comments and habitat information for all 37 fish species managed by the councils (NEFMC, MAFMC, and SAFMC) with EFH identified in the Northeast Shelf region. Table 3.8 presents EFH parameters for the five invertebrate species managed by the councils with EFH identified in the region. EFH has also been identified for 23 highly migratory species and billfish that are managed by NMFS. These are large, pelagic, piscivorous fishes that carry out extensive migrations. These species are typically less likely to be impacted by offshore alternative energy projects than are groups such as demersal fishes. In waters of the Northeast Shelf region, EFH has been identified for the following highly migratory species: Atlantic albacore (*Thunnus alalunga*), Atlantic angel shark (*Squatina dumerili*), bigeye tuna (*Thunnus obesus*), bluefin tuna (*Thunnus thynnus*), Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), skipjack tuna (*Katsuwonus pelamis*), swordfish (*Xiphias gladius*), Atlantic yellowfin tuna (*Thunnus albacares*), basking shark (*Cetorhinus maximus*), blue marlin (*Makaira nigricans*), blue shark (*Prionace glauca*), dusky shark (*Carcharhinus obscurus*), longfin mako (*Isurus paucus*), porbeagle (*Lamna nasus*), sand tiger (*Carcharias taurus*), sandbar shark (*Carcharhinus plumbeus*), scalloped hammerhead (*Sphyrna lewini*), shortfin mako (*Isurus oxyrinchus*), silky shark (*Carcharhinus falciformis*), thresher shark (*Alopias vulpinus*), tiger shark (*Galeocerdo cuvieri*), white marlin (*Tetrapturus albidus*), and white shark (*Carcharodon carcharias*). Species profiles for these fishes are available at the NMFS website (see USDOC, NMFS 2009).

Information to characterize species with EFH identified in the Northeast Shelf region is available at the NMFS website and in various sources discussed in Section 3.4.2. In addition, NEFSC has compiled detailed species profiles for the 32 fish and 5 invertebrate species that are managed by the NEFMC or the MAFMC. This information is published in reference documents referred to as the "EFH source documents," which are available at the NEFSC website (see NEFSC 2009). Table 3.9 lists species for which EFH source documents are available.

Table 3.7

Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
American plaice	Eggs	GOM, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME, and from Mass. Bay to Cape Cod Bay, MA	<12	(32)	30 – 90	All year in GOM Dec - June on GB Peaks April & May both	Surface waters	
	Larvae	GOM, GB, Southern NE and estuaries from Passamaquoddy Bay to Saco Bay, ME, and from Mass Bay to Cape Cod Bay, MA	<14	(32)	30 – 130	Between January and August, with peaks in April and May	Surface Waters	
	Juveniles	GOM and estuaries from Passamaquoddy Bay to Saco Bay, ME, and from Mass Bay to Cape Cod Bay, MA	<17	(32)	45 – 150		Bottom habitats with fine-grained sediments or substrate of sand or gravel	(Strong concentrations inside and around 100-m isobath in Western GOM; major prey: echinoderms, arthropods, annelids)
	Adults	GOM, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME, and from Mass Bay to Cape Cod Bay, MA	<17	(34-20)	45 – 175		Bottom habitats with fine-grained sediments or a substrate of sand or gravel	
	Spawning adults	GOM, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass Bay to Cape Cod Bay, MA	<14	(32)	<90	March through June	Bottom habitats of all substrate types	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic cod	Eggs	GOM, GB, eastern portion of continental shelf off southern NE and the following estuaries: Englishman/ Machias Bay to Blue Hill Bay; Sheepscot R., Casco Bay, Saco Bay, Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<12	32 – 33 (10 – 35)	<110	Begins in fall, peaks in winter and spring	Surface waters	
	Larvae	GOM, GB, eastern portion of continental shelf off southern NE and the following estuaries: Passamaquoddy Bay to Penobscot Bay; Sheepscot R., Casco Bay, Saco Bay, Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	32 – 33	30 – 70	Spring	Pelagic waters	
	Juveniles	GOM, GB, eastern portion of continental shelf off southern NE and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<20	30 – 35	25 – 75		Bottom habitats with a substrate of cobble or gravel	HAPC – An area approximate of 300 sq. nm along the northern edge of GB and the Hague line containing gravel cobble substrate.
	Adults	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	(29 – 34)	10 – 150		Bottom habitats with a substrate of rocks, pebbles, or gravel	(Major prey: fish crustaceans, decapods, amphipods)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic cod (cont'd)	Spawning adults	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Englishman/ Machias Bay to Blue Hill Bay; Sheepscot R., Mass Bay, Boston Harbor, Cape Cod Bay, MA	<10	(10 - 35)	10 - 150	spawn during fall, winter, and early spring	Bottom habitats with a substrate of smooth sand, rocks, pebbles, or gravel	
Atlantic halibut	Eggs	GOM, GB	4 - 7	<35	<700	Between late fall and early spring, peak Nov and Dec.	Pelagic waters to the sea floor	
	Larvae	GOM, GB		30 - 35			Surface waters	
	Juveniles	GOM, GB	>2		20 - 60		Bottom habitats with a substrate of sand, gravel, or clay	
	Adults	GOM, GB	<13.6	30.4 - 35.3	100 - 700		Bottom habitats with a substrate of sand, gravel, or clay	(Major prey: crustaceans, fish, cod, squid)
	Spawning adults	GOM, GB	<7	<35	<700	Between late fall and early spring;, peaks in Nov. and Dec.	Bottom habitats with a substrate of soft mud, clay, sand, or gravel; rough or rocky bottom locations along slopes of the outer banks	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic herring	Eggs	GOM, GB and the following estuaries: Englishman/ /Machias Bay, Casco Bay,& Cape Cod Bay	<15	32 - 33	20 - 80	July through November	Bottom habitats with a substrate of gravel, sand, cobble, shell fragments & aquatic macrophytes. .	Eggs adhere to bottom forming extensive beds. Eggs most often found in areas of well-mixed water, with tidal currents between 1.5 and 3.0 knots (Egg beds can range from 4,500 to 10,000 per km^2 on GB. Eggs susceptible to suffocation from high densities and siltation)
	Larvae	GOM, GB, Southern NE and the following estuaries: Passamaquoddy Bay to Cape Cod Bay, Narragansett Bay, & Hudson R./Raritan Bay	<16	32	50 - 90	Between August and April, peaks from Sept. - Nov.	Pelagic waters	
	Juveniles	GOM, GB, Southern NE and Middle Mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay to Delaware Bay	<10	26 - 32	15 - 135		Pelagic waters and bottom habitats	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	**Life Stage**	**Geographic Area**	**Temp. (°C)**	**Salinity (‰)**	**Depth (m)**	**Seasonal Occurrence**	**Habitat Description**	**Comments**
Atlantic herring (cont'd)	Adults	GOM, GB, southern NE and middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay to Delaware Bay; & Chesapeake Bay	<10	>28	20 - 130		Pelagic waters and bottom habitats	(Major prey: zooplankton)
	Spawning adults	GOM, GB, southern NE and middle mid-Atlantic south to Delaware Bay and Englishman/ /Machias Bay Estuary	<15	32 - 33	20 - 80	July through November	Bottom habitats with a substrate of gravel, sand, cobble and shell fragments, also on aquatic macrophytes	Herring eggs are spawned in areas of well-mixed water, with tidal currents between 1.5 and 3.0 knots
Atlantic mackerel	Eggs	Continental shelf from ME through Cape Hatteras, NC, including estuaries from Great Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay and Great South Bay	5 - 23	(18 - >30)	0 - 15		Pelagic waters	(peak spawning in salinities >30 ppt)
	Larvae	Continental shelf from GOM through Cape Hatteras, NC, also includes estuaries from Great Bay to Cape Cod Bay; Narragansett Bay to Long Island Sound; Gardiners Bay and Great South Bay	6 - 22	(>30)	10 - 130		Pelagic waters	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic mackerel (cont'd)	Juveniles	Continental shelf from GOM through Cape Hatteras, NC, also includes estuaries from Passamaquoddy Bay; Penobscot Bay to Saco Bay; Great Bay; Mass Bay to Cape Cod Bay; Narragansett Bay, Long Island Bay; Gardiners Bay to Hudson R./ /Raritan Bay	4 - 22	(>25)	0 - 320		Pelagic waters	
	Adults	Continental shelf from GOM through Cape Hatteras, NC, also includes estuaries from Passamaquoddy Bay to Saco Bay; Mass Bay to Long Island Bay; Gardiners Bay to Hudson R./ Raritan Bay	4 - 16	(>25)	0 - 380		Pelagic waters	(Opportunistic feeding: can filter feed or select individual prey. Major prey: crustaceans, pelagic mullosks, polychaetes, squid, fish)
Atlantic salmon	Eggs	Rivers from CT to ME: Connecticut, Pawcatuck, Merrimack, Cocheco, Saco, Androscoggin, Presumpscot, Kennebec,	<10	Fresh water	30 - 31 cm	Between Oct and April	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	Need clean, well-oxygenated freshwater
	Larvae	Sheepscot, Ducktrap, Union, Penobscot, Narraguagus, Machias, East Machias, Pleasant, St. Croix, Denny's, Passagassawaukeag Aroostook, Lamprey, Boyden, Orland Rivers,	<10	Fresh water		Between March and June for alevins/fry	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic salmon (cont'd)	Juveniles	and the Turk, Hobart & Patten Streams; and the following estuaries for juveniles and adults: Passamaquoddy Bay to Muscongus Bay; Casco Bay to Wells Harbor; Mass Bay, Long Island Sound, Gardiners Bay to Great South Bay.	<25	Freshwater to oceanic	10 - 61 cm		Bottom habitats of shallow gravel/cobble riffles interspersed with deeper riffles and pools in rivers and estuaries Water velocities between 30 -– 92 cm/sec	As they grow, parr transform into smolts. Atlantic salmon smolts require access downstream to the ocean. Upon entering the ocean, post-smolts become pelagic and range from the Labrador Sea south to Long Island Sound.
	Adults	All aquatic habitats in the watersheds of the above-listed rivers, including all tributaries to the extent that they are currently or were historically accessible for salmon migration.	<22.8	Freshwater to oceanic			Oceanic adult Atlantic salmon are primarily pelagic and range from waters of the continental shelf off southern NE north throughout the GOM. Dissolved oxygen above 5 ppm for migratory pathway.	HAPC - Eleven rivers in ME including: St. Croix, Denny's, East Machias, Machias, Pleasant, Turk stream, Narraguagus, Penobscot, Ducktrap, Sheepscot, and Kennebec Rivers.
	Spawning adults		<10	Freshwater	30 - 61 cm	Oct and November	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	Water velocity around 61 cm/sec

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Barndoor skate*	Juveniles and Adults	(GOM to Cape Hatteras)	(1.2 - 20)	(32 - 36)	(shoreline to 750)		(Bottom habitats with mud, sand or gravel)	*Information for skates extracted from EFH source documents
Black sea bass	Eggs	Continental shelf and estuaries from southern NE to NC, also includes Buzzards Bay			0 – 200	May - Oct	Water column of coastal Mid-Atlantic Bight and Buzzards Bay	
	Larvae	Pelagic waters over continental shelf from GOM to Cape Hatteras, NC, also includes Buzzards Bay	(11 - 26)	(30 - 35)	(<100)	(May - Nov, peak Jun - Jul)	Habitats for transforming larvae to juveniles are near coastal areas and into marine parts of estuaries between VA and NY. When larvae become demersal, found on structured inshore habitat such as sponge beds.	
	Juveniles	Demersal waters over continental shelf from GOM to Cape Hatteras, NC, and estuaries from Buzzards Bay to Long Island Sound; Gardiners Bay, Barnegat Bay to Chesapeake Bay; Tangier/Pocomoke Sound and James River	>6	>18	(1 - 38)	Found in coastal areas (Apr -Dec , peak Jun - Nov) between VA and MA, but winter offshore from NJ and south; found in estuaries in summer and spring	Rough bottom, shellfish and eelgrass beds, man-made structures in sandy-shelly areas. Offshore clam beds and shell patches may be used during wintering	(YOY use salt marsh edges and channels; high habitat fidelity)

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Abbreviations: GOM – Gulf of Maine; GB – George’s Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Black sea bass (cont'd)	Adults	Demersal waters over continental shelf from GOM to Cape Hatteras, NC, also includes estuaries: Buzzards Bay, Narragansett Bay, Gardiners Bay, Great South Bay, Barnegat Bay to Chesapeake Bay; Tangier/Pocomoke Sound and James River	>6	(>20)	(20 - 50)	Wintering adults (Nov. to April) offshore, south of NY to NC inshore, estuaries from May to Oct	Structured habitats (natural & man-made) sand and shell substrates preferred	(Spawn in coastal bays but not estuaries; change sex to males with growth; prey: benthic and near bottom inverts, small fish, squid)
Bluefish	Eggs	North of Cape Hatteras, found over continental shelf from Montauk Point, NY south to Cape Hatteras. South of Cape Hatteras, found over continental shelf through Key West, FL	>18	>31	Mid-shelf depths	April to August	Pelagic waters	No EFH designation inshore
	Larvae	North of Cape Hatteras, found over continental shelf from Montauk Point, NY south to Cape Hatteras, South of Cape Hatteras, found over continental shelf through Key West, FL, the slope sea and Gulf Stream between latitudes 29N and 40N; includes the following estuary: Narragansett Bay	>18	>30	>15	April to September	Pelagic waters	No EFH designation inshore for larvae

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Bluefish (cont'd)	Juveniles	North of Cape Hatteras, found over continental shelf from Nantucket Island, MA, south to Cape Hatteras. South of Cape Hatteras, found over continental shelf through Key West, FL, the slope sea and Gulf Stream between latitudes 29N and 40N Includes estuaries from Penobscot Bay to Great Bay; Mass Bay to James R.; Albemarie Sound to St. Johns River, FL	(19 24)	(23 - 36) freshwater zone in Albemarie Sound		North Atlantic estuaries from June to Oct Mid-Atlantic estuaries from May to Oct South Atlantic estuaries from March to December	Pelagic waters	(use estuaries as nursery areas; can intrude into areas with salinities as low as 3 ppt)
	Adults	North of Cape Hatteras, found over continental shelf from Cape Cod Bay, MA south to Cape Hatteras. South of Cape Hatteras, found over continental shelf through Key West, FL also includes estuaries from Penobscot Bay to Great Bay; Mass Bay to James R.; Albemarie Sound to Pamilco/Pungo R., Bougue Sound, Cape Fear R., St. Helena Sound, Broad R., St. Johns R., & Indian R.	(14 - 16)	>25		North Atlantic estuaries from June to Oct Mid-Atlantic estuaries from April to Oct South Atlantic estuaries from May to January	Pelagic waters	Highly migratory (Major prey: fish)

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Butterfish	Eggs	Over Continental shelf from GOM through Cape Hatteras, NC, and in estuaries from Mass Bay to Long Island Sound: Gardiners Bay, Great South Bay, and Chesapeake Bay	11 - 17	(25 - 33)	0 - 1829	(Spring and summer)	Pelagic waters	
	Larvae	Over Continental shelf from GOM through Cape Hatteras, NC,also in estuaries from Boston Harbor, Waquoit Bay to Long Island Sound; Gardiners Bay to Hudson R./ Raritan Bay; Delaware Bay and Chesapeake Bay	9 - 19	(6.4 - 37)	10 - 1829	(Summer and fall)	Pelagic waters	
	Juveniles	Over Continental shelf from GOM through Cape Hatteras, NC also in estuaries from Mass Bay, Cape Cod Bay to Delaware Inland Bays; Chesapeake Bay, York R. and James R.	3 - 28	(3 - 37)	10 - 365 (most <120)	(Winter - shelf spring to fall - estuaries)	Pelagic waters (larger individuals found over sandy and muddy substrates)	(Pelagic schooling - smaller individuals associated with floating objects including jellyfish)
	Adults	Over continental shelf from GOM through Cape Hatteras, NC; also in estuaries from Mass Bay, Cape Cod Bay to Hudson R./ Raritan Bay; Delaware Bay and Inland Bays; York R. and James R.	3 - 28	(4 - 26)	10 - 365 (most <120)	(Winter: shelf; summer to fall: estuaries)	Pelagic waters (schools form over sandy, sandy-silt and muddy substrates)	(Common in inshore areas and surf zone; prey: planktonic, thaliacians, squid, copepods)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Clearnose skate*	Juveniles and Adults	(GOM to South Atlantic Bight; rare north of MA)	(4 - 30)	(12 - 36; most >21)	(1 - 329)		(Bottom habitats with soft substrate but also rocky or gravelly bottoms)	*Information for skates extracted from EFH source documents
Cobia		South Atlantic and Mid-Atlantic Bights	>20	>25			Sandy shoals of capes and offshore bars high-profile rock bottoms and barrier island ocean-side waters from surf zone to shelf break but from the Gulf Stream shoreward; high-salinity bays, estuaries, sea grass.	All coastal inlets
Haddock	Eggs	GB southwest to Nantucket Shoals and coastal areas of GOM and the following estuaries: Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	34 - 36	50 – 90	March to May, peak in April	Surface waters	
	Larvae	GB southwest to the middle mid-Atlantic south to Delaware Bay and the following estuaries: Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay, and Narragansett Bay	<14	34 - 36	30 – 90	January to July, peak in April and May	Surface waters	

Notes***:*** Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Haddock (cont'd)	Juveniles	GB, GOM, mid-Atlantic south to Delaware Bay	<11	31.5 - 34	35 - 100		Bottom habitats with a substrate of pebble and gravel	
	Adults	GB and eastern side of Nantucket Shoals, throughout GOM, **Additional area: Nantucket Shoals and Great South Channel	<7	31.5 - 35	40 - 150		Bottom habitats with a substrate of broken ground, pebbles, smooth hard sand, and smooth areas between rocky patches	**The addition of Nantucket Shoals and the Great South Channel reflects historic patterns of distribution and abundance.
	Spawning adults	GB, Nantucket Shoals, Great South Channel, throughout GOM	<6	31.5 - 34	40 - 150	January to June	Bottom habitats with a substrate of pebble gravel or gravelly sand	
King mackerel		South Atlantic and Mid-Atlantic Bights	>20	>30			Sandy shoals of capes and offshore bars, high-profile rock bottoms and barrier island ocean-side waters from surf zone to shelf break but from the Gulf Stream shoreward;	All coastal inlets

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Little skate*	Juveniles and Adults	(GOM to Cape Hatteras)	(1 - 21)	(15 - 36)	(1 - 400; generally >111)		(Bottom habitats with sand, gravel, or mud)	(Among the dominant demersal fishes in northeast region; generally move to shallow water during spring, deeper water in winter) *Information for skates extracted from EFH source documents
Monkfish (Goosefish)	Eggs	GOM, GB, southern NE, middle mid-Atlantic south to Cape Hatteras, NC	<18		15 - 1000	March to September	Surface waters	(Eggs contained in long mucus veils that float near or at the surface)
	Larvae	GOM, GB, southern NE, middle mid-Atlantic south to Cape Hatteras, NC	15		25 - 1000	March to September	Pelagic waters	
	Juveniles	All areas of GOM, mid-shelf off southern NE, Outer Continental Shelf in the mid-Atlantic	<13	29.9 - 36.7	25 - 200		Bottom habitats with substrates of a sand-shell mix, algae covered rocks, hard sand, pebbly gravel, or mud	
	Adults	All areas of GOM, outer perimeter of GB, mid-shelf off southern NE, Outer Continental Shelf in the mid-Atlantic	<15	29.9 - 36.7	25 - 200		Bottom habitats with substrates of a sand-shell mix, algae-covered rocks, hard sand, pebbly gravel, or mud	(Major prey: fish, shrimp, squid, crustaceans, mollusks)

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Monkfish (Goosefish) (cont'd)	Spawning adults	All areas of GOM, outer perimeter of GB, mid-shelf off southern NE, Outer Continental Shelf in the mid-Atlantic	<13	29.9 - 36.7	25 - 200	February to August	Bottom habitats with substrates of a sand-shell mix, algae - covered rocks, hard sand, pebbly gravel, or mud	
Ocean pout	Eggs	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, and Cape Cod Bay	<10	32 - 34	<50	Late fall and winter	Bottom habitats, generally hard-bottom sheltered nests, holes, or crevices where they are guarded by parents	(Eggs are laid in gelatinous masses and take 2-3 months to develop.)
	Larvae	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay and Cape Cod Bay	<10	>25	<50	Late fall to spring	Bottom habitats in close proximity to hard-bottom nesting areas	
	Juveniles	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor and Cape Cod Bay	<14	>25	<80		Bottom habitats, often smooth-bottom near rocks or algae	

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Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Ocean pout	Adults	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor and Cape Cod Bay	<15	32 - 34	<110		Bottom habitats. (Dig depressions in soft sediments, which are then used by other species)	(Major prey: mollusks, crustaceans, echinoderms, sand dollars)
	Spawning adults	GOM, GB, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, and Cape Cod Bay	<10	32 - 34	<50	Late summer to early winter, peaks in Sept. and Oct	Bottom habitats with a hard bottom substrate, including artificial reefs and shipwrecks	(internal fertilization)
Offshore hake	Eggs	Outer Continental Shelf of GB and southern NE south to Cape Hatteras, NC	<20		<1250	Observed all year and primarily collected at depths from 110 – 270 m	Pelagic waters	
	Larvae	Outer Continental Shelf of GB and southern NE south to Chesapeake Bay	<19		<1250	Observed all year and primarily collected at depths from 70 – 130 m	Pelagic waters	
	Juveniles	Outer Continental Shelf of GB and southern NE south to Cape Hatteras, NC	<12		170 - 350		Bottom habitats	

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Offshore hake (cont'd)	Adults	Outer Continental Shelf of GB and southern NE south to Cape Hatteras, NC	<12		150 - 380		Bottom habitats	(Major prey: fish - cannibalistic, shrimp, other crustaceans)
	Spawning adults	Outer Continental Shelf of GB and southern NE south to the Middle Mid-Atlantic Bight	<12		330 - 550	Spawn all throughout the year	Bottom habitats	
Pollock	Eggs	GOM, GB and the following estuaries: Great Bay to Boston Harbor	<17	32 - 32.8	30 - 270	Oct to June, peaks in November to February	Pelagic waters	
	Larvae	GOM, GB and the following estuaries: Passamaquoddy Bay, Sheepscot R., Great Bay to Cape Cod Bay	<17		10 - 250	September to July, peaks from Dec. to February	Pelagic waters	(Migrate inshore as they grow)
	Juveniles	GOM, GB and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay to Waquoit Bay; Long Island Sound, Great South Bay	<18	29 - 32	0 - 250		Bottom habitats with aquatic vegetation or a substrate of sand, mud or rocks	(Intertidal zone may be important nursery area. Juveniles present in shallow intertidal zone at all tide stages throughout summer. Sub-tidal marsh creeks such as Little Egg Harbor, NJ, are also seasonally important as nursery)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Pollock (cont'd)	Adults	GOM, GB, southern NE, and middle mid-Atlantic south to NJ and the following estuaries: Passamaquoddy Bay, Damariscotta R., Mass Bay, Cape Cod Bay, Long Island Sound	<14	31 - 34			Hard-bottom habitats, including artificial reefs	(Major prey: crustaceans, fish, mollusks)
	Spawning adults	GOM, southern NE, and middle mid-Atlantic south to NJ includes Mass Bay	<8	32 - 32.8	15 - 365	September to April, peaks December to February	Bottom habitats with a substrate of hard, stony, or rocky bottom including artificial reefs	
Red drum	Larvae	Along the Atlantic coast from VA through the Florida Keys	2 - 33	Low salinity	<50		Estuarine wetlands especially important .Flooded saltmarshes, brackish marsh, tidal creeks, mangrove fringe, sea grasses	Red drum are euryhaline.
	Juveniles	Along the Atlantic coast from VA through the Florida Keys	2 - 33	20 - 40	<50	Found throughout Chesapeake Bay from Sept. - Nov.	Utilize shallow backwaters of estuaries as nursery areas and remain till they move to deeper-water portions of the estuary associated with river mouths, oyster bars and front beaches	Red drum are eurythermal and larger juveniles and adults more susceptible than small fish to effects of winter cold waves

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Red drum (cont'd)	Adults	Along the Atlantic coast from VA through the Florida Keys	2 - 33	20 - 40	<50	Found in Chesapeake in spring and fall and also along Eastern Shore of VA	Concentrate around inlets, shoals, capes along the Atlantic coast - shallow bay bottoms or oyster reef substrate preferred. Also nearshore artificial reefs.	HAPCs for red drum include all coastal inlets, all state-designated nursery habitats of particular importance to red drum (NC - all primary and secondary nursery areas), SAV extremely important, barrier islands in NC, SC, GA, FL and passes between barrier islands into estuaries
Red hake	Eggs	GOM, GB, continental shelf off southern NE, and middle mid-Atlantic south to Cape Hatteras	<10	< 25		May to November, peaks in June and July	Surface waters of inner continental shelf	
	Larvae	GOM, GB, continental shelf off southern NE, and middle mid-Atlantic south to Cape Hatteras and following estuaries: Sheepscot R., Mass Bay to Cape Cod Bay; Buzzards Bay, Narragansett Bay & Hudson R./ /Raritan Bay	<19	>0.5	<200	May to December, peaks in Sept. and Oct	Surface waters	(Newly settled larvae need shelter, including live sea scallops; also use floating or mid-water objects for shelter.)

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Red hake (cont'd)	Juveniles	GOM, GB, continental shelf off southern NE, and middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay, Mass Bay to Cape Cod Bay; Buzzards Bay to Conn. R.; Hudson R./ /Raritan Bay, & Chesapeake Bay	<16	31 - 33	<100		Bottom habitats with substrate of shell fragments, including areas with an abundance of live scallops	
	Adults	GOM, GB, continental shelf off southern NE, and middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay, Mass Bay to Cape Cod Bay; Buzzards Bay to Conn. R.; Hudson R./ /Raritan, Delaware Bay, & Chesapeake Bay	<12	33 - 34	10 - 130		Bottom habitats in depressions with a substrate of sand and mud	(Major prey: fish and crustaceans)
	Spawning adults	GOM, southern edge of GB, continental shelf off southern NE, and middle mid-Atlantic south to Cape Hatteras and following estuaries: Sheepscott R., Mass Bay, Cape Cod Bay, Buzzards Bay, & Narragansett Bay	<10	>25	<100	May to November, peaks in June and July	Bottom habitats in depressions with a substrate of sand and mud	

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Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Redfish	Eggs	No EFH identification or description for this life history stage						Redfish are ovoviviparous (live bearers)
	Larvae	GOM, southern GB	<15		50 - 270	March to Oct, peak in August	Pelagic waters	
	Juveniles	GOM, southern edge of GB	<13	31 - 34	25 - 400		Bottom habitats with a substrate of silt, mud, or hard bottom	
	Adults	GOM, southern edge of GB	<13	31 - 34	50 - 350		Bottom habitats with a substrate of silt, mud, or hard bottom	
	Spawning adults	GOM, southern edge of GB	<13	31 - 34	5 - 350	April to August	Bottom habitats with a substrate of silt, mud, or hard bottom	Copulation occurs between Oct-Jan. Fertilization is delayed until Feb-Apr
Rosette skate*	Juveniles and Adults	(Nantucket shoals to South Atlantic Bight)	(5 - 24; most found at 10 - 14)	(32 - 36)	(33 - 530)		(Bottom habitats with soft substrate; sand-to -mud bottoms)	*Information for skates extracted from EFH source documents
Scup	Eggs	Southern NE to coastal VA including the following estuaries: Waquoit Bay to Long Island Sound; Gardiners Bay, Hudson R./ /Raritan Bay	13 - 23	>15	(<30)	May - August	Pelagic waters in estuaries	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	**Life Stage**	**Geographic Area**	**Temp. (°C)**	**Salinity (‰)**	**Depth (m)**	**Seasonal Occurrence**	**Habitat Description**	**Comments**
Scup (cont'd)	Larvae	Southern NE to coastal VA including the following estuaries: Waquoit Bay to Long Island Sound; Gardiners Bay, Hudson R./ /Raritan Bay	13 - 23	>15	(<20)	May - September	Pelagic waters in estuaries	
	Juveniles	The continental shelf from GOM to Cape Hatteras, NC, including the following estuaries: Mass Bay, Cape Cod Bay to Long Island Sound; Gardiners Bay to Delaware Inland Bays; & Chesapeake Bay	>7	>15	(0 - 38)	Spring and summer in estuaries and bays	Dermersal waters north of Cape Hatteras and inshore on various sands, mud, mussel, and eelgrass bed type substrates	
	Adults	The continental shelf from GOM to Cape Hatteras, NC, including the following estuaries: Cape Cod Bay to Long Island Sound; Gardiners Bay to Hudson R./ /Raritan Bay; Delaware Bay & Inland Bays; & Chesapeake Bay	>7	>15	(2 - 185)	Wintering adults (November - April) are usually offshore, south of NY to NC.	Dermersal waters north of Cape Hatteras and inshore estuaries (various substrate types)	(Spawn < 30m during inshore migration - May - Aug; prey: small benthic inverts)
Smooth skate*	Juveniles and Adults	(GOM to Cape Hatteras)	(0.5 - 13)	(32 - 35)	(31 - 874)		(Bottom habitats; mostly soft mud, but also broken shell, sand, gravel)	*Information for skates extracted from EFH source documents

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Spanish mackerel		South Atlantic and Mid-Atlantic Bights	>20	>30			Sandy shoals of capes and offshore bars, high high-profile rock bottoms and barrier island ocean-side waters from surf zone to shelf break but from the Gulf Stream shoreward	All coastal inlets
Spiny Dogfish	Juveniles	GOM through Cape Hatteras, NC, across the continental shelf; continental shelf waters South of Cape Hatteras, NC, through FL; also includes estuaries from Passamaquaddy Bay to Saco Bay; Mass Bay & Cape Cod Bay	3 - 28		10 - 390		Continental shelf waters and estuaries	
	Adults	GOM through Cape Hatteras, NC, across the continental shelf waters South of Cape Hatteras, NC, through FL; also includes estuaries from Passamaquaddy Bay to Saco Bay; Mass Bay & Cape Cod Bay	3 - 28	(30 - 32)	10 - 450		Continental shelf waters and estuaries	(Major prey: crabs, eels, small fish)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Summer flounder	Eggs	Over continental shelf from GOM to Cape Hatteras, NC; South of Cape Hatteras to FL			30 - 70 fall; 110 winter; 9 - 30 spring	Oct to May	Pelagic waters; heaviest concentrations within 9 mi of shore off NJ and NY	
	Larvae	Over continental shelf from GOM to Cape Hatteras, NC; South of Cape Hatteras to FL; also includes estuaries from Waquoit Bay to Narragansett Bay; Hudson River/ /Raritan Bay; Barnegat Bay, Chesapeake Bay, Rappahannock R., York R., James R., Albemarie Sound, Pamlico Sound, Neuse R. to Indian R.	(9 - 12)	(23 - 33) Fresh in Hudson R. Raritan Bay area	10 - 70	Mid-Atlantic Bight from Sept. to Feb.; Southern part from Nov. to May at depths 9-30 m	Pelagic waters, larvae most abundant 19-83 km from shore; Southern areas 12 - 52 mi from shore	(High use of tidal creeks and creek mouths)
	Juveniles	Over continental shelf from GOM to Cape Hatteras, NC; South of Cape Hatteras to FL; also includes estuaries from Waquoit Bay to James R.; Albemarie Sound to Indian R.	>11	10 - 30 Fresh in Narraganset Bay, Albemarle /Pamlico Sound, & St. Johns R.	(0.5 - 5) in estuary		Demersal waters, muddy substrate but prefer mostly sand; found in the lower estuaries in flats, channels, salt marsh creeks, and eelgrass beds	HAPC - All native species of macroalgae, sea grasses and freshwater and tidal macrophytes in any size bed as well as loose aggregations, within adult and juvenile EFH. (Major prey: mysid shrimp)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Summer flounder (cont'd)	Adults	Over continental shelf from GOM to Cape Hatteras, NC; South of Cape Hatteras to FL; also includes estuaries from Buzzards Bay, Narragansett Bay, Conn. R. to James R.; Albemarie Sound to Broad R.; St. Johns R., & Indian R.		Fresh in Albemarie Sound, Pamlico Sound, & St. Johns R.	(0 - 25)	Inhabit shallow coastal and estuarine waters during warmer months and move offshore on Outer Continental Shelf at depths of 150 m in colder months	Demersal waters and estuaries	HAPC - All native species of macroalgae, sea grasses and freshwater and tidal macrophytes in any size bed as well as loose aggregations, within adult and juvenile EFH. (Major prey: fish, shrimp, squid, polychaetes)
Thorny skate*	Juveniles and Adults	(GOM to Cape Hatteras)	(-1.3 - 14)	(31 - 36)	(18 -1200; most common at 50 - 100)		(Bottom habitats rangr from broken shell to sand, gravel, or mud.)	*Information for skates extracted from EFH source documents
Tilefish	Eggs	U.S./Canadian boundary to VA/NC boundary (shelf break; GB to Cape Hatteras)	8 - 19	(34 - 36)	76 - 365	(Serial spawning March - Nov; peaks April - Oct)	Water column	
	Larvae	U.S./Canadian boundary to VA/NC boundary Outer Continental Shelf; (GB to Cape Hatteras)	8 - 19	(33 - 35)	76 - 365	(Feb - Oct; peaks July - Oct)	Water column	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Tilefish (cont'd)	Juveniles	U.S./Canadian boundary to VA/NC boundary (shelf break, submarine canyon walls and flanks; GB to Cape Hatteras)	8 - 18	(33 - 36)	76 - 365	(All year; may leave GB in winter)	Rough bottom, small burrows, and sheltered areas. (Substrate - rocky, stiff clay, human debris)	(Tilefish are shelter-seeking and habitat limited.) HAPC is substrate between the 76 and 365m isobath, from U.S./ Canadian boundary to the VA /NC boundary within statistical areas 616 and 537 (intersection of isobaths east of Cape May, NJ, and south of Provincetown, MA)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Tilefish (cont'd)	Adults	U.S./Canadian boundary to VA/NC boundary (shelf break, submarine canyon walls and flanks; GB to Cape Hatteras)	8 - 18	(33 - 36)	76 - 365	(All year; may leave GB in winter)	Rough bottom, small burrows, and sheltered areas. (Substrate - rocky exposed ledges, stiff clay)	HAPC is substrate between the 76 and 366m isobath, from U.S./Canadian boundary to the VA /NC boundary within statistical areas 616 and 537 (intersection of isobaths east of Cape May, NJ. and south of Provincetown, MA.) (Prey: crustaceans, fish, decapods, benthic epifauna)
White hake	Eggs	GOM, GB, southern NE and the following estuaries: Great Bay to Cape Cod Bay				August to September	Surface waters	
	Larvae	GOM, southern edge of GB, southern NE to middle mid-Atlantic and the following estuaries: Mass Bay, to Cape Cod Bay				May-mid-Atlantic area Aug. and Sept. - GOM, GB area	Pelagic waters	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
White hake (cont'd)	Juveniles	GOM, southern edge of GB, southern NE to middle mid-Atlantic and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay	<19		5 - 225	May-Sep - pelagic	Pelagic stage: pelagic waters; Dermersal stage : Bottom habitat with sea grass beds or substrate of mud or fine-grained sand	
	Adults	GOM, southern edge of GB, southern NE to middle mid-Atlantic and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay	<14		5 - 325		Bottom habitats with substrate of mud or fine-grained sand	(Major prey: small fish, shrimp and other crustaceans)
	Spawning adults	GOM, southern edge of GB, southern NE to mid-Atlantic	<14		5 - 325	April to May: southern part of range; August – Sept: northern part of range	Bottom habitats with substrate of mud or fine-grained sand in deep water.	
Whiting (Silver hake)	Eggs	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Merrimack R. to Cape Cod Bay	<20		50 - 130	All year, peaks June to Oct	Surface waters	
	Larvae	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Mass Bay to Cape Cod Bay	<20		50 - 130	All year, peaks July to September	Surface waters	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Whiting (Silver hake) (cont'd)	Juveniles	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Casco Bay, Mass Bay to Cape Cod Bay	<21	>20	20 - 270		Bottom habitats of all substrate types	
	Adults	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Casco Bay, Mass Bay to Cape Cod Bay	<22		30 - 325		Bottom habitats of all substrate types	
	Spawning adults	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Mass Bay and Cape Cod Bay	<13		30 - 325		Bottom habitats of all substrate types	
Windowpane flounder	Eggs	GOM, GB, southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<20		<70	February to November, peaks May and Oct in middle mid-Atlantic July - August on GB	Surface waters	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Windowpane flounder (cont'd)	Larvae	GOM, GB, southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<20		<70	February to November, peaks May and Oct in middle mid-Atlantic July - August on GB	Pelagic waters	
	Juveniles	GOM, GB, southern NE, middle mid-Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Chesapeake Bay	<25	5.5 - 36	1 - 100		Bottom habitats with substrate of mud or fine-grained sand	
	Adults	GOM, GB, southern NE, middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Chesapeake Bay	<26.8	5.5 - 36	1 - 75		Bottom habitats with substrate of mud or fine-grained sand	(Major prey: polychaetes, small crustaceans, mysids, small fish)
	Spawning adults	GOM, GB, southern NE, middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<21	5.5 - 36	1 - 75	February - December, peak in May in mid-Atlantic	Bottom habitats with substrate of mud or fine-grained sand	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Winter flounder	Eggs	GB, inshore areas of GOM, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<10	10 - 30	<5	February to June, peak in April on GB	Bottom habitats with a substrate of sand, muddy sand, mud, and gravel	On GB, eggs are generally found in water temp < 8°C, and < 90 m deep.
	Larvae	GB, inshore areas of GOM, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<15	4 - 30	<6	March to July, peaks in April and May on GB	Pelagic and bottom waters	
	Juveniles (age 1+)	GB, inshore areas of GOM, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	<25	10 - 30	1 - 50		Bottom habitats with a substrate of mud or fine-grained sand	YOY exist where water temp < 28 °C, depths 0.1 – 10 m, salinities 5 - 33 (Major prey: amphipods, copepods, polychaetes, bivalve siphons)
	Adults	GB, inshore areas of GOM, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	<25	15 - 33	1 - 100		Bottom habitats including estuaries with substrate of mud, sand, gravel	(Major prey: amphipods, polychaetes, bivalve siphons, crustaceans)

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Winter flounder (cont'd)	Spawning adults	GB, inshore areas of GOM, southern NE, middle mid-Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<15	5.5 - 36	<6**	February to June	Bottom habitats, including estuaries with substrate of mud, sand, gravel	**except on GB, where they spawn as deep as 80m
Winter skate*	Juveniles and Adults	(GOM to Cape Hatteras)	(-1.2 - 19)	(15 - 36)	(0 - 371)		(Bottom habitats with sand, gravel, or mud)	*Information for skates extracted from EFH source documents

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Witch flounder	Eggs	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras	<13	High	Deep	March to Oct	Surface waters	
	Larvae	GOM, GB, continental shelf off southern NE, middle mid-Atlantic south to Cape Hatteras	<13	High	Deep	March to November, peaks in May - July	Surface waters to 250m	
	Juveniles	GOM, Outer Continental Shelf from GB south to Cape Hatteras	<13	34 - 36	50 – 1,500 m		Bottom habitats with fine-grained substrate	(the upper slope is nursery area; major prey: crustaceans, polychaetes, mollusks)
	Adults	GOM, Outer Continental Shelf from GB south to Chesapeake Bay	<13	32 - 36	25 - 300		Bottom habitats with fine-grained substrate	(Major prey: polychaetes, echinoderms, crustaceans, mollusks, squid)
	Spawning adults	GOM, Outer Continental Shelf from GB south to Chesapeake Bay	<15	32 - 36	25 - 360	March to November, peaks in May-August	Bottom habitats with fine-grained substrate	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.7. Essential Fish Habitat (EFH) Parameters in U.S. Waters of the North or Central Atlantic (continued).

Species	**Life Stage**	**Geographic Area**	**Temp. (°C)**	**Salinity (‰)**	**Depth (m)**	**Seasonal Occurrence**	**Habitat Description**	**Comments**
Yellowtail flounder	Eggs	GB, Mass Bay, Cape Cod Bay, southern NE continental shelf south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay to Cape Cod Bay	<15	32.4 - 33.5	30 - 90	Mid-March to July, peaks in April to June in southern NE	Surface waters	
	Larvae	GB, Mass Bay, Cape Cod Bay, southern NE continental shelf, middle mid-Atlantic south to Chesapeake Bay and the following estuaries: Passamaquoddy Bay to Cape Cod Bay	<17	32.4 - 33.5	10 - 90	March to April in New York bight; May to July in south NE and southeastern GB	Surface waters	(Largely an oceanic nursery)
	Juveniles	GB, GOM, southern NE continental shelf south to Delaware Bay and the following estuaries: Sheepscot R., Casco Bay, Mass Bay to Cape Cod Bay	<15	32.4 - 33.5	20 - 50		Bottom habitats with substrate of sand or sand and mud	
	Adults	GB, GOM, southern NE continental shelf south to Delaware Bay and the following estuaries: Sheepscot R., Casco Bay, Mass Bay to Cape Cod Bay	<15	32.4 - 33.5	20 - 50		Bottom habitats with substrate of sand or sand and mud	(Major prey: annelids, arthropods, mollusks)
Yellowtail flounder (cont'd)	Spawning adults	GB, GOM, southern NE continental shelf south to Delaware Bay and the following estuaries: Mass Bay to Cape Cod Bay	<17	32.4 33.5	10 - 125		Bottom habitats with substrate of sand or sand and mud	

Notes: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Ecological information from sources other than EFH designations is contained in parentheses.

Abbreviations: GOM – Gulf of Maine; GB – George's Bank; NE: New England; Mass Bay: Massachusetts Bay; HAPC – Habitat area of particular concern; YOY –young-of-year.

Highly migratory species (sharks, tunas, billfish) are omitted from the table.

Table 3.8.

Summary of Essential Fish Habitat (EFH) Parameters for Federally Managed Invertebrate Species.

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic sea scallop	Eggs	GOM, GB, southern NE and middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<17			May through Oct. Peaks in May and June in middle mid-Atlantic area, and in Sept. and Oct on GB and GOM	Bottom habitats	Eggs remain on sea floor until they develop into the first free-swimming larval stage.
	Larvae	GOM, GB, southern NE and middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<18	16.9 - 30			Pelagic waters and bottom habitats with a substrate of gravelly sand, shell fragments, pebbles, or on various red algae, hydroids, amphipod tubes and bryozoans	
	Juveniles	GOM, GB, southern NE and middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Great Bay, Mass Bay, and Cape Cod Bay	<15		18 - 110		Bottom habitats with a substrate of cobble, shells, and silt	(Prey: filter feeders on phytoplankton; preferred substrates are associated with low concentrations of inorganics for optimal feeding.)
	Adults	GOM, GB, southern NE and middle mid-Atlantic south to VA/NC border and the following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Great Bay, Mass Bay, and Cape Cod Bay	<21	>16.5	18 - 110		Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand.	

Source: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Additional ecological information, from sources other than EFH designations, is contained in parentheses. Abbreviations: GOM – Gulf of Maine; GB – George's Bank; HAPC – habitat area of particular concern; YOY – young of year.

Note: EFH is identified in U.S. waters of the North and Central Atlantic.

Table 3.8. Summary of Essential Fish Habitat (EFH) Parameters for Federally Managed Invertebrate Species (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic sea scallop, (con't)	Spawning adults	GOM, GB, southern NE and middle mid-Atlantic south to VA-NC border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<16	>16.5	18 - 110	May through Oct, peaks in May and June in middle mid-Atlantic area, and in Sept. and Oct on GB and in GOM	Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand	
Illex squid	Juveniles	Over continental shelf from GOM through Cape Hatteras, NC	2 - 23		0 - 182	(Carried northward by Gulf Stream)	Pelagic waters	
	Adults	Over continental shelf from GOM through Cape Hatteras, NC	4 - 19		0 - 182	(late fall - offshore, spawn Dec- Mar)	Pelagic waters	(prey: fish, crustaceans, squid; die after spwaning)
Loligo squid	Eggs***	Over continental shelf from GOM through Cape Hatteras, NC	(>8)	(30 - 32)	(<50)	(Spawn in May, hatch in Jul)	(Demersal egg masses are commonly found on sandy/mud bottom, usually attached to rocks/boulders, pilings, or algae such as fucus, ulva, laminaria, porphyra)	*** EFH is not currently designated for this life stage. (Eggs are demersal, enclosed in gelatinous capsules each containing up to 200 eggs. Laid in masses of hundreds of capsules from different females)
	Juveniles	Over continental shelf from GOM through Cape Hatteras, NC	4 - 27	(31 - 34)	0 - 213	Spring – fall: inshore Winter: offshore	Pelagic waters	(Inhabit upper 10 m at depth of 50 – 100 m on continental shelf)

Source: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Additional ecological information, from sources other than EFH designations, is contained in parentheses. Abbreviations: GOM – Gulf of Maine; GB – George's Bank; HAPC – habitat area of particular concern; YOY – young of year.

Note: EFH is identified in U.S. waters of the North and Central Atlantic.

Table 3.8. Summary of Essential Fish Habitat (EFH) Parameters for Federally Managed Invertebrate Species (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Adults	Over Continental shelf from GOM through Cape Hatteras, NC	4 - 28		0 – 305	(Mar - Oct - inshore; winter - offshore)	Pelagic waters	(prey: fish, crustaceans)
Ocean quahog	Juveniles	Eastern edge of GB and GOM throughout the Atlantic EEZ	<18	(>25)	8 – 245		Throughout substrate to a depth of 3 ft within Federal waters, occurs progressively further offshore between Cape Cod and Cape Hatteras	(medium to fine fine-grained sands, sandy mud, silty sand)
	Adults	Eastern edge of GB and GOM throughout the Atlantic EEZ	<18	(>25)	8 – 245	(Spawn May-Dec with several peaks)	Throughout substrate to a depth of 3 ft within Federal waters, occurs progressively further offshore between Cape Cod and Cape Hatteras	(Medium-to- fine-grained sands, sandy mud, silty sand; earliest age of maturity 7 yrs, avg 13 yrs; suspension feeders on phytoplankton)

Source: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Additional ecological information, from sources other than EFH designations, is contained in parentheses. Abbreviations: GOM – Gulf of Maine; GB – George's Bank; HAPC – habitat area of particular concern; YOY – young of year.

Note: EFH is identified in U.S. waters of the North and Central Atlantic.

Table 3.8. Summary of Essential Fish Habitat (EFH) Parameters for Federally Managed Invertebrate Species (continued).

Species	Life Stage	Geographic Area	Temp. (°C)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Surf clams	Juveniles	Eastern edge of GB and the GOM throughout Atlantic EEZ	(2 - 30)		0 - 60 , low density beyond 38		Throughout substrate to a depth of 3 feet within Federal waters. (Burrow in medium-to-coarse sand and gravel substrates. Also found in silty to fine sand, not in mud)	
	Adults	Eastern edge of GB and the GOM throughout Atlantic EEZ	(2 - 30)		0 - 60 , low density beyond 38	(Spawn summer to fall at 19 - 30 °C)	Throughout substrate to a depth of 3 feet within Federal waters	

Source: Table adapted from USDOC, NMFS (2009). The majority of information presented was extracted from the Regional Fishery Management Council's EFH designations. Additional ecological information, from sources other than EFH designations, is contained in parentheses. Abbreviations: GOM – Gulf of Maine; GB – George's Bank; HAPC – habitat area of particular concern; YOY – young of year.

Note: EFH is identified in U.S. waters of the North and Central Atlantic.

Table 3.9

Species with EFH Source Documents Available at the NEFSC Website

Common name	**Scientific name**	**EFH source document**
Acadian redfish	*Sebastes fasciatus*	Pikanowski et al. 1999
American plaice	*Hippoglossoides platessoides*	Johnson 2005
Atlantic cod	*Gadus morhua*	Lough 2004
Atlantic halibut	*Hippoglossus hippoglossus*	Cargnelli et al. 1999a
Atlantic herring	*Clupea harengus*	Stevenson and Scott 2005
Atlantic mackerel	*Scomber scombrus*	Studholme et al. 1999
Atlantic surf clam	*Spisula solidissima*	Cargnelli et al. 1999d
Barndoor skate	*Dipturus laevis*	Packer et al. 2003a
Black sea bass	*Centropristis striata*	Drohan et al. 2007
Bluefish	*Pomatomus saltatrix*	Shepherd and Packer 2005
Butterfish	*Peprilus triacanthus*	Cross et al. 1999
Clearnose skate	*Raja eglanteria*	Packer et al. 2003b
Goosefish (monkfish)	*Lophius americanus*	Steimle et al. 1999a
Haddock	*Melanogrammus aeglefinus*	Brodziak 2005
Little skate	*Raja erinacea*	Packer et al. 2003c
Longfin inshore squid	*Loligo pealeii*	Jacobson 2005
Northern shortfin squid	*Illex illecebrosus*	Hendrickson and Holmes 2004
Ocean pout	*Marcozoarces americanus*	Steimle et al. 1999b
Ocean quahog	*Arctica islandica*	Cargnelli et al. 1999e
Offshore hake	*Merluccius albidus*	Chang et al. 1999a
Pollock	*Pollachius virens*	Cargnelli et al. 1999b
Red hake	*Urophycis chuss*	Steimle et al. 1999c
Rosette skate	*Leucoraja garmani virginica*	Packer et al. 2003d
Scup	*Stenotomus chrysops*	Steimle et al. 1999d
Sea Scallop	*Placopecten magellanicus*	Hart and Chute 2004
Silver hake (whiting)	*Merluccius bilinearis*	Lock and Packer 2004
Smooth skate	*Malacoraja senta*	Packer et al. 2003e
Spiny dogfish	*Squalus acanthias*	Stehlik 2007
Summer flounder	*Paralichthys dentatus*	Packer et al. 1999
Thorny skate	*Amblyraja radiata*	Packer et al. 2003f
Tilefish	*Lopholatilus chamaeleonticeps*	Steimle et al. 1999e
White hake	*Urophycis tenuis*	Chang et al. 1999c
Windowpane	*Scophthalmus aquosus*	Chang et al. 1999b
Winter flounder	*Pseudopleuronectes americanus*	Pereira 1999
Winter skate	*Raja ocellata*	Packer et al. 2003g
Witch flounder	*Glyptocephalus cynoglossus*	Cargnelli et al. 1999c
Yellowtail flounder	*Limanda ferruginea*	Johnson et al. 1999

Source: NEFSC 2009

3.5 BENTHIC RESOURCES AND SEAFLOOR HABITATS

Benthic communities are composed of plants and animals living in close association with seafloor habitat. These communities form diverse and productive components of the Northeast

Shelf LME. Benthic organisms serve vital ecological functions in wide-ranging capacities. Some species decompose organic material as a crucial step in nutrient cycling; others filter suspended particles from the water column, contributing to water clarity. Benthic fauna are also an essential food source for fish and other organisms. As such, spatial and temporal variation in benthic prey items can affect the growth, survival, and population levels of predator species at all higher trophic levels. In addition to their ecological importance, benthic communities are useful indicators of environmental change and anthropogenic impacts, and a number of invertebrate species support valuable commercial fisheries.

The most valuable commercial fisheries in the northeast region are supported, not by fish species, but by two benthic invertebrate species, American lobster (*Homarus americanus*) and sea scallop (*Placopecten magellanicus*) (Aquarone and Adams 2009). Many other invertebrates, including hard clam (*Mercenaria mercenaria*), Atlantic surfclam (*Spisula solidissima*), white shrimp (*Penaeus setiferus*), longfin squid (*Loligo pealeii*), shortfin squid (*Illex illecebrosus*), ocean quahog (*Arctica islandica*), and softshell clam (*Mya arenaria*), also support important commercial fisheries. Like fish, these high-profile commercial species have received considerable attention from researchers. Invertebrate fisheries are managed under the same system as described for fish in section 3.4. Essential fish habitat (EFH) has been designated for five invertebrate species (sea scallop, Atlantic surfclam, longfin squid, shortfin squid, and ocean quahog) in the northeast region; EFH for these species is discussed in section 3.4.3. In addition to their commercial value, the large, dominant species that support invertebrate fisheries play important ecological roles in benthic communities.

Information and data to characterize benthic communities and seafloor habitats have been produced by a number of sources including Federal and state government agencies and academic research. NMFS technical reports provide a key source of information for living benthic resources. Steimle et al. (1995) reviewed the history of benthic research at the NMFS Northeast Fisheries Science Center (NEFSC). Beginning in the 1870s, NEFSC conducted a plethora of studies that have produced an extensive benthic database (Steimle et al. 1995). The U.S. Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) has also provided valuable data and information on benthic communities and habitat for a number of areas within the northeast region. The BOEMRE has conducted environmental surveys to support responsible decision making in their offshore sand-and-gravel leasing programs. Technical reports that characterize benthic communities in potential offshore borrow areas are available for several areas within the region. Benthic communities comprise a diverse assemblage of organisms that function within the complex ecological dynamics of the Northeast Shelf LME, and despite over a century of research much remains to be learned about benthic resources and the habitats that support them.

The following review of benthic resources characterizes the benthos with a focus on information that is most relevant to understanding potential impacts to benthic resources from offshore alternative energy facilities. In addition to characterizing the composition of benthic communities in the region, this review includes information regarding distribution and habitat associations for benthic assemblages. No invertebrate marine species in the northeast region are currently federally listed as threatened or endangered, and the individual species discussed herein generally include community dominants or high-profile, commercially important species.

Benthic communities are typically delineated based on bottom substrate type into soft-bottom and hard-bottom communities. Marine organisms have evolved to exploit these different substrates, resulting in differing species compositions (to some extent) associated with each. Sampling methods to survey these habitat types also differ, by necessity, and research often focuses separately on either soft-bottom or hard-bottom habitats. Hence, this synthesis is divided into separate sections for soft-bottom (section 3.5.1) and hard-bottom communities (section 3.5.2).

3.5.1 Soft-Bottom Benthic Communities

The majority of benthic habitat throughout the Northeast Shelf region is soft-bottom habitat with a substrate composed of unconsolidated sediments including clay, silt, sand, or gravel, in some combination (Stevenson et al. 2004). Benthic invertebrates in soft-bottom habitats are grouped based on whether they normally live within the sediments or on their surface. Organisms living within soft sediments are referred to as infauna, while those that reside on the seafloor surface are known as epifauna.

Benthic organisms are often further delineated based on body size into different sub-components of the benthic community. *Megafauna* (greater than 1 cm), *macrofauna* (greater than 0.5 mm), *meiofauna* (less than 0.5 mm), and *microfauna* (less than 0.05 mm) refer to size classes of benthic invertebrates that are often considered separately based on differing ecological roles and sample collection methodology. Most surveys of soft-bottom benthos focus on macrofauna, although research on meiofauna is also common (Brooks et al. 2006). Epibenthic megafauna are collected in bottom trawl surveys, and often reported along with fish data (e.g., Bonzek et al. 2008). In addition, benthic studies are rarely designed to strictly delineate a particular component of the benthic community. Grab samples capture both epifauna and infauna, and a 0.5-mm-mesh screen (often used for macrofaunal surveys in the northeast region) retains both megafauna and macrofauna (along with some organisms that could be classified as meiofauna). Comparisons among studies therefore require careful attention to the details of sampling methodology regarding the faunal community reported. Based on available research, most of the following review focuses on macrofaunal and megafaunal invertebrates.

Faunal Composition

Comprehensive quantitative surveys of the macrobenthic invertebrate fauna in the Northeast Shelf region were conducted by NMFS (formerly the Bureau of Commercial Fisheries) in cooperation with the U.S. Geological Survey and the Woods Hole Oceanographic Institution during the mid-1950s to the mid-1960s. Macrofaunal samples were collected using various grab samplers in water depths ranging from 3 to 3,975 m, and were sieved through a 1-mm mesh screen. The majority of samples were collected from shelf depths. Results of these surveys were reported by Wigley and Theroux (1981) and Theroux and Wigley (1998).

Wigley and Theroux (1981) reported on the distribution, density and biomass of the macrobenthos in offshore waters of the MAB from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts, based on samples from 563 sites in the region. Four hundred forty-one species representing 17 phyla were collected. The numerically dominant higher taxonomic groups were Arthropoda (45 percent of total), Mollusca (25 percent of total), Annelida (21 percent of total), and Echinodermata (4 percent of total); remaining miscellaneous groups accounted for 5 percent of total. Within these groups, the following genera were listed as dominants: *Trichophoxus*, *Leptocheirus*, *Ampelisca*, *Unciola* (Arthropoda: Amphipoda); *Cirolana* (Arthropoda: Isopoda); *Balanus* (Arthropoda: Cirripedia); *Alvania*, *Cylichna*, *Nassarius* (Mollusca: Gastropoda); *Nucula*, *Cyclocardia*, *Astarte*, *Thyasira* (Mollusca: Bivalvia); *Scalibregma*, *Nephtys*, *Maldane*, *Sabella*, *Spiophanes* (Annelida: Polychaeta); and *Echinarachnius* (Echinodermata: Echinoidea). When characterized based on biomass, the macrobenthos of the MAB was dominated by the same four major taxonomic groups, with the following relative contributions: Mollusca (71 percent), Echinodermata (12 percent), Annelida (7 percent), and Arthropoda (5 percent); remaining miscellaneous groups accounted for 5 percent of total. Mollusks that were major contributors to the biomass included the bivalves *Arctica*, *Astarte*, *Cyclocardia*, *Mulinia*, and *Ensis*, and the gastropods *Buccinum* and *Nassarius*. Dominant echinoderms in terms of biomass included the asteroid *Astropecten* and the echinoids *Echinarachnius* and *Brisaster* (Wigley and Theroux 1981).

Theroux and Wigley (1998) reported on the faunal composition of the New England macrobenthos in the offshore waters from Maine to Long Island, New York, based on 1,076 samples collected mostly from shelf depths. Similar to the MAB and typical of boreal-temperate faunal assemblages, a moderate number of macrofaunal species (567 species, representing 13 phyla) were identified from the New England samples. The four phyla that were reported as dominant in the MAB (i.e., Mollusca, Echinodermata, Annelida, and Arthropoda), were also dominant in New England waters. And the relative dominance of the major taxonomic groups in New England waters was very similar to that in the MAB. By percentage of total specimens, the following groups were dominant: Amphipoda (43 percent), Annelida (28 percent), and Bivalvia (11 percent). By percentage of total biomass, the dominant groups were: Bivalvia (44 percent), Echinoidea (20 percent), Annelida (10 percent), and Holothuroidea (7 percent). Notable species in New England waters based on common occurrence or regional ubiquity included the polychaetes *Aphrodita hastata*, *Scalibregma inflatum*, and *Sternaspis scutata*; the bivalves *Arctica islandica* (ocean quahog), *Astarte undata*, *Cyclocardia borealis*, *Modiolus modiolus* (horse mussel), and *Placopecten magellanicus* (sea scallop); the amphipods *Ampelisca agassizi*, *Leptocheirus pinguis*, and *Unciola irrorata*; the decapods *Crangon septemspinosa* and *Homarus americanus* (American lobster); members of the isopod genus *Cirolana*; the echinoderms *Asterias vulgaris*, *Echinarachnius parma* (northern sand dollar), *Strongylocentrotus droebachiensis* (green sea urchin), and *Ophiura* spp. (Theroux and Wigley 1998).

Faunal Distribution

Wigley and Theroux (1981) and Theroux and Wigley (1998) reported clear patterns in macrofaunal density and biomass relative to geography and bathymetry. Throughout the Northeast Shelf region faunal density and biomass decreased from shallow to deep water.

The pattern of decreasing faunal abundance with depth in New England was striking. Mean densities of over 2,200 individuals per square meter of bottom area were reported for samples from less than 100 m depth, while numbers per square meter dropped precipitously to 907 between 100 and 200m, 505 between 200 and 500 m, 272 between 500 and 1,000 m, 122 between 1,000 and 2,000 m, and 75 between 2,000 and 4,000 m (Theroux and Wigley 1998).

Within shelf depths, mean faunal densities were highest in the shallow waters (2,503 between 0 and 25 m) and similar throughout the remainder of the shelf (2,232 between 25 and 50 m, 2,257 between 50 and 100 m; Theroux and Wigley 1998).

Faunal quantities decreased from north to south within the MAB, while both density and biomass increased from northeast to southwest in New England waters (Wigley and Theroux 1981; Theroux and Wigley 1998). Despite these general trends in geographic distribution of faunal densities, substantial differences in faunal quantities and in the composition of assemblages were found among different geographic subareas within the region. For example, annelid worms were numerical dominants in the GOM (35 percent), followed by bivalve mollusks (33 percent), and amphipod crustaceans (14 percent; Theroux and Wigley 1998). In contrast, samples collected on Georges Bank were numerically dominated by amphipod crustaceans (49 percent) and annelid worms (28 percent; Theroux and Wigley 1998).

Several unique areas with high faunal densities and biomass were also identified within the Northeast Shelf region (see Figures 3.5 to 3.7). Included among these was an exceedingly rich area at the mouth of the Bay of Fundy where densities were greater than 5,000 per square meter and biomass was over 500 grams per square meter (Theroux and Wigley 1998). Other rich areas were located throughout much of the near-coastal zone in the GOM; on southwestern Georges Bank, near the southern end of Great South Channel; and in several smaller areas in the coastal region of Rhode Island and New York (Theroux and Wigley 1998). Uniquely high quantities of animals were also identified in several regions of the MAB including small areas off the south coast of New Jersey, near the mouth of Delaware Bay; near the shelf break offshore from Chesapeake Bay; and in near-coastal waters off Maryland (Wigley and Theroux 1981). Prezant et al. (2002) also reported unique attributes of the fauna from shallow waters surrounding Assateague Island, Maryland, and Virginia. Exceptionally large individuals of certain mollusk species were collected during surveys (including benthic grabs, trawls, and hand collecting) of malacofaunal species, adding to previous records of gigantism for the region (Prezant et al. 2002).

Habitat Associations

The distribution of benthic organisms and assemblages is influenced by a number of physical and biological factors. Patterns of distribution and abundance vary at different spatial scales. At large spatial scales, faunal distribution in the Northeast Shelf region varies with geography and bathymetry (Wigley and Theroux 1981; Theroux and Wigley 1998). At smaller spatial scales, recognition of distributional patterns becomes more complex, with habitat attributes such as composition of the substrate and hydrographic conditions contributing to the list of factors that may influence faunal distribution.

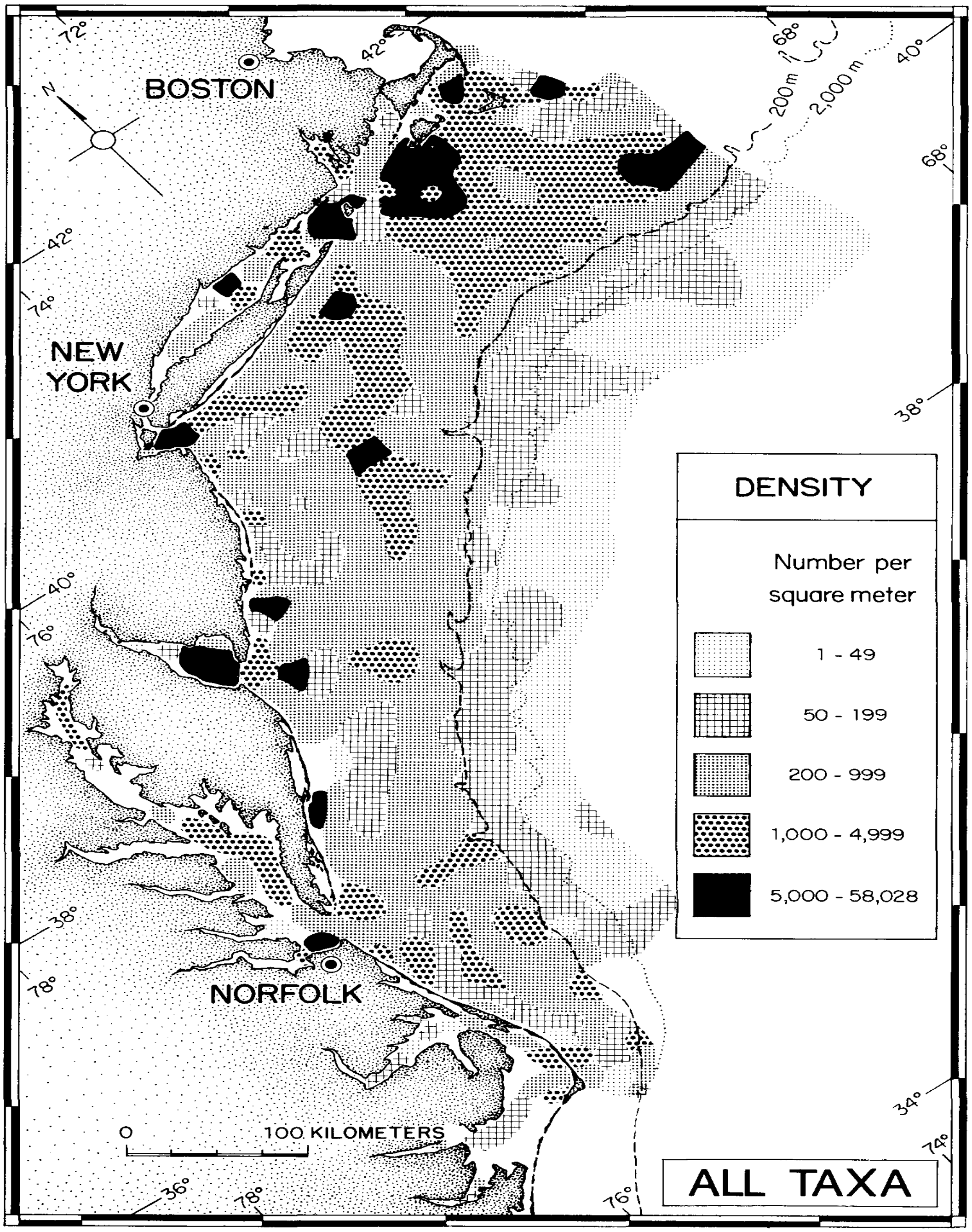

Figure 3.5. Density (number of individuals per square meter) distribution of macrofaunal taxa in the MAB. (Source: Wigley and Theroux 1981).

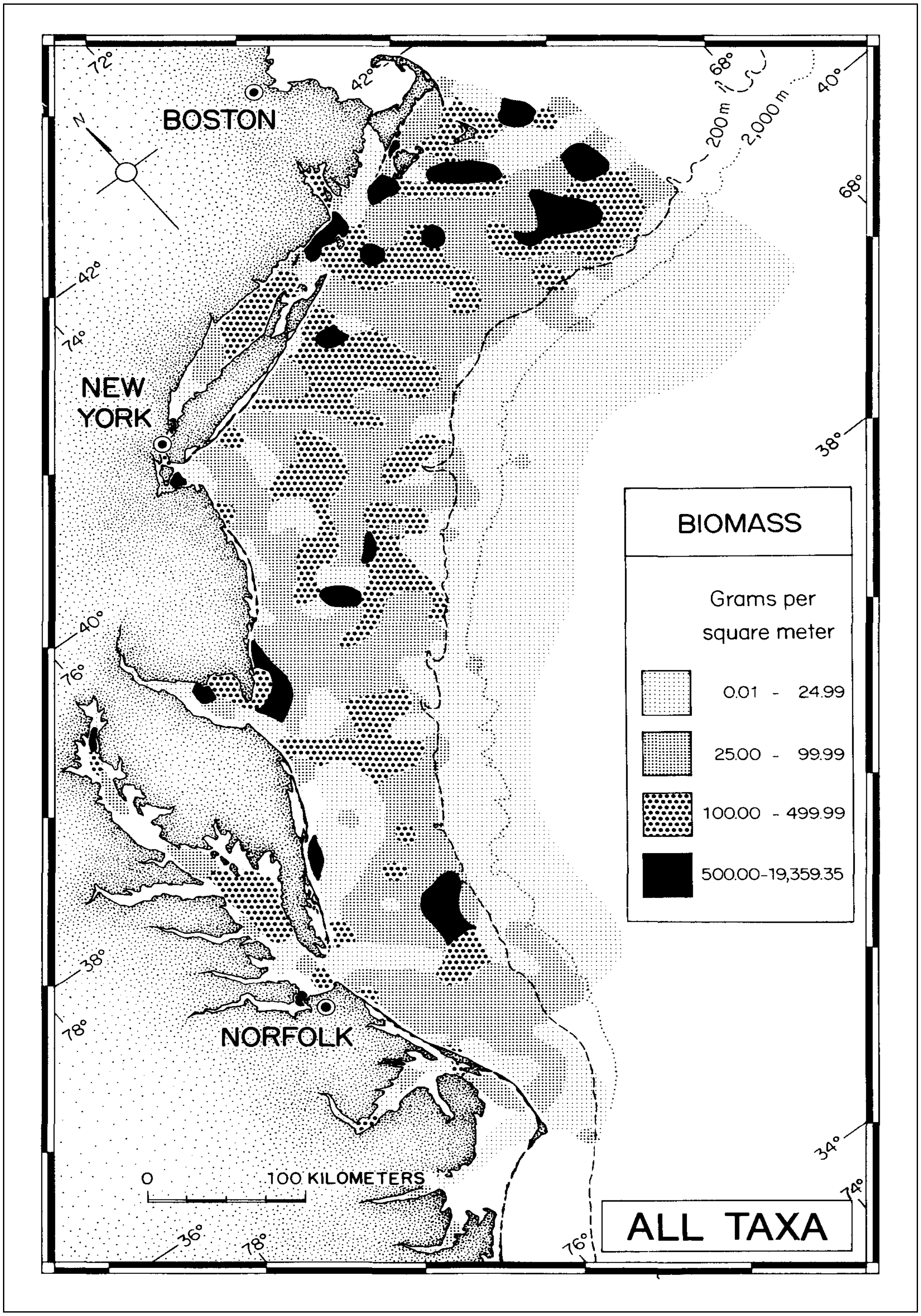

Figure 3.6. Biomass (grams per square meter) distribution of macrofaunal taxa in the MAB. (Source: Wigley and Theroux 1981)

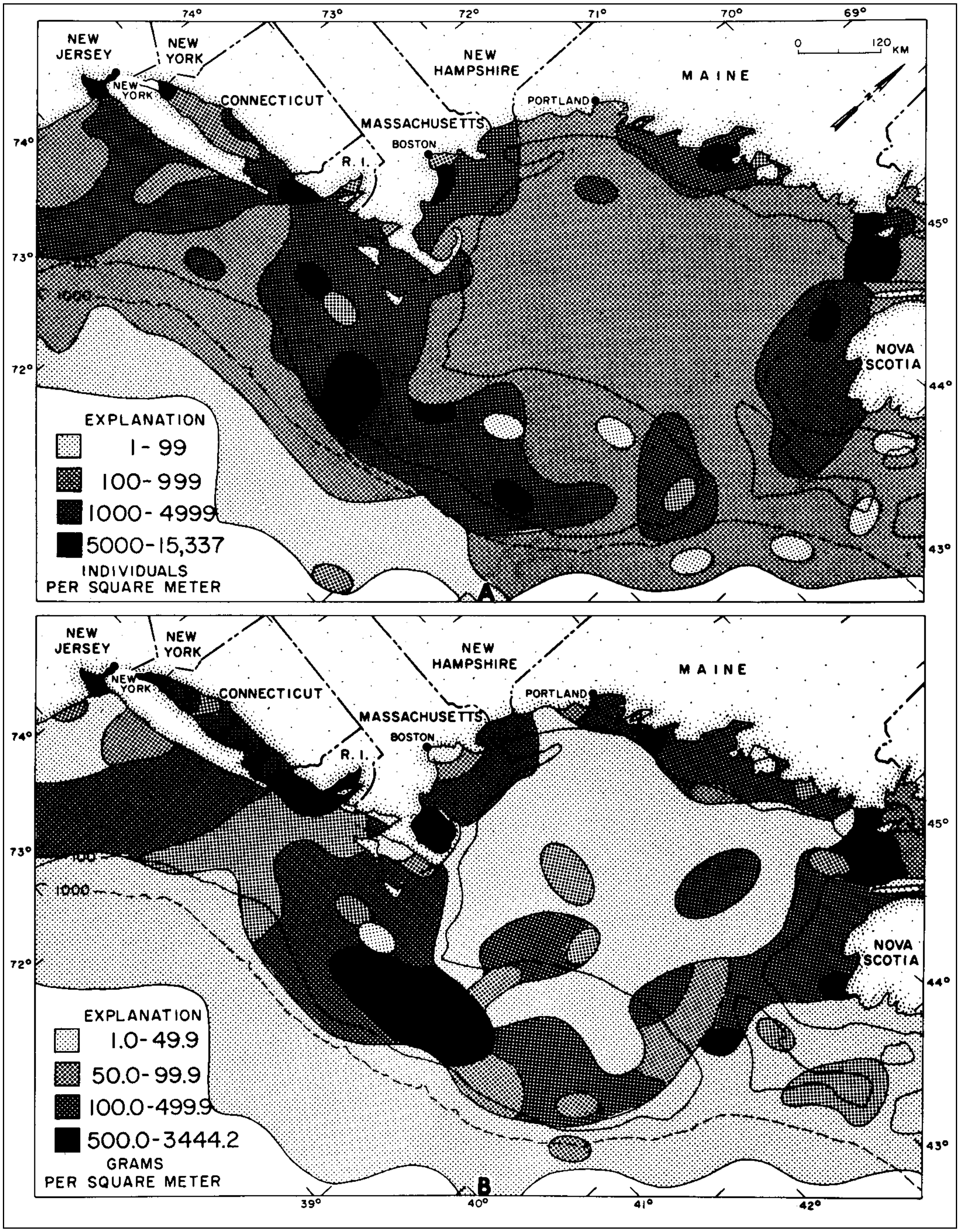

Figure 3.7. (A) Density (number of individuals per square meter) distribution of macrofaunal taxa in New England waters. (B) Biomass (grams per square meter) distribution of macrofaunal taxa in New England waters. (Source: Theroux and Wigley 1998)

Sisson et al. (2002) used a mapping technique that involved scuba divers and underwater acoustic location to survey epibenthic assemblages relative to sedimentary features at a shallow-water, high-energy environment off the southern shore of Martha's Vineyard Island, Massachusetts. The authors reported that large patches (on the order of 100 m) of the tube worm *Spiophanes bombyx* were found in fine sand habitats while the sand dollar, *Echinarachnius. parma,* was found in coarse sand. Theroux and Wigley (1998) also reported that sediment composition was an important factor influencing both species composition and abundance in benthic communities of New England waters. Coarser-grained sediments supported a higher diversity and quantity of fauna than did fine-grained sediments (Theroux and Wigley 1998). Although similar relationships have been reported by a number of benthic researchers, Snelgrove and Butman (1994) questioned the strength of the relationship between sediment characteristics and the distribution of soft-bottom macroinvertebrates. Their critical review of animal-sediment relationships suggested that associations between fauna and sediment types are less distinct than traditionally purported.

In addition to research investigating associations between benthic organisms and habitat, a number of surveys have targeted specific areas or habitats in the northeast region for the purpose of assessing environmental impacts from human activities. The primary focus of these surveys has been sand habitats in the MAB, although projects ranging from wastewater discharge monitoring in Massachusetts Bay (Werme and Hunt 2007) to the Cape Wind Energy Project in Nantucket Sound (USDOI, MMS 2009) provide site-specific benthic data. Valente (2001) also reported site-specific survey data for benthic invertebrate communities in Massachusetts waters. Benthic surveys were conducted in eastern Buzzards Bay, Massachusetts, at two candidate dredged- material disposal sites and nearby reference areas. Survey data is also available for soft-bottom benthos in the New York Bight. Reid et al. (1991) and Chang et al. (1992) reported on benthic macrofaunal assemblages relative to sediment conditions and levels of sediment contamination in the New York Bight. Over a decade of survey data was reviewed for effects on the benthos from the sewage sludge dump site.

BOEMRE has conducted a number of benthic surveys to support its leasing program for sand and gravel mining in Federal waters on the Outer Continental Shelf. Technical reports that characterize benthic communities in potential offshore borrow areas are available for several areas in the MAB. These reports provide site-specific information on benthic communities in areas offshore North Carolina (Byrnes et al. 2003), Virginia (Cutter and Diaz 1998; TLB Group 1999), Maryland (Slacum et al. 2006; Cutter et al. 2000; TLB Group 1999), Delaware (Slacum et al. 2006; Cutter et al. 2000; TLB Group 1999), New Jersey (Byrnes et al. 2004; Byrnes et al. 2000; TLB Group 1999) and New York (Byrnes et al. 2004). These surveys were all conducted in Federal waters, generally beginning just seaward of the Federal-state line at 3 mi, and typically remaining within the 20-meter isobath.

Much of the research on soft-bottom benthos in the northeast region was reviewed by Brooks et al. (2004) and Brooks et al. (2006). These literature reviews (a USGS technical report and a journal article on the same project) focused on benthic faunal assemblages associated with sand banks along the U.S. East Coast and Gulf of Mexico Outer Continental Shelf. Faunal communities associated with sand banks were reviewed relative to potential impacts from sand mining. Polychaetes, archiannelids, asteroids, and amphipods were all reported as dominant taxa in surveys from the northern East Coast (Brooks et al. 2006). In those references that identified dominant species, the spionid polychaete *Spiophanes bombyx* was most often cited as the numerical dominant. The amphipod genera *Ampelisca* and *Unicola*; the bivalve genera *Ensis*, *Nucula*, *Tellina*, and *Astarte*; the archiannelid genus *Polygordius*; and the echinoid *Echinarachnius parma* were also commonly reported as dominants (Brooks et al. 2006). Clear relationships between faunal communities and depth or sediment were not apparent in an overall review of the literature on soft-bottom benthos (Brooks et al. 2006). Brooks et al. (2006) also reviewed times for recovery from physical disturbance; reported times generally ranged from 3 months to 2.5 years, but measures of assessing recovery varied.

Recruitment and Colonization

Recovery time following physical disturbance of the benthos is dependent upon recruitment and colonization processes. Hence, these are important processes in benthic ecology that are relevant to understanding potential impacts to benthic resources from offshore alternative energy development. Snelgrove et al. (2001) conducted field studies at the LEO-15 study area (~3km off the coast of New Jersey at about 15 m bottom depth), to investigate the role of colonization in producing patterns of community composition. The authors employed faunal surveys and sediment transplant experiments to investigate whether pattern and diversity in soft-bottom benthic communities are determined by colonization or post-settlement processes. Recruitment and colonization patterns corresponded well to the local community, but the authors suggest that post-colonization processes such as competition and predation likely play a major role for some species. Osman and Whitlatch (1998) conducted research on recruitment in sub-tidal epifaunal communities in southern New England. Recruitment was measured in field studies using artificial substrates including plastic doormat and PVC 'pilings.' Patterns in recruitment, abundance, and dominance were found to persist year after year over large areas of the seafloor. The authors attributed these unexpected and persistent patterns to strong local control of recruitment via predation.

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) refers to vascular, rooted, flowering plants that live and grow mostly underwater. SAV typically occurs completely submerged in the sub-tidal zone with leaves and stems that float upward towards the surface and sunlight. SAV provides food, refuge, and nursery habitat for many waterfowl, fish, shellfish, and invertebrates, and produces oxygen in the water column. The prevalence and health of SAV is largely dependent on water quality (in particular, water clarity and nutrient levels) and salinity. In addition, SAV stabilizes the substrate and helps to recirculate oxygen and nutrients (Stevenson et al. 2004).

SAV occurs in shallow, nearshore waters; light availability appears to limit its depth distribution (Thayer et al. 1984). Three species of SAV are known to occur in the Northeast Shelf region: eelgrass (*Zostera marina*), widgeon grass (*Ruppia maritima*), and Cuban shoalgrass (*Halodule wrightii*) (Thayer et al. 1984). Eelgrass dominates the sea grass communities of the northeast region (Thayer et al. 1984). Shoalgrass occurs along the east coast as far north as North Carolina, and eelgrass and widgeon grass are found throughout the northeast region. Widgeon grass is considered a freshwater angiosperm rather than a true sea grass, although it tolerates salinities as high as 45 parts per thousand, and can co-occur with eelgrass (Thayer et al. 1984).

Eelgrass inhabits shallow estuarine and marine waters in soft sediments ranging from mud to coarse sand (Thayer et al. 1984). Light availability appears to limit the maximum depth at which eelgrass occurs; that depth varies also with local water clarity and tidal range (Thayer et al. 1984). Eelgrass meadows provide an important coastal habitat and form a discrete sea grass ecosystem. Important functional roles of eelgrass ecosystems include primary production and a high rate of leaf growth; support of epiphytic organisms that inhabit leaves, are grazed on by predators, and may represent a comparable biomass to the plants themselves; production of large amounts of organic material that decomposes within the meadow or in nearby systems; stabilization of the sediments; and nutrient cycling between the sediments and water column (Thayer et al. 1984). Duffy (2006) recently reviewed function and process in relation to biodiversity in sea grass ecosystems. Biodiversity was considered at the levels of genotypes, species, functional groups, ecosystems, and landscapes. At various levels, biodiversity was found to be essential for productivity and stability in sea grass meadows, and was identified as an important conservation and management goal.

3.5.2 Hard-Bottom Benthic Communities

Natural hard substrate is generally restricted to high-energy shallow waters where erosional processes dominate. This represents a small percentage of the benthic habitat within the Northeast Shelf region. For example, only isolated occurrences of natural reef are found in the MAB in clay or sandstone formations, gravel ridges, and some glacially exposed rock along the southern New England Coast (Steimle and Zetlin 2000). Nonetheless, glacially-exposed rock provides important habitat in nearshore waters of the GOM, where substratum in the ecologically important rocky sub-tidal includes bedrock ledge, boulders, and cobble.

Rocky Sub-Tidal

The rocky sub-tidal in the GOM supports highly productive and structurally complex kelp forest communities (Ojeda and Dearborn 1989). The diversity and productivity in these communities are accomplished through modification of the typically two-dimensional substratum by the attached macroalgae and animals to create a multitiered community that increases the number of biological niches. Various kelp species (e.g., *Laminaria saccharina*, *L. digitata*, and *Alaria esculenta*) form an extensive canopy, beneath or between which understory layers produce secondary levels of foliose and filamentous algae (e.g., *Corallina officinalis*, *Phycodrys rubens, and Phyllophora* sp.) and upright attached macroinvertebrates (e.g., the horse mussel, *Modiolus modiolus*). Much of the remaining primary rock surfaces is occupied by a layer of encrusting algal and faunal species (Ojeda and Dearborn 1989). Also, many niches created in and around this attached biota are occupied by mobile predator and herbivore species such as fish, crabs, snails, sea urchins, sea stars, and amphipods (Ojeda and Dearborn 1989, Steneck et al. 2004). As many as 171 invertebrate species are reported from surveys of rocky sub-tidal habitats in the GOM (Witman 1985 as cited in Ojeda and Dearborn 1989). Green sea urchin (*Strongylocentrotus droebachiensis*) and horse mussel are consistently cited as community dominants, and other commonly cited taxa include small motile invertebrates such as the gastropod *Lacuna vincta*, isopods in the genus *Idotea*, and amphipods in the genera *Caprella* and

Jassa, as well as sessile forms such as the ascidians *Aplidium glabrum* and *Molgula* sp., and various encrusting sponges and bryozoans (Ojeda and Dearborn 1989, Miller and Etter 2008).

The rocky sub-tidal is further characterized by distinct zonation patterns that result from a variety of interacting physical mechanisms (e.g., water movement, temperature, turbidity, and light penetration) and biological mechanisms (e.g., herbivory, predation, recruitment, and inter- and intraspecific competition for space). These patterns of zonation generally follow water depth, and differ based on wave-exposed versus wave-protected habitats (Ojeda and Dearborn 1989). The distribution of benthic communities within the rocky sub-tidal is also influenced by small-scale spatial heterogeneity, with major differences, for example, between vertical and horizontal rocky surfaces based on light availability (Miller and Etter 2008).

Artificial Reefs

In contrast to the GOM, sea bottom in the MAB is characterized as being relatively homogeneous, topographically flat, of soft sediments composed mostly of sand, with areas of gravel, shell hash, silt, and clay (Steimle and Zetlin 2000). Although natural reef exists in isolated locations, the predominant reef habitat in the MAB comes from man-made structures such as shipwrecks, lost cargos, and artificial reef. Such human-made structures can be found throughout the Northeast Shelf region and often support typical hard-bottom communities found on natural reef. Depending on the geographic location, depth, reef material, and other factors, artificial reef structures may be colonized by macroalgae and various species of attached invertebrates such as barnacles, mussels, sponges, bryozoans, anemones, stone corals, soft corals and tunicates, as well as motile invertebrates including lobster, crabs, sea urchins, and sea stars (Steimle and Zetlin 2000). Steimle and Zetlin (2000) reviewed available information about reef habitats and associated communities in the MAB. They summarized available information on the abundance and distribution of reef habitat and the associated biological communities, and reviewed the status and trends in the use of artificial reefs to manage marine resources. Several species that support invertebrate fisheries were listed as associated with reef habitat in the MAB. The longfin squid attaches its egg masses to hard substrate, relying on reef habitat for a portion of its life cycle. American lobster, Jonah crab (*Cancer borealis*), rock crab (*Cancer irroratus*), and blue mussels (*Mytilus edulis*) also utilize reef habitat in marine waters of the MAB.

Deep Corals

Deep corals are colonial, azooxanthellate corals that typically occur at depths greater than 50 m (Lumsden et al. 2007). The ecological importance of habitats created by structure-forming deep corals has received increasing attention during recent years. Similar to the well-known shallow-water tropical corals, deep corals are long-lived, slow-growing organisms that are highly vulnerable to physical disturbance. Deep corals include anthozoans such as scleractinians (hard corals), alcyonaceans (soft corals) and gorgonians (sea whips or sea fans). These groups are reported from parts of the Gulf of Maine, from Georges Bank and from canyons throughout the Northeast Shelf region (Lumsden et al. 2007; Theroux and Wigley 1998). Although several species are known to occur in shallow waters, the majority of deep coral species found in the northeast region occur in depths below 100 m. Structure-forming deep corals in the northeast region do not appear to reach the levels of abundance that are found in more southern waters (Lumsden et al. 2007).

3.6 AREAS OF SPECIAL CONCERN

The northeast region contains a number of areas of special concern to biological resources. These include areas that are currently protected under legislation or regulations, and other areas of particular ecological significance that are not currently designated for protection. Many areas of special concern are included under the definition of Marine Protected Areas (MPAs). MPAs are defined by Executive Order 13158, issued May 26, 2000, as "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (MPA 2009). The purpose of creating a national system is “to support the effective stewardship, conservation, restoration, sustainable use, and public understanding and appreciation of the nation’s significant natural and cultural marine heritage and sustainable production marine resources, with consideration of the interests of and implications for all who use, benefit from, and care about the national marine environment” (MPA 2009).

The National Marine Protected Areas Center, created to fulfill this order, is administered by NOAA, provides technical information, training and support for the areas included under the listing, and provides coordination for the Federal Advisory Committee that was established to provide guidance on the framework for the national system and stewardship of the sites; the Center also manages a website that provides information about MPAs (www.mpa.gov).

Through the MPA Center, the Marine Protected Areas Inventory was developed as a joint collaboration between the U.S. Department of Commerce (DOC) and the U.S. Department of the Interior (DOI) with the purpose of gathering and making publicly available comprehensive information on site-specific marine conservation efforts under U.S. Federal, state, territorial, local, and tribal jurisdiction. This comprehensive inventory of MPA sites will provide governments and stakeholders with information to make better decisions about the current and future use and conservation of these areas. The inventory will be used in the development of the national system of marine protected areas as required by Executive Order 13158.

MPAs include the following: National Marine Sanctuaries (NMS), National Wildlife Refuges (NWR), National Estuarine Research Reserve System (NERRS), National Parks, and estuaries within the National Estuary Program of the Atlantic. The entire list of potential and listed MPAs can be accessed via the MPA website under the MPA Inventory. Approximately 1,800 sites throughout the United States fall under the definition of MPAs and thus have the potential to be included as officially designated MPAs. Only a fraction of these have been formally recognized to date. The initial List of Charter Members of the National System of MPA, dated April 2009, includes 54 sites that lie within the Northeast Region (Table 3.10). This list is the official inventory of all MPAs that have been formally recognized as part of the national system. The MPAs on the list are those that went through the nomination process, and have been mutually agreed upon by both the MPA Center and the managing agency. Other sites included for potential future listing are found under a separate listing within the MPA Inventory site.

The scope of this synthesis does not include estuaries or wildlife refuges that are primarily terrestrial or estuarine, so those types of sites listed in Table 3.10 were excluded from the literature search. Information on marine sanctuaries is discussed below in summary.

Table 3.10

Marine Protected Areas

Site Name[a]	State	Managing Agency[b]	Size (km^2)	Conservation Focus
Alligator River NWR	NC	USFWS	547.4	Natural heritage
Assateague Island National Seashore	VA and MD	NPS	124.4	Natural heritage
Back Bay NWR	VA	USFWS	64.8	Natural heritage
Bethel Beach NAP	VA	VA Department of Conservation and Recreation	Not listed	Natural heritage
Blackwater NWR	MD	USFWS	Not listed	Natural heritage
Block Island NWR	RI	USFWS	0.3	Natural heritage
Blue Crab Sanctuary	VA	VA Marine Resource Commission	2447.5	Sustainable production
Bombay Hook NWR	DE	USFWS	85.7	Natural heritage
Cape May NWR	DE	USFWS	73.3	Natural heritage
Cedar Island NWR	NC	USFWS	68.0	Natural heritage
Chincoteague NWR	VA and MD	USFWS	59.4	Natural heritage
Conscience Point NWR	NY	USFWS	0.2	Natural heritage
Cross Island NWR	ME	USFWS	6.2	Natural heritage
Currituck NWR	NC	USFWS	1.2	Natural heritage
Dameron Marsh NAP	VA	VA Department of Conservation and Recreation	0.1	Natural heritage
Eastern Neck NWR	MD	USFWS	8.6	Natural heritage
Eastern Shore of Virginia NWR	VA	USFWS	5.7	Natural heritage
Edwin B. Forsythe NWR	NJ	USFWS	276.8	Natural heritage
False Cape State Park	VA	VA Department of Conservation and Recreation	15.7	Natural heritage
Featherstone NWR	VA	USFWS	1.3	Natural heritage
Fisherman Island NWR	VA	USFWS	6.8	Natural heritage
Gerry E. Studds/Stellwagen Bank NMS	MA	NMS	2189.8	Natural heritage
Great Bay NWR	NJ	USFWS	4.3	Natural heritage
Hughlett Point NAP	VA	VA Department of Conservation and Recreation	Not listed	Natural heritage
Jacques Cousteau NERR	NJ	Rutgers University/Institute of Marine and Coastal Sciences	450.5	Natural heritage

[a] NWR= National Wildlife Refuge; NAP = National Area Preserve; NMS = National Marine Sanctuary; NERR = National Estuarine Research Reserve

[b] USFWS = U.S. Fish and Wildlife Service; NPS = National Park Service; NMS = National Marine Sanctuaries

Source: www.mpa.gov, List dated April 22, 2009

Table 3.10.Marine Protected Areas (continued).

Site Name[a]	State	Managing Agency[b]	Size (km^2)	Conservation Focus
John H. Chafee NWR	RI	USFWS	3.8	Natural heritage
Kiptopeke State Park	VA	VA Department of Conservation and Recreation	2.0	Natural heritage
Mackay Island NWR	VA and NC	USFWS	29.9	Natural heritage
Martin NWR	VA	USFWS	16.9	Natural heritage
Mashpee NWR	MA	USFWS	26.1	Natural heritage
Monomoy NWR	MA	USFWS	29.6	Natural heritage
Ninigret NWR	RI	USFWS	1.8	Natural heritage
Monitor NMS	NC	NMS	2.2	Cultural heritage
Nomans Land Island NWR	MA	USFWS	2.5	Natural heritage
Occoquan Bay NWR	VA	USFWS	0.3	Natural heritage
Oyster Bay NWR	NY	USFWS	13.8	Sustainable production
Parker River NWR	MA	USFWS	25.8	Natural heritage
Pea Island NWR	NC	USFWS	18.8	Natural heritage
Plum Tree Island NWR	VA	USFWS	11.5	Natural heritage
Pond Island NWR	ME	USFWS	Not listed	Natural heritage
Prime Hook NWR	DE	USFWS	39.6	Natural heritage
Rachel Carson NWR	ME	USFWS	35.6	Natural heritage
Sachuest Point NWR	RI	USFWS	1.0	Natural heritage
Savage Neck Dunes NAP	VA	VA Department of Conservation and Recreation	Not listed	Natural heritage
Seatuck NWR	NY	USFWS	0.9	Natural heritage
Stewart B. McKinney NWR	Connecticut	USFWS	4.5	Natural heritage
Supawna Meadows NWR	NJ	USFWS	17.9	Natural heritage
Susquehanna NWR	MD	USFWS	Not listed	Natural heritage
Swanquarter NWR	NC	USFWS	67.1	Natural heritage
Target Rock NWR	NY	USFWS	0.3	Natural heritage
U-1105 Black Panther Historic Shipwreck Preserve	MD	Navy/St. Mary's County Department of Recreation and Parks	0.1	Cultural heritage
Wallops Island NWR	VA	USFWS	26.0	Natural heritage
Waquoit Bay NERR	MA	MA Department of Conservation and Recreation	11.5	Natural heritage
Wertheim NWR	NY	USFWS	11.6	Natural heritage

[a] NWR= National Wildlife Refuge; NAP = National Area Preserve; NMS = National Marine Sanctuary; NERR = National Estuarine Research Reserve

[b] USFWS = U.S. Fish and Wildlife Service; NPS = National Park Service; NMS = National Marine Sanctuaries

Source: www.mpa.gov, list dated April 22, 2009

3.6.1 The Gerry E. Studds Stellwagen Bank National Marine Sanctuary

The National Marine Sanctuary Program (NMSP) manages marine sanctuaries in both nearshore and open ocean waters (USDOC, NOAA 2009). NMSP regulations are codified at 15 CFR Part

922; these are used by the NMSP to implement the National Marine Sanctuaries Act and National Marine Sanctuary Management Plans. Each sanctuary has its own set of regulations within 15 CFR Part 922 defined in the subparts to these regulations. While each sanctuary has its own set of regulations, the following prohibitions apply for many sanctuaries:

> Discharging material or other matter into the sanctuary,
>
> Disturbance of, construction on, or alteration of the seabed,
>
> Disturbance of cultural resources, and
>
> Exploring for, developing, or producing oil, gas, or minerals (with a grandfather clause for preexisting operations).

Some sanctuaries also prohibit other activities, including: disturbing marine mammals, seabirds, and sea turtles; operating aircraft in certain zones; using personal watercraft; mining minerals and anchoring vessels (USDOC, NOAA 2009).

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary (SBNMS) is the only National Marine Sanctuary located within waters of the Northeast Shelf region. The Monitor National Marine Sanctuary (MNMS) is located just south of the geographical boundary for this project, 16 miles south-southeast of Cape Hatteras, North Carolina. It was established to preserve the archaeologically significant wreck site of the Civil War ironclad USS Monitor. The MNMS website (www.monitor.noaa.gov) contains links to pertinent information for the MNMS.

The SBNMS was congressionally designated in 1992 based on the history of human use and high natural productivity of the area (SBNMS 2009). The sanctuary's mission is to conserve, protect, and enhance biodiversity, ecological integrity, and cultural legacy while facilitating compatible uses. The sanctuary is administered by the National Oceanic and Atmospheric Administration (NOAA), within the Department of Commerce. A key component of the sanctuary's long-term vision is that the ecological integrity of the site will be fully restored.

SBNMS is the largest federally protected MPA in the northeast region and has been well-studied. The Stellwagen Bank Management Plan and Final Environmental Impact Statement (USDOC, NOAA 1993) is the most thorough document available that reviews the biological features of the sanctuary and is the source of information reviewed below, unless otherwise cited. In addition to this document, the following documents provide excellent information to characterize biological resources in the sanctuary: the SBNMS Site Characterization Report (USDOC, NOAA 1995), the SBNMS Draft Management Plan and Environmental Assessment (USDOC, NOAA 2008), The Stellwagen Bank NMS Condition Report (NMSP 2007) and An Ecological Characterization of the Stellwagen Bank National Marine Sanctuary Region; Oceanographic, Biogeographic and Contaminants Assessment (USDOC, NOAA 2006). The species-specific data provided by the studies conducted in association with the SBNMS and named above provide a valuable resource for environmental analyses in New England waters, and as such are discussed in detail in the corresponding sections of this report. What follows below is a general overview of the sanctuary and its associated resources.

The sanctuary boundary occurs entirely within Federal waters; however, the southern boundary lies adjacent to the Cape Cod Bay Ocean Sanctuary and the northwest border of SBNMS coincides with the border of the North Shore Ocean Sanctuary; both of these are designated and directed by the Commonwealth of Massachusetts (SBNMS 2009). Stellwagen Bank is a unique geological feature located in the southwestern edge of the Gulf of Maine, between Cape Ann and Cape Cod at the mouth of Massachusetts Bay. Stellwagen Bank is a shallow, kidney-shaped plateau located at the bay's eastern edge, curving in a southeast-to-northwest direction. Water depths over and around the bank range from approximately 65 feet at the southwest corner to approximately 600 feet in deep passages along the northeast edge. Stellwagen Bank is primarily a sandy feature, although the sanctuary contains five major seafloor habitat types typical to the Gulf of Maine: rocky outcrop, piled boulder, gravel, sand, and mud. These habitats are spread across a series of banks and deep basins and comprise a diverse topographic area (USDOC, NOAA 1995).

The waters around Stellwagen Bank provide valuable habitat for benthic organisms, fish, seabirds, sea turtles, and marine mammals. Baseline surveys of macrobenthic communities conducted at Jeffreys Ledge, north of Stellwagen Bank, identified 149 faunal and algal species within horizontal and vertical communities at various depths (NMSP 2007). The diverse seafloor topography and benthic communities in SBNMS support 72 species of pelagic and demersal fish (SBNMS 2009). The cyclic biological productivity unique to the sanctuary supports a large variety of commercially important fisheries. Pelagic species include herring, mackerel, sharks, swordfish, bluefish, bluefin tuna, capelin, and menhaden. Demersal species include cod, haddock, hake, pollock, whiting, cusk, and several species of flatfish such as flounders and halibut. Many fish species, such as cod, haddock, silver hake, sand dabs, and witch flounder may breed on Stellwagen Bank or in adjacent nearshore coastal waters, but not over deeper Gulf waters. There is also evidence that Stellwagen Bank provides important spawning habitat for the American sand lance (*Ammodytes americanus*), a primary forage species for many fish, birds, and cetaceans including humpback and fin whales.

High levels of biological productivity at Stellwagen Bank result in a predictable and abundant variety of prey that attracts both coastal and marine seabird species including loons, fulmars, shearwaters, storm petrels, cormorants, phalaropes, alcids, gulls, jaegers, and terns. With the exception of Leach's storm petrel (*Oceanodroma leucorhoa*) all seabirds occurring around the SBNMS area are either migrants or nonbreeding residents. Spring months are typically the time of greatest seabird abundance on Stellwagen Bank (SBNMS 2009; USDOC, NOAA 2008; USDOC, NOAA 1995). The SBNMS also provides a seasonal habitat for two species of sea turtles, the Atlantic or Kemp's ridley (*Lepiochelys kempi*) and the leatherback (*Dermochelys coriacea*). Leatherback turtles can be seen during summer months when jellyfish are abundant, and Atlantic or Kemp's ridley turtles have been seen in the sanctuary as juveniles, having either swum or drifted north in the Gulf Stream from hatching areas off the southern coast of Mexico (SBNMS 2009).

Seventeen species of cetaceans have been sighted in the sanctuary, seven of which are listed as endangered under the Endangered Species Act: blue, fin, humpback, sei, beluga, North Atlantic right, and sperm whales (USDOC, NOAA 2008). Annually, one-third of the North Atlantic right whale population utilizes the sanctuary and nearby waters for feeding and nursing (SBNMS

2009). SBNMS is also one of the primary feeding grounds for humpback whales in the North Atlantic. Other whales that use the sanctuary include the non-endangered minke, pilot, and killer whales. Six species of dolphin and one porpoise complete the list of cetaceans sighted within the SBNMS (USDOC, NOAA 2008). The following five species of pinnipeds have also been documented in the Stellwagen Bank area: harbor, hooded, harp, ringed and gray seals (USDOC, NOAA 2008).

3.6.2 National Park System

The National Park System (NPS) protects large areas of the country's natural, cultural, and recreational resources under the U.S. Department of the Interior (USDOI, NPS 2009). The system includes national parks, national seashores, national monuments and national recreation areas, some or all of which are included within the purview of MPAs. Sites within the Northeast Region include Acadia National Park (Maine), Cape Cod National Seashore (Massachusetts), Fire Island National Seashore (New York), Gateway National Recreation Area (New York), Assateague Island National Seashore (Virginia), and Cape Hatteras National Seashore (North Carolina) (USDOI, MMS 2007).

The protected areas within each of these locations typically include a mix of terrestrial (both upland and shoreline) and estuarine habitats. The variety of habitats support diverse ecological communities, including plant and animal species that are federally and state-listed for protection. For example, both the federally endangered roseate tern (*Sterna dougallii*) and the federally threatened piping plover (*Charadrius melodus*) breed on beach/shoreline habitat included in the Cape Cod and Fire Island National Seashores (USDOI, FWS 1998; USDOI, FWS 1996). Seabirds, shorebirds, and waterfowl are the primary species that utilize the beach/dune habitat located at the edge of the terrestrial habitat.

3.6.3 National Wildlife Refuges

National Wildlife Refuges (NWRs) are a system of public lands and waters set aside to conserve America's fish, wildlife, and plants and are included in the inventory of MPAs (USDOI, FWS 2009). Most of the NWR areas are managed for wildlife, and a majority of those with coastal locations were established to provide feeding, stopover and/or wintering habitat for migratory birds, including waterfowl, shorebirds, and passerines. Some of these refuges are significant habitat for Neotropical migrants that winter in the Central and South Americas (USDOI, MMS 2007). Some of the refuges contain habitat for threatened or endangered species such as piping plover (Back Bay, Currituck, Parker River, Pea Island, and Rachel Carson), sea turtles including the federally threatened loggerhead (Back Bay, Chincoteague, Fisherman Island, Pea Island and Target Rock), the federally endangered Kemp's ridley and leatherback sea turtles (Eastern Shore of Virginia, Elizabeth A. Morton, Fisherman Island and Oyster Bay) and green sea turtle (Sandy Point) (USDOI, FWS 2009).

3.6.4 National Estuarine Research Reserve System and the National Estuary Program

The National Estuarine Research Reserve System (NERRS) sites were created to provide representative estuarine areas for research, education and stewardship. As a partnership program between NOAA and the coastal states, NERRS protects estuarine lands and water, which provide essential habitat for wildlife; offers educational opportunities for students, teachers and the public; and serves as living laboratories for scientists (NERRS 2009). There are 10 NERRS sites located within the Northeast Region (Table 3.11).

Table 3.11

National Estuarine Research Reserve System locations within the Northeast Region

Reserve Name	Date Designated	Area (acres)	Area (km^2)
Narragansett Bay, RI	1980	4,259	17.2
Hudson River, NY (4 components)	1982	4,838	19.6
North Carolina (4 components)	1985, 1991	10,000	40.5
Wells, ME	1986	2,250	6.5
Chesapeake Bay, MD (3 components)	1985, 1990	6,249	19.5
Waquoit Bay, MA	1988	2780	9.1
Great Bay, NH	1989	10,235	21.4
Chesapeake Bay, VA (4 components)	1991	4,435	17.9
Delaware	1993	4,930	20.0
Jacques Cousteau, NJ	1998	114,665	461.3

Source: NERRS 2009

The National Estuary Program was established in 1987 as an amendment to the Clean Water Act for the purpose of identifying and protecting nationally significant estuaries and to enhance their living resources (USDOI, MMS 2007). The Clean Water Act Section 320 directs EPA to create plans for each estuary which include: “attaining or maintaining water quality in an estuary, including protection of public water supplies and the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife; [allowing] recreational activities, in and on water; and requir[ing] …control of point and nonpoint sources of pollution to supplement existing controls of pollution.” In several cases, more than one State is participating in a National Estuary Program (USEPA 2009). Each program establishes a Comprehensive Conservation and Management Plan to meet the goals. In the Northeast Region there are thirteen estuaries in the National Estuary Program (Table 3.12).

3.6.5 Other Areas of Special Concern

In addition to the MPAs, there are other areas in the Northeast Shelf region that are not currently designated for protection, which can be identified as areas of particular ecological significance.

Table 3.12

Estuaries in the National Estuary Program

Estuary	State	Area (km^2)
Albemarle-Pamlico Sounds	NC	81,791
Barnegat Bay	NJ	3,525
Buzzards Bay	MA	1,939
Casco Bay	ME	2,965
Delaware Estuary	DE, NJ and PA	35,297
Delaware Inland Bays	DE	804
Long Island Sound	NY, CT	45,050
Maryland Coastal Bays	MD	1,035
Massachusetts Bay	MA	19,038
Narragansett Bay	RI, MA	4,674
Piscataqua Region Estuaries	NH, ME	2,789
New York-New Jersey Harbor	NY, NJ	42,128
Peconic Bay	NY	1,187

Source: USEPA 2009

3.6.5.1 Mid-Atlantic Bight

Based on recommendations from the scientific community, the Natural Resources Defense Council (NRDC) has identified priority ocean areas for protection in the Mid-Atlantic Bight (MAB) (NRDC 2009). Scientists were asked by NRDC to identify priority areas based on the following seven criteria:

Biodiversity: high numbers of plant or animal species.

High abundance: high density of organisms.

Migratory pathway: corridors used by marine fauna, generally for seasonal movements for feeding, spawning, or other functions.

Physical features: topographical or hydrographical features associated with productivity or diversity.

Nursery or spawning areas: locations where important reproductive functions of a particular species are known to occur.

Endangered or threatened species: primary habitat or migratory pathway for listed species.

Fisheries: the combination of fish and commercial or recreational fishing activity.

The five areas that are profiled below were identified based on overlapping recommendations by participating scientists. Information below comes from NRDC (2009) unless otherwise cited.

Submarine Canyons

Submarine canyons support high quantities and diversity of marine fauna. Important canyons that were specifically identified in the MAB include (north to south): Lydonia, Oceanographer, Hydrographer, Veatch, Norfolk, Hudson, Wilmington, Baltimore, and Washington. Canyons are associated with upwelling and a high flux of fine particle nutrients that support high biological productivity. Exposed hard substrate in canyons can provide habitat for sessile organisms including deepwater corals. Tilefish burrows at the head of Hudson Canyon support a highly diverse community and they have been specifically identified as important habitat.

Offshore Waters near Cape Hatteras

The offshore waters near Cape Hatteras, extending out to the 2,000-meter isobath, are recognized as an area of high diversity and abundance. A variety of physical habitat and hydrographic features support a wide variety of marine fauna including an exceptionally high diversity of marine fish species, and seasonal concentrations of seabirds, turtles, and other marine life.

Tilefish Habitat

Tilefish habitat between Cape May, New Jersey, and Cape Cod, Massachusetts, from the 80-to 400-meter isobaths is recognized as important habitat that supports a diversity of fauna. Tilefish create burrows that provide refuge to lobsters, crabs, and eels, among other species. Tilefish also support an important commercial fishery.

Nearshore Waters

Nearshore waters from the coastline to 35 km offshore represent a highly productive zone with important feeding, nursery, and spawning areas, as well as providing an important migration corridor for right whales, sea turtles, and many fish species.

Continental shelf/slope break

The continental shelf/slope break area, from the 100-meter to the 400-meter isobath, has also been identified as a highly productive zone, supporting high densities of Illex and Loligo squid, which are commercially valuable and also are important prey of many marine species. This zone is also important to loggerhead sea turtles and many species of fish and cetaceans.

3.6.5.2 New England

Many of the important habitats that were identified for the MAB also occur in New England waters. For example, the submarine canyons that occur along the southeastern edge of Georges Bank (e.g., Stevenson et al. 2004; Lumsden et al. 2007), the highly productive nearshore waters of the Gulf of Maine (e.g., Theroux and Wigley 1998), and the continental shelf/slope break (e.g., Stevenson et al. 2004) also represent ecologically significant areas in the northern reaches of the Northeastern Shelf region. Other important features or areas in offshore New England waters include Georges Bank, Nantucket Shoals, and the Great South Channel that separates the main part of Georges Bank from Nantucket shoals (e.g., Stevenson et al. 2004). The significance of many of these areas is discussed in previous sections of this report.

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4. CHEMICAL OCEANOGRAPHY

For the purposes of this study, chemical oceanography includes consideration of the impact of natural and anthropogenic processes on chemical concentrations, distributions, gradients, and fluxes in the coastal ocean. In addition to the dissolved and particulate chemistry of marine waters, this topic includes consideration of the chemistry of marine sediments as well as sediment-water, land-water, and air-sea interfaces. The concentrations and distributions of chemicals in the ocean are strongly influenced by geological, physical, and biological processes. Conversely, chemical processes can have a strong influence on biological and geological processes.

The topic outline includes a subset of topics within chemical oceanography. The topic selection has been guided by the project focus of renewable and alternative energy development with emphasis on wind energy, wave energy, and tidal kinetic energy.

4.1 WATER PROPERTIES

4.1.1 Nutrients

The term "nutrients" in the oceanographic literature commonly refers to nitrogen, phosphorous and silica. Nitrogen in the marine environment is present mostly as dissolved N_2 gas. The largest fractions of "dissolved inorganic nitrogen" (DIN) forms are nitrate (NO_3^-), nitrite (NO_2^-) and ammonium ion (NH_4^+). There are also organic reservoirs of nitrogen compounds known as "dissolved organic nitrogen" (DON) and "particulate organic nitrogen" (PON), which are synthesized in productive surface waters by phytoplankton and remineralized in the ocean depths by bacteria.

Inorganic phosphate ($PO_4^{\equiv}$) comprises all of the dissolved phosphorous in the ocean depths and generally over half of the total at the surface. It exists as one of three anions, collectively referred to as orthophosphate. At the surface some phosphate is present in organic matter, up to 50 percent of the total.

Silica is present predominantly in the form of silicate minerals. The fraction of silica dissolved in the ocean is referred to as silicate.

Nutrients enter the continental shelf marine environment via

- Recycling/resuspension from the sediment.
- Continental washing (inputs from rivers and streams)
- Advection onto the shelf from offshore waters
- Atmospheric deposition
- Upwelling

The general processes that control nutrient distribution and cycling on the Atlantic Continental Shelf (ACS) can be summarized under biology, chemistry, and physics.

Atmospheric deposition of inorganic nitrogen and phosphorous to the North Atlantic Ocean is estimated to be 8.6 teragrams (10^{12} grams) of nitrogen per year (tg N/yr) and 0.2 teragrams of phosphorus per year (tg P/yr), respectively (Prospero et al. 1996). These estimations are for the entire North Atlantic Ocean and are not representative of the coastal environment. They are included to demonstrate the magnitude of atmospheric deposition. On the ACS, direct measurements of nitrogen deposition are extrapolated to an annual deposition estimated at 9.3 g-at N/yr in the Gulf of Maine (Townsend and Mosher unpublished, as cited by (Townsend 1998) and 14.9 Mmol N/yr (nitrate and ammonium only) in the Barnegat Bay ecosystem, New York Bight (Gao 2002). Modeled estimates of nitrogen deposition to the Northwest Atlantic OCS indicate 11 kg N /hectare may enter the ocean via the atmosphere (Paerl et al. 2002).

Nutrients are carried to the continental shelf via freshwater inputs from rivers. Nutrient content is generally presented as an average annual value, the average of the seasonal fluctuations of nutrient exports from the land to the sea. In the northern planning area, the Gulf of Maine, nitrogen loading via rivers is calculated to be 0.8 g-at N/yr (Townsend 1998) and the Boston Harbor is calculated to contribute 7850 mmols/m^2/yr in N and 629 mmols/m^2/year in P, Table 4.1 (Nixon et al. 1996)*. The contributions of N and P in the Mid-Atlantic planning area, from the Chesapeake Bay, Delaware Bay and Narragansett, are also presented with an estimate of total estuarine contributions of Northeast coast in Table 4.1 (Nixon et al. 1996).

Table 4.1

Nitrogen and Phosphorous Contributions Originating from Larger Bays Entering the Northern and Mid-Atlantic Outer Continental Shelf Study Areas

	mmoles/m^2/ year		
Contributary	N	P	Area (km^2)
Chesapeake Bay	282	0	11,542
Delaware Bay	620-820	135	1,989
Narragansett Bay	765-1410	76 -98	328
Boston Harbor	7850	629	108

Source: Summarized from Nixon et al. (1996)

The estimated fluxes of nitrogen and phosphorus from estuaries onto the continental shelf from the Northeast Coast total between 13 and 26 billion moles nitrogen and between 300 and 500 million moles phosphorus per year. This includes the fluxes from large rivers that discharge directly on the shelf after correction for the estimated burial of nitrogen and phosphorus in large river deltas and on the continental slope.

In the Mid-Atlantic Bight (MAB) off the coast of southeast North Carolina, the majority of the nitrogen and phosphorous entering the shelf from estuaries into Long and Oslo Bays is dissolved because the particulate fractions tend to settle out (Dafner et al. 2007). In the upper reaches of these estuaries there is a concentration increase in all chemical forms of nitrogen and phosphorous attributed to anthropogenic loading. Most of this load is attenuated in the estuaries, indicating self-regulation of nutrients. However, the control on primary productivity in both coastal and open ocean ecosystems is dependent on a complex and poorly understood interaction between nitrogen and phosphorous mobilization and availability (Galloway et al. 1996; Dafner et al. 2007).

The concentration of phosphate in the MAB changes by season. During the winter months, riverine plumes can stretch out to the continental slope. Phosphate concentrations within the plumes at this time of year are above 1.0 µmolP/l (units in this paper were originally presented as gram-atoms). Outside of the plume, concentrations are less than 0.5 µmolP/l. During the rest of the year, concentrations are below 0.5 µmolP/l everywhere on the shelf (Roberts et al. 1974).

Nitrate-Nitrite concentrations at the surface are below 1 µmolN/l during all seasons, most often the concentration is below 0.5 µmolN/l except near estuaries (Roberts et al. 1974).

Nutrients also make their way onto the continental shelf in deep water from the continental slope and from surface water entering either from the open ocean or from other parts of the shelf. On the Gulf of Maine's continental shelf, deep water comes onto the shelf via the Northeast Channel. At the surface, water originating on the Scotian shelf brings nutrients onto the Gulf of Maine's continental shelf. These inputs are the dominant sources of nutrients but the fate of nutrients is poorly understood.

The nutrient concentration ranges on Georges Bank and in the Gulf of Maine are summarized in TRIGOM (1974). Inorganic phosphate concentrations on Gulf of Maine in May are 0.44 µg P/l at the surface and 1.2 µgP/l at 120-m depth. On the Georges Bank, the surface values of Phosphate were 0.03 µgP/l at the surface and 1.2 µg P/l at 120-m depth. Nitrate concentrations in both areas were between 0.7 µgN/l and 9.7 µgN/l. Nitrite values were close to zero and ammonia values were about 1 µgN/l (TRIGOM 1974).

A box model is used to determine the mass balance on a basin scale (Table 4.2) (Townsend 1998).

Townsend (1998) concludes that better understanding of the nutrient concentrations of water flows into the Gulf of Maine is needed, in addition to knowledge about the recycling rates on the shelf to balance the nutrient budgets, which overestimate the amount of nitrogen found on the continental shelf. The imbalance is hypothesized to be a result of denitrification in the sediments.

Table 4.2

Advective Fluxes of Nitrogen into and out of the Gulf of Maine.

Flux	**Source**	**Volume Flux (10^{12} m^3 /yr)**	**Concentration [N] (μ g-at N/L)**	**Mass Flux (10^9 g-at N /yr)**
Inflows	Atmosphere wet and dry[a]			9.3
	Rivers[b]	0.08	10	0.8
	Scotian Shelf water[b]	6.31	5	31.5
	Slope water NE Channel[b]	8.7	17	147.9
	Total			189.5
Outflows	Maine surface water (MSW)[c]	5.04	3.5	17.6
	Maine intermediate water (MIW)[c]	10.06	8	80.5
	Total			98.1
Other losses	Denitrification[d]			33.1
	Burial[e]			4.4
Net flux				+53.1

Notes: The fluxes are for the area of the Gulf of Maine, assumed to equal 1.03x10^{11} m^2.

a From Talbot and Mosher, unpublished As cited by Townsend (1998).
b Modified from Christensen et al. (1995) and Mcadie (1994).
c From Townsend and Christensen (1986) and Townsend et al. (1987).
d From Christensen et al. (1995).
e From Christensen (1989).

Source: Townsend 1998

On the continental shelf, tidal and wind-driven currents mobilize nutrients. Depending on direction and strength, wind can drive upwelling, bringing nutrient-rich waters to the surface, or it can push low-nutrient water from the open ocean out and onto the continental shelf. With regard to the Atlantic Continental Shelf, there is documented seasonal upwelling off of the coast of New Jersey. Particulate carbon and nitrogen ratios within upwelled water were close to 10 during an event in July of 1998. The concentration of POC, and by association PON, decreased progressively offshore from 1.2 mg/L POC (0.12 mg/L PON) to 0.1 mg/L POC (0.01 mg/L PON). These values can be compared to a period when no upwelling was occurring in July of 1999. Figure 4.1 (Glenn et al. 2004).

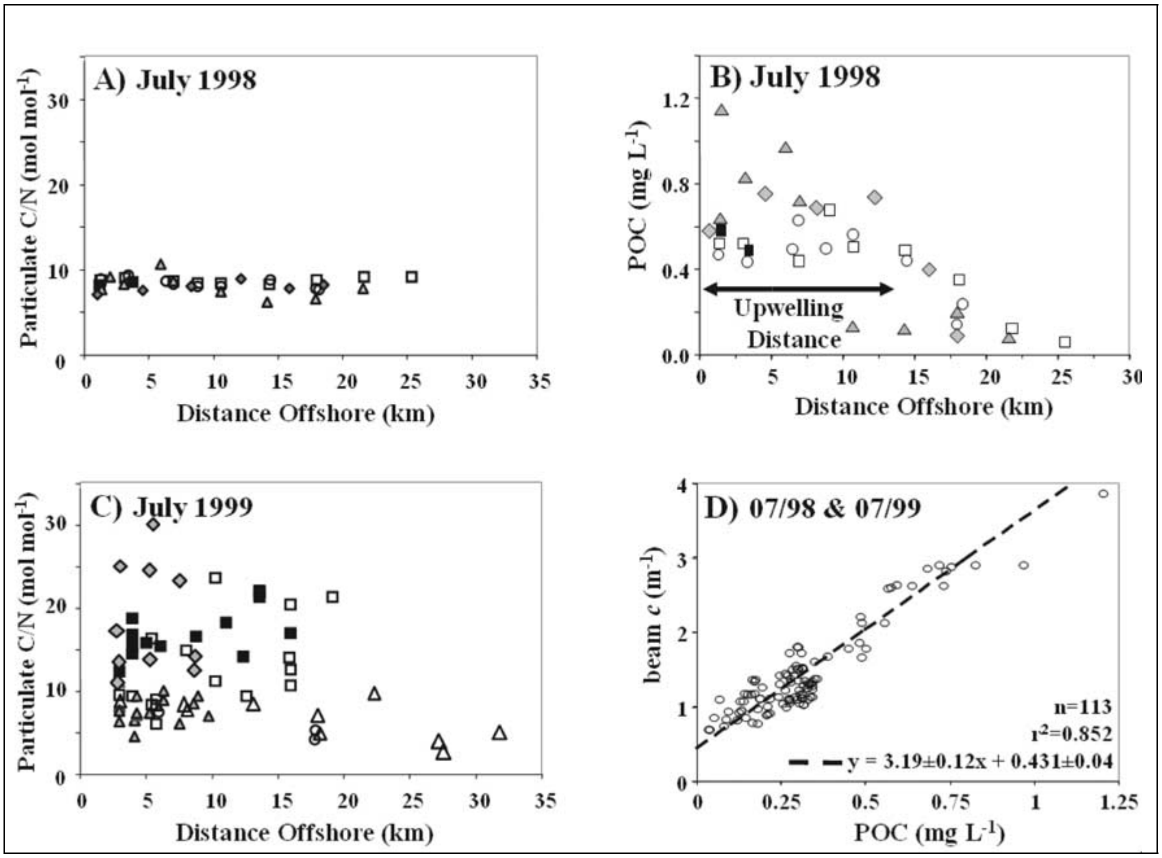

Figure 4.1. (a) The particulate carbon/nitrogen ratios taken during upwelling in summer 1998. (b) Particulate organic carbon concentrations were enhanced within the summer 1998 upwelling. (c) The carbon/nitrogen ratios collected in 1999 during periods of nonupwelling. The highly variable C/N values suggest a significant terrestrial influence. (d) The correlation between beam attenuation and POC for the POC data collected during the summers of 1998 and 1999. From Glenn et al. (2004). Reproduced by permission of American Geophysical Union.

Nutrient distributions are also controlled by tidal forces, which move water masses laterally along the continental shelf. Additionally, fast-moving tides in enclosed areas may cause scouring and the release of nutrients from the sediment. Tidal resuspension is documented in Buzzards Bay, resulting in increases in particulate organic carbon, DIN, DON and chlorophyll a (Roman 1980).

In the photic zone, phytoplankton uptake nutrients during their life cycle to support photosynthesis and growth. The fate of phytoplankton in the water column is to be grazed by animals in higher trophic levels or to die (senescence). The nutrients contained within the body structure of the grazed or senesced plankton can remain in the water column or sink to the bottom to be broken down by bacteria in the sediment. Measurements of springtime nutrient concentrations were conducted as part of South Channel Ocean Productivity Experiment (SCOPEX) in the southern Gulf of Maine (Durbin et al. 1995). The seasonal changes in hydrography were tracked by three cruises in mid-March, April, and early June. The objective was to identify the causes of dense surface aggregations of copepods in the late spring. The cause was hypothesized to have been increased productivity, but this was not found to be the case. Additional research on Georges Bank (GB) concerning the winter-spring dynamics of phytoplankton and nutrients was conducted as part of the Global Ocean Ecosystem Dynamics (GLOBEC). Near-surface nitrate plus nitrite concentrations in February were less than 6 µmol/L over most of GB and below 4 µmol/L on the western half. Silicate concentrations were generally less than 6 µmol/L over the majority of GB in February and were down to 2-3 µmol/L inside the 60-m isobaths (Townsend and Thomas 2001). Model results of tidal pumping on GB produce inhomogeneous nutrient fluxes. The greatest flux is generated by tidal pumping into surface waters along GB's northern flank. The surface maximum occurs on the northeast flank because of advection and bifurcation of flow as waters circulate around the eastern portion of GB (Hu et al. 2008).

"Nitrification" is the process of converting the dominant form of nitrogen, N_2 gas, into a biologically available form. In the marine environment, lightning has enough activation energy to facilitate a reaction between nitrogen gas and oxygen, producing nitrogen oxides. These nitrogen oxides can dissolve in rain where they form nitrates and are carried to the earth. The product of lightning nitrification makes its way into the sea from the atmosphere. Nitrification by the bacteria *Trichodesmium spp* is not constrained in the nitrogen budget. A review of the available data estimates shows that nitrogen fixation could reach 1.09×10^{12} mol N/yr in the North Atlantic basin but the actual figure could be higher or lower because of methodology limitations (Lipschultz and Owens 1996). The extent to which fixation occurs on the shelf is not covered in the literature database.

"Denitrification" is the biological process performed by bacteria of converting biologically available forms of nitrogen back to N_2 gas. In the marine environment this process happens in low-oxygen or no-oxygen environments. On the continental shelf of the Atlantic, the bottom sediment environment is typically the only environment that is consistently low in oxygen. The exceptions are Cape Cod Bay and the New York Bight, which have documented seasonal, hypoxic-to-anoxic conditions in the water column (see Section 4.1.2).

4.1.2 Dissolved Oxygen

Oxygen enters the ocean at the air-sea boundary via exchange with the atmosphere. The main factors controlling oxygen concentrations in the water column on the ACS are physical (temperature) and biological (respiration photosynthesis and bacterial decomposition). Typical values of dissolved oxygen fall within the range of 3 to 10 ml/l over the study area. In the Gulf of Maine, concentrations range between 8 ml/l and 6.5 ml/l in March, 7.5 – 6 ml/l in May, 5.5 - 6.5 ml/l in September and 7.0-5 ml/l in December (Roberts et al. 1974). Off Cape Hatteras, dissolved oxygen concentrations are 4.5 ml/l at the surface and 3 - 4 ml/l at depths of 150-400 m in the winter, spring and summer months (Roberts et al. 1974).

Nutrient overload to the marine environment can drive biological oxygen demand to exceed the oxygen content of the water. Low dissolved oxygen concentration is referred to as hypoxia, but it is not a major concern in the study area as it is not a widespread phenomenon. However, there are two documented areas that experience hypoxia during the summer months.

Organic matter is transported from Massachusetts Bay to Cape Cod Bay, where it remains long enough to settle to the sediment. The decomposition of the organic matter by bacteria exhausts the oxygen supply when calm conditions and temperature-induced stratification during the summer months prevent the bottom waters from being exchanged (Jiang et al. 2007).

Hypoxia is also documented in the New York Bight, along the New Jersey coast. An anoxic event occurring in the summer of 1976 that resulted in a $60 million shellfish loss (Falkowski et al. 1980). The anoxia was attributed to a mild winter with large continental freshwater runoff and a deep summer thermocline. The event was deemed possible to have occurred on the open shelf as a direct result of natural physical forcing and biologic response with no anthropogenic contribution. Further investigation has demonstrated that the recurring hypoxia events that are associated with Barnegat Bay, the Hudson-Raritan estuary, Mullica River estuary, and Townsend/Hereford inlets are associated with southerly winds, which cause upwelling on the coast. This upwelling brings nutrient-rich water to the surface, increasing the amount of organic matter, which falls to the sediment and increases oxygen demand. A simplified budget in this area projects that the oxygen demand could reduce the oxygen concentration from 240 μmol/kg down to 58 μmol/kg (Glenn et al. 2004).

4.1.3 Carbonate System Chemistry and pH

Seawater carbon dioxide (CO_2) concentration is controlled by physical, biological, and chemical factors. Physical forces include ocean temperature, sea state and upwelling. Biological forces include respiration and photosynthesis. The predominant chemical reaction is between CO_2 and water. This last reaction is a dominant controller of seawater pH and it is noted that the documented increase in atmospheric CO_2 concentrations will cause an acidification of the world's oceans. However, no references on the acidification of the ocean on the OCS due to the atmospheric increase in CO_2 have been found. In the MAB, pH values are between 8.0 and 8.3 in the Cape Fear River plume and 8.3 and 8.5 in shelf waters (Dafner et al. 2007). Decreases in pH of roughly 0.5 units in magnitude compared to the surface water have been observed above the sediment-water interface in the New York Bight. These decreases are attributed to anaerobic bacteria activity within the sediments scavenging oxygen from the waters above (Friedman et al. 2000).

The majority of CO_2 is hydrated in the water column to form carbonic acid, which then dissociates to carbonate, a biologically useable form that can be used to make calcareous (calcium carbonate) shells of some species of plankton, or used in photosynthesis. Photosynthesis can produce small changes in surface CO_2 concentration, depending on phytoplankton bloom duration, which is on the order of days.

The ocean is predominantly a sink for $CO_{2,}$ as CO_2 concentrations at the ocean surface are generally higher than those in the air. Measurements taken during the Ocean Margins Program indicate the MAB is a net annual sink of CO_2 (Degrandpre et al. 2002). The New Jersey shelf is also an annual net sink, but it acts as a source during the summer and fall months (Boehme et al. 1998).

There are two mechanisms relevant to ocean releases of CO_2. First, upwelling along the coastline brings CO_2-rich water to the surface. The concentration of CO_2 is roughly 40 times higher in bottom waters than in surface waters and in the atmosphere because of respiration (Pilson 1998). The disequilibrium causes CO_2 to be released to the atmosphere. Upwelling has been documented to occur repeatedly during the summer months off of the coast of New Jersey, driven by offshore winds and bringing bottom waters to the surface (Ingham and Eberwine 1984; Glenn et al. 1996; Yankovsky and Garvine 1998; Chant 2001; Chant et al. 2004; Glenn et al. 2004).

Second, sediment on the Atlantic continental shelf is a place of significant denitrification (Section 4.1.1). Denitrification reduces primary production, reducing the carbon incorporation into organic matter, thereby leading to more CO_2 in the seawater. The latter mechanism also increases alkalinity, which acts to reduce CO_2 in seawater (Fennel et al. 2008). It is a poorly understood mechanism with many variables that are poorly quantified, but a study using a physical-biological coupled model predicts that the waters of the Mid-Atlantic Bight continental shelf may act as an annual source of atmospheric CO_2 (Fennel et al. 2006).

4.1.4 Trace Metals

Trace metals are arbitrarily defined as metals with a concentration of less than one part per million. Trace metals can enter the ocean naturally through continental runoff, sediment resuspension, atmospheric input, and cosmic impacts. Trace metals also enter the marine environment as a result of human activities such as industrial discharges, sewage discharges, and the burning of fossil fuels. Trace metals are generally present only in minute amounts in the ocean except in areas where they are, or have been, routinely deposited. Examples of such sites are sewage sludge and chemical dumpsites (Figure 4.2). In Massachusetts Bay, concentrations of metals from sewage discharges were less than the "effects range median," the concentration of a contaminant above which harmful effects always or almost always occur (Bothner et al. 2002). Atmospheric inputs of toxic metals to Massachusetts Bay are given in Table 4.3 (Golomb et al. 1997) along with the approximate mean concentration of metals in the ocean (summarized from Pilson 1998).

Metals such as iron, copper and manganese are biologically active: They exhibit nutrient-like distributions in the ocean and in some instances act as micronutrients. Iron is found in concentrations of 0.001-0.002 µmol/L in surface waters of the northwest Atlantic and 0.004-0.007 µmol/L in bottom waters (Symes and Kester 1985). Concentrations of dissolved copper and nickel at the shelf – slope break of the New York Bight have been measured between 0.77-8.67 nmol/kg and 2.3-14.7 nmol/kg respectively. The concentration of the organically complexed copper, measured concurrently was 0.24-1.67 nmol/kg and increased with distance from shore across the shelf (Hanson and Quinn 1983). In regions characterized by high suspended particle concentrations (> 1–10 mg/L), such as near-shore and estuarine waters, 10–30% of copper and nickel in the dissolved fraction may exist in the colloidal size range (Greenamoyer and Moran 1997). In the tissues of deepwater seaweeds from the Gulf of Maine and Rhode Island Sound, the concentrations of the metals barium, cadmium, chromium, copper, mercury, lead, and zinc are low compared to published concentration values from a variety of other seaweeds from outside of the ACS (Sears et al. 1985).

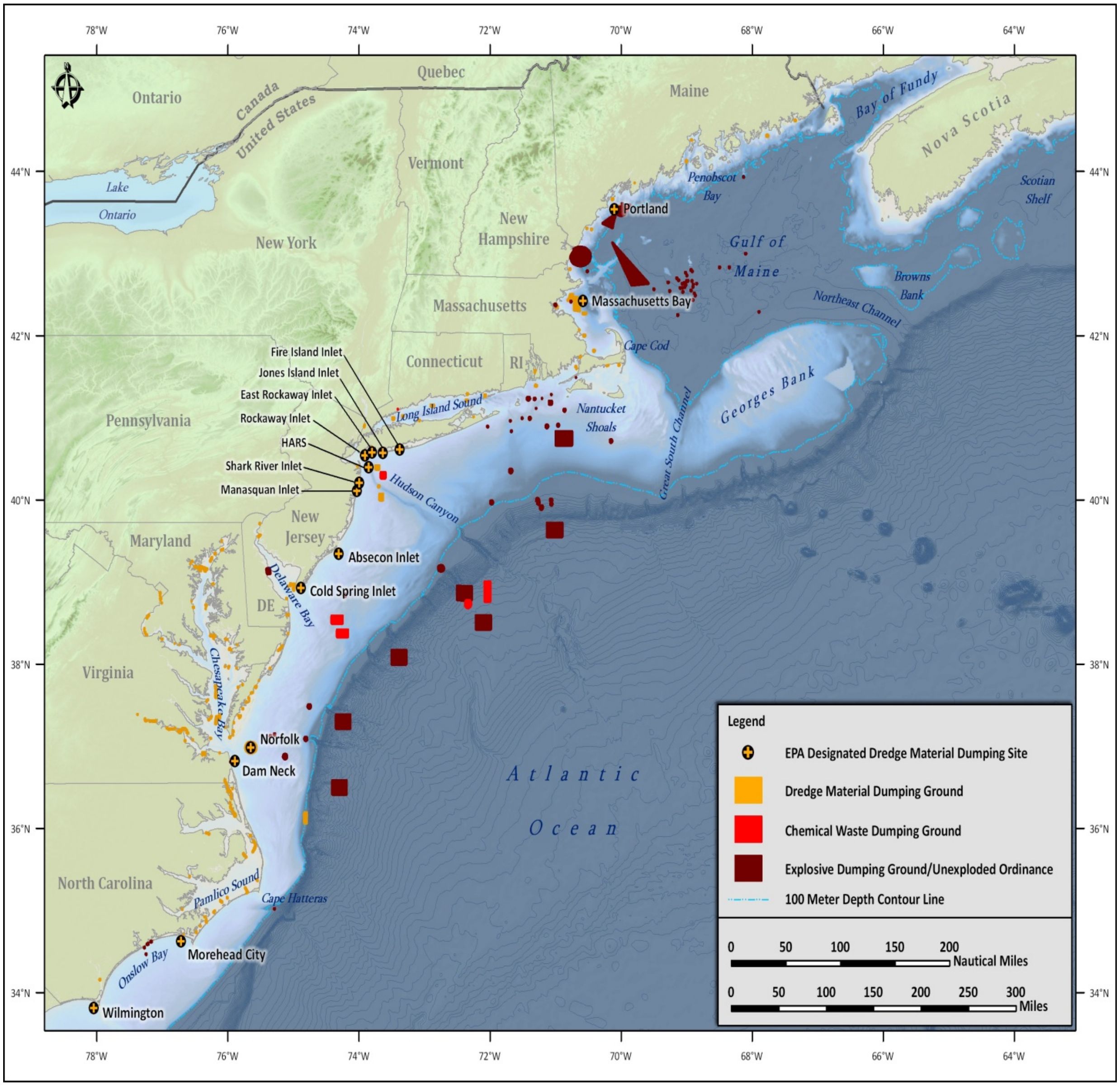

Figure 4.2. Disposal Sites within the North and Mid-Atlantic Study Areas. From USDOC, NOAA et al. 2009.

Table 4.3

Atmospheric Deposition to Massachusetts Bay and Concentration Ranges of Metals in the Ocean

Metal	Deposition[a]	Range[b]
	µg /m^2 yr	µmol/kg
Aluminum	102,000	0.0001-0.4
Antimony	160	?
Arsenic	132	0.015-0.025
Cadmium	405	0.000001-0.0011
Chromium	2,700	0.002-0.005
Cobalt	58	0.00001-0.0001
Copper	3500	0.0005-0.006
Iron	140,000	0.0001-0.0025
Lead	2,700	0.000005-0.000175
Manganese	420	0.0002-0.003
Nickel	7,200	0.002-0.012
Selenium	264	0.0005-0.0023
Zinc	7,800	0.00005-0.009

a From Golomb et al. (2001).
b Taken from Pilson (1998)

A small number of metals are “conservative” in the water column, meaning that the concentration does not change from the surface to the bottom. They may have small fluctuations laterally but the variability is generally discussed relative to ocean basin scales. Particle-reactive metals have an affinity to sinking sediment and are taken from the water column at all depths and deposited at the bottom. Trace metals do not appear to cause significant toxicity at the uptake/primary production level but they do have the potential to bio-accumulate up the food chain.

Sewage sludge dumpsites along the ACS are documented to have high concentrations of metals (Watling et al. 1974; Butman 2006) that could be released to the water column if the sediment is disturbed. The areas of note are two sewage sludge dumping sites and an acid waste disposal site off of Delaware Bay, and the historic area remediation site (HARS) located in the New York Bight Apex. The HARS is the only site that still accepts material. This material must be suitable for remediation, defined as uncontaminated dredged material that will not cause significant undesirable effects including bio-accumulation (Table 4.4). The locations of these areas are displayed in Figure 4.2.

Table 4.4

Sludge and Acid Waste Disposal Sites

State	Site	Size	Amount Disposed	Disposal Since:	Status	Type
PA	Old Delaware Bay sludge disposal site[a]	8 km^2	0.557×10^6 metric tons	1961	1973	Sewage Sludge
PA	Delaware Bay Sewage sludge disposal site[a]	172 km^2	0.570×10^6 metric tons	1973	1980	Sewage Sludge
PA	Delaware Bay Acid Waste site[a]	2 mi^2	Unknown	1968	1977	Chemical waste from DuPont
NY	Historic Area Remediation Site (HARS)[b]	15.7 nmi^2	125×10^6 m^3	1914	1997	Sewage Sludge
NY	Historic Area Remediation Site (HARS)[b]	15.7 nmi^2	Maximum 100×10^6 yd^3	1997	Selectively active	Remediation Material (capping)

[a] From Duedall (1983)

[b] From USDOD, ACE (2009)

In addition to sewage sludge and chemical waste sites, there are dredge disposal sites servicing dredging projects in the study area. No information on the chemical contaminants of the dredge site was found. These sites are designated to receive material from channel-dredging projects. Material deposited at the sites is intended to remain at the site (containment site). The exception is Cornfield Shoals in Connecticut waters, where deposited material is intended to be mobilized by the currents (Table 4.5) (USEPA 2008).

4.1.5 Redox Chemicals

Redox reactions are electron transfer processes. Oxidation is the process by which a chemical or element donates an electron. The reverse process, reduction, is a reaction in which a chemical or element receives an electron. Depending on environmental conditions, redox reactions can influence the dissolved oxygen and trace metal concentrations of a system. Organic matter is food for bacteria, which oxidize it to carbon dioxide. Because dissolved oxygen provides the highest energy yield, it is used by bacteria first. Once oxygen consumption exceeds oxygen replenishment and the water becomes anoxic, nitrates and manganese oxide minerals are energetically favored as the oxidizing agents. As it is reduced, the manganese is released into the water system as a free ion. Iron oxides are also reduced, releasing iron into the water. Carbon is similarly reduced. This leads to the release of methane gas.

Sulfide in the marine environment is present as dimethyl sulfide (DMS), produced by phytoplankton, and as carbonyl sulfide, produced by photochemical reactions in surface waters. Dimethyl sulfide concentrations follow patterns similar to primary production. There are no direct measurements of DMS in the study area, but the global weighted concentration is 102 ng/L.

Table 4.5

Dredged Material Disposal Sites from Long Island Sound to Maine

State	Site	Size	Yd^3 disposed	Disposal Since:	Status	Type
ME	Cape Arundel	500-yd diameter circle	1.32 X 10^6	1985	Active	Containment site
MA	Cape Cod Bay	1.0 nm^2	0.82 X 10^6	1994	Active	Containment site
CT	Central Long Island sound	11.04 km^2	8.34 X 10^6	1980	Active	Containment site
CT	Cornfield Shoals	1.0 nm^2	1.34 X 10^6	1982	Active	Dispersive site
MA	Massachusetts Bay	2.0 nm diameter	N/A* 12.69 X 10^6 *	1993	Active	Containment site
MA	Massachusetts Bay interim site	N/A		1977	Closed 1993	Containment site
CT	New London	1.0 nm^2	2.81 X 10^6	1981	Active	Containment site
ME	Portland	1.0 nm^2	2.73 X 10^6	1982	Active	Containment site
RI	Rhode Island Sound	1.0 nm^2	5.31 X 10^6	2003	Active	Containment site
ME	Rockland	0.25 nm^2	1.38 X 10^6	1982	Active	Containment site
CT	Western Long Island Sound	2.0 nm^2	1.91 X 10^6	1982	Active	Containment site

From USDOD, ACE (2009)
*MA totals represent total of interim and current site

Measurements of dissolved carbonyl sulfide concentrations in the shelf waters of the Atlantic average 0.4 nmol/L. The mechanism source of carbonyl sulfide is not identified, but organic matter decomposition and sulfate reduction are thought to be contributors (Cutter and Radford-Knoery 1993).

Generally, redox reactions are considered sedimentary reactions, occurring after oxygen has been depleted to the point that it is no longer the predominant electron acceptor and other molecules are utilized as electron acceptors. The redox resources in the water column, such as pH changes and nitrification, are covered in Sections 4.1.1 and 4.1.3. Sediment redox resources are discussed in Section 4.2.5.

4.1.6 Trace Gases

Trace gases are defined as volatile organic substances (VOS) detected in seawater. The five gases with the highest concentrations are carbon monoxide, dimethyl sulfide, methane, ethylene and carbonyl sulfide (Table 4.6). These values are representative of the open ocean and not of the ACS, but they provide insight into how small trace gas concentrations are in seawater.

Table 4.6

Trace Volatile Organic Substance Concentrations in Seawater (summarized from Pilson 1998)

VOS	pmol/L	
	Surface	Deep
Carbon monoxide	12,800	
Dimethyl sulfide	2,600	100
Methane	2,000	1,000
Ethene	100	
Carbonyl sulfide	30	

As discussed in the section on oxygen (4.1.2.), gases in the ocean are regulated by exchange with the atmosphere, temperature, biological activity, and exchange with the sediment. To constrain the carbon cycle on the continental shelf, evidence of methane production off New Jersey was investigated in the sediment, pore water and sulfate chemistry. Methane production was not an important process on the outer shelf, but evidence in the sediment record showed it appeared to be more important at some point in the geologic past (Neogene period, from 23 million years ago to present) and could be a variable and unaccounted for process in the carbon cycle (Malone et al. 2002). There are no other references in the literature database that specifically address ethene or carbon monoxide. Measurements of dimethyl sulfide and carbonyl sulfide are addressed in Section 4.1.5.

4.1.7 Radionuclides

Radionuclides are isotopes of elements with too many or too few neutrons in relation to the number of protons in the nucleus. The unstable nucleus spontaneously transforms, either directly or through some intermediary forms, into a stable nucleus. Radionuclides in the marine environment are of interest because of their ability to act as transport tracers. They are important as labels for measuring the transport rates at which gases and insoluble substances are removed from the water column, for example gas exchange rates of both the sediment-sea and air-sea interfaces and sediment surface depositional history. Radionuclides relevant to the northwest ACS are thorium-228 (^{228}Th), thorium-234 (^{234}Th), radium (^{226}Ra), radon (^{222}Rn), lead (^{210}Pb), carbon 14(^{14}C), carbon 13 (^{13}C), and polonium (^{210}Po). In the New York Bight, ^{228}Th removal time is on the order of 11 days in shelf surface water in the summer and 29 days in shelf winter water. During the winter months, the inner shelf has a half-removal time of 17 days and the outer shelf has a half-removal time of 28 days (Li et al. 1979; Kaufman et al. 1981). The half-removal time of ^{228}Th from the surface waters by particle settling does not change appreciably between the spring summer and fall. In the winter regenerated ^{228}Th, ^{210}Pb and ^{210}Po can be transported back to the surface water from the bottom water and/or nearshore sediments. The removal of ^{228}Th and ^{210}Pb from the surface waters of New York Bight by phytoplankton-zooplankton-fecal pellet route is not important in the shelf but is on the continental slope (Li et al. 1981). In the shelf waters of New England, ^{234}Th has been used to investigate the role of reactive metal scavenging in surface waters. The activities of total ^{234}Th increase proportionally with distance from shore. in off-shore waters, 93-98% of total super ^{234}Th is dissolved, 2-16% is particulate and 1% is colloidal (Moran and Buesseler 1993). The profile of colloidal ^{234}Th represented 7-36% of the total ^{234}Th in the Gulf of Maine in the summers of 1996 and 1997. ^{234}Th was correlated with the chlorophyll-a fluorescence maximum (Dai and Benitez-Nelson 2001). Measured ^{14}C and ^{13}C distributions of total dissolved organic carbon, suspended particulate organic carbon, and dissolved inorganic carbon are used to evaluate the ages, potential sources, and transformations of organic matter in the waters of the MAB (Bauer et al. 2001).

^{226}Ra is a radionuclide with a half life of 1600 years. It is formed in the sediment of the ocean when ^{230}Th undergoes alpha decay. ^{226}Ra is soluble: as it is formed in the sediment; a portion will diffuse into the water column above, thus entering the ocean. Continental washing will also carry ^{226}Ra into the sea. ^{226}Ra will also undergo alpha decay to produce ^{222}Rn. ^{222}Rn has a half-life of 3.85 days, decaying through a number of short lived daughter nuclides to ^{210}Pb, which has a half life of 22.3 years. Because of the short-lived nature and its lack of chemical reactivity under the conditions found in seawater, ^{222}Rn, is used a tracer of ocean processes that occur on a time scale of days. The most commonly studied processes are exchanges at the boundaries and vertical mixing rates but no references on these process rates were found in the study area. The surface concentration of ^{226}Ra in the Atlantic is close to $4x10^{-14}$ gram per liter (Broeker et al. 1967).

4.1.8 Organic Chemicals

Organic matter is found either as a particulate or dissolved in the water column. It can be referred to as organic carbon; common terms are “particulate organic carbon” (POC), “particulate organic matter” (POM), “dissolved organic/inorganic carbon” (DOC, DIC), and “dissolved organic material” (DOM). The component of DOM that is optically measurable is referred to as “chromophoric dissolved organic material” (CDOM) and the component that is fluorescent is referred to as FDOM. Additionally, there is atmospheric deposition of “black carbon” (BC) to the North Atlantic. BC is combustion-derived organic carbon formed during the incomplete combustion of fossil fuels.

Phytoplankton contributes the highest fraction of total organic matter in the sea, mostly on the continental shelves. Riverine inputs contribute the second greatest fraction of the total. The production and fate of organic matter factor heavily into the cycling of nutrients, oxygen concentration, and biological assemblages. The major sources of DOC and POC in the MAB are the York River (VA), Cheseapeake Bay, primary production, surface sediments, and the open ocean (Bauer et al. 2001; 2002). Studies of dynamics of DOC in the MAB show clear spatial and temporal trends in DOC. Concentrations of DOC are greater inshore than offshore and increase southward along the shelf (Vlahos et al. 2002). The total DOC inventory on the shelf during March and April is estimated to be 5.88×10^{12} g carbon, increasing 0.4×10^{12} g carbon by

August (Vlahos et al. 2002). The composition of high-molecular-weight DOM from the MAB is characterized as between 50 percent and 80 percent acyl polysaccharide (APS), a biopolymer product of marine production, and up to 49 percent humic substances, which are from terrestrial sources. FDOM measurements in the MAB during spring and summer show a seasonal spike in FDOM concentrations during the spring compared to the summer, when photodegradation create FDOM deficits. The majority of FDOM (about 90 percent) on the shelf is from the continental slope, with the remaining fraction coming from terrestrial sources (Chen et al. 2002). CDOM represents only a small portion of the DOC pool in offshore waters; the sources and sinks of CDOM and DOC are uncoupled despite the often-observed correlation between CDOM and DOC in the coastal environment (Valente 2004).

The source of organic matter on GB is primarily primary production and resuspension of bottom sediments (Bothner et al. 1981). Photosynthetic production rates throughout the Gulf of Maine and GB range from 1.3 to 182 milligrams of carbon (C) per meter cubed per day (mg $C/m^3/d$). Calcification rates range from 0 to 9.3 mg C/m^3d for all depths and locations during the months of March, June, and December. The annual carbon production for the Gulf of Maine is estimated to be 182 g/m organic carbon and 3.7 g inorganic carbon (Graziano et al. 2000). Concentrations of DOC during the spring are between 72 and 85 µmol/L in the surface waters and between 54 and 56 µmol/L in deeper waters (Chen et al. 1996). Measurements of DIC suggest that annual production is between 87 and 153.3 g/m of carbon (Sambrotto and Langdon 1994). The contribution of BC to the POC concentration is between 1 and 20 percent during the spring and summer. The BC concentrations range between 0.1 and 16 µg/L in the same time period. The observed distributions of BC imply that it is carried offshore by the wind, and the majority is accumulated in the coastal sediments (Gschwend 2008; Flores-Cervantes et al. 2009). There were no direct references to DIC measurements in the MAB.

4.1.9 Density (temperature and salinity)

Density is discussed in the Physical Oceanography resources section, Section 2.4 of this synthesis report.

4.2 SEDIMENT PROPERTIES

4.2.1 Nutrients

A portion of the nutrients incorporated into organic matter at the surface will sink and settle to the sediment. As the organic matter is broken down by bacteria, the nutrients will be released into the sediment and the interfacial bottom water. The term “release” is used broadly, as nitrogen may be transformed by denitrification or released as dissolved organic and inorganic forms. The movement of water at the sediment-water interface is slow, causing nutrients in the bottom layer to build up to concentrations greater than that of the surface. Eventually this nutrient-rich water will be brought back up to the surface when it is upwelled by wind or tidal forcing.

In the Gulf of Maine the loss of nitrogen to the sediment through denitrification and burial is 37.5×10^9 g-at N/yr (Townsend 1998). Burial accounts for about 10 percent of this loss, but there is no specific information on the chemical forms and concentrations of the bottom water nitrogen, phosphorous, and silica in the Atlantic Continental Shelf (ACS) region.

Sediment denitrification is considered a very important nitrogen-removal mechanism on the shelves. The process is so large that estimates of denitrification outweigh the measurable inputs. A model of coupled nitrification/denitrification suggests that approximately 13 percent of the nitrogen incorporated into phytoplankton in shelf waters is eventually denitrified in the sediments via coupled nitrification/denitrification, based on a carbon-to-nitrogen ratio of 6.625:1 for phytoplankton (Seitzinger and Giblin 1996). A model-predicted average denitrification rate for continental shelf sediments in the North Atlantic Basin is 0.69 mmol N/m^2/d. Model denitrification rates per unit area are highest for the continental shelf region in the western North Atlantic south of Cape Hatteras and lowest for Hudson Bay, the Baffin Island region, and Greenland. The total loss of nitrogen due to denitrification in the mid-latitude region of the Atlantic Shelf is 60 x 10^{10} mol N/y (Seitzinger and Giblin 1996).

4.2.2 Dissolved Oxygen

Beneath the sediment-water interface, oxygen concentration is reduced to near zero within centimeters of the sediment surface. Bacterial activity uses oxygen very quickly to the extent that other as electron acceptors, such as nitrate, need to be used. Oxygen depletion can extend upwards from the sediment-water interface to the water column. The extent of oxygen depletion above the sediment surface is dependent on the physical environment, such as the flow of water, seasonal stratification, and productivity in the overlying waters. In waters with a high level of organic matter the oxygen levels at the bottom can approach zero. Two examples are Cape Cod Bay (Jiang et al. 2007) and the New York Bight (Falkowski et al. 1980). There is evidence to suggest sediment oxygen uptake is directly related to denitrification in the Gulf of Maine (Seitzinger and Giblin 1996) but there is a dearth of sources that comprehensively examine oxygen in the sediment.

4.2.3 Carbonate System and pH

The pH of the sediment is a function of redox potential chemistry. The sediment profile will exhibit a pH minimum in the first few centimeters, where organic matter is rich, and then become stabilized within the first meter. The spatial scales used to characterize pH in the sediment are typically measured in tens of centimeters. There were no references found for the ACS region that specifically address pH in the sediment, but decreases in pH of roughly 0.5 units in magnitude compared to the surface water have been observed above the sediment-water interface in the New York Bight. These decreases are attributed to anaerobic bacterial activity within the sediments scavenging oxygen from the waters above (Friedman et al. 2000).

4.2.4 Trace Metals

Metals enter the sediment by settling out from the waters above. Once in the sediment, they are sequestered to particles or remain labile in the pore water. Heavy metals are sequestered by acid volatile sulfides (AVS) and the “total organic carbon” (TOC) fraction of marine sediments (U.S. Environmental Protection Agency 2005). Bioavailability is governed by an excess of AVS concentrations relative to the metal concentrations as normalized by TOC (USEPA 2005).

Few studies have analyzed the trace metal concentrations of the ACS sediment. The notable exceptions are the Georges Bank Monitoring program and trace metal concentration monitoring associated with sewage discharge and sludge disposal on the continental shelf. The results from the Georges Bank Study showed that sediment trace metal concentrations were low compared to the surrounding crustal rocks and that variability was related to grain size (Bothner et al. 1986).

Sludge disposal sites and outfalls are displayed in Figure 4.2. Direct introduction of metals to the Atlantic Continental Shelf occurred in the New York Bight when it was permissible to dump treated sludge, which contained trace metals, into the ocean. The harmful nature of the metals in sewage sludge is dependent on the chemical associations within the sludge. The most active carriers of metals are organic matter and sulfides, accounting for 85 percent of copper, lead, and zinc and over 60 percent of cadmium and chromium. The fate of the metals is dependent on the oxidation and physiochemical alteration of the metal carriers. Organic matter will be oxidized and the metals released while metals attached to sediment will tend to remain with the sediment and not be labile (Angelidis and Gibbs 1989).

The introduction of a sewage pipe in Massachusetts Bay, MA, increased silver concentrations associated with suspended sediment by 38 percent, 1.3 km south of the outfall, while chromium, copper, and zinc had no increase in concentrations. Sediment concentrations of silver 2.5 km west of the outfall remained unchanged (Bothner et al. 2002).

4.2.5 Redox chemicals

Redox chemistry describes the movement of electrons. In the sediment there is a series of reactions starting with oxidative metabolism (respiration) and ending with fermentation, that occur as one electron donor is exhausted by bacteria and another is used in its place. These reactions are controlled by factors like the bacterial assemblage, chemical forces such as pH, and the availability of organic matter and the geological makeup of the sediment. The reactions occur in the pore water, the water in the spaces between, and on the surface of sediment particles. The only reference to sulfide in the sediment of the ACS indicated that a pore water concentration of carbonyl sulfide was in excess of 700 nmol/L (Cutter and Radford-Knoery 1993).

4.2.6 Trace gases

The trace gas concentrations of the Atlantic Continental Shelf sediment are poorly covered in the literature. Generally trace gases in the sediment are produced by decomposition of organic matter or weathering of minerals. An example of organic release is the release of methane by the sediment over geologic time. There is no appreciable release now but the presence of indicative minerals in the sediment demonstrates that there has been a release within the last 23 million years on the ACS of New Jersey (Malone et al. 2002).

4.2.7 Radionuclides

Radionuclides in the sediment can be used as labels to track the mechanisms of particle settling and recycling. There is a relatively large amount of literature on radionuclides in seawater in Buzzards Bay, MA.

Pore water profiles of uranium and thorium isotopes in mud sediments display how diagenetic redox reactions affect the geochemical behavior of these elements. Minimum uranium activities in the pore water are approximately 1.2 disintegrations per minute per kilogram (dpm/kg) in the first 3 cm of the sediment near the water interface, coinciding with the pore water iron maximum. Uranium concentrations then increase with depth into the sediment to a maximum, which exceed the overlying seawater, before decreasing (Cochran et al. 1986).

Pore water profiles of the thorium isotopes ^{232}Th and ^{230}Th have activities of 0.02 dpm/kg and are relatively constant with depth but at concentrations greater than those in the bottom layer of seawater. The isotope ^{234}Th has its greatest activity in the upper 5 cm of the sediment and has activities of practically zero in other parts of the sediment column (Cochran et al. 1986).

As stated in the previous section, ^{226}Ra is formed in the sediment of the ocean when ^{230}Th undergoes alpha decay. A portion of ^{226}Ra will diffuse into the water column above, thus entering the ocean. ^{226}Ra will also undergo alpha decay to produce ^{222}Rn. No articles concerning this process were found for the study area.

The pore water profile of the plutonium isotopes ^{239,240}Pu displays a subsurface maximum of 0.0028 dpm/ kg in the 3-to-11-cm range. The overlying seawater has an activity of 0.00001 dpm/ kg. Below 11 cm, the pore water ^{239,240}Pu distribution decreases rapidly with depth (Sholkovitz and Mann 1984).

The pore water profiles of the cesium isotope ^{137}Cs exhibit maximum activities of about 0.35–0.40 dpm/kg from a few centimeters below the surface to several meters in depth. The overlying seawater has activities ranging between 0.17 dpm/kg and 0.24 dpm/ kg. The conclusions drawn by the authors from these observations are that there is a preferential downward diffusion of ^{137}Cs and that ^{239,240}Pu does not demonstrate an active diagenetic chemistry and is not significantly mobile in these coastal sediments (Sholkovitz and Mann 1984).

4.2.8 Organic Chemicals (i.e., hydrocarbons)

4.2.8.1 Organic Matter

Organic matter is present in the sediment from particulate snow falling from surface waters. The major source of the particulate matter is primary productivity (photosynthesis) at the ocean's surface. The next largest source is continental input from rivers bringing nutrients, dissolved organic carbon, and particulate organic carbon. Finally, wind and rain deposition at the ocean surface can add significant amounts of organic matter, a portion of which settles onto the sediment.

The concentrations of carbon, hydrogen, and nitrogen (CHN) in the sediment of western Long Island Sound (LIS) average 1.54, 1.40, and 0.17 percent by weight, respectively. Individual CHN concentrations inversely correlate with sediment grain size, with higher CHN concentrations in finer sediment. TOC and nitrogen values increase on a westward progression in the LIS, a result of increasing nutrient inputs and decreasing circulation. The primary source of sedimentary organic matter in LIS study area is believed to be marine phytoplankton. Concentrations of the sedimentary organic matter are significantly higher in the spring than in the late summer, which suggests that concentrations are seasonally variable (Poppe et al. 1996).

The concentration of "black carbon" (BC) in the marine sediments of the Atlantic continental shelf are between 0.11 and 1.7 mg/gram-dry-weight. The distribution in sediment cores are consistent with anthropogenic fossil fuel combustion deposition seen in recent times. The fluxes of BC are between 1 and 2 $g/m^2/yr$ and this suggests that the Shelf sink in this area is of comparable magnitude to BC production from fossil fuel combustion and biomass burning in the northeast region of the US (Gustafsson and Gschwend 1998).

In the inner New York Bight, the accumulation of pore-water dissolved organic carbon (DOC) is more limited in the mixed-redox (an environment that alternates between oxidizing and reducing) than in anoxic marine sediments. Humic-like fluorescence intensity also differs between mixed-redox and anoxic zones of the sediment, such that anoxic pore waters are comparatively enriched in humic-like fluorescent compounds. Modeling of pore-water DOC suggests that the majority of pore-water DOC is comprised of poorly reactive material, with the exception of the upper centimeters of the sediment column. Model results also suggest that DOC accumulation is inhibited in the mixed-redox compared to the anoxic zones of the sediment due to the rapid oxidation of high-molecular-weight DOC, and limited production and enhanced oxidation of the less reactive, low-molecular-weight component of the DOC pool (Komada et al. 2004).

4.2.8.2 Hydrocarbons, PCB's, and Dioxins

Hydrocarbons are present either naturally or from anthropogenic inputs. Information on the extent of natural hydrocarbons on the ACS is restricted because in-depth surveys are privately funded and not available to the public.

Persistent organic pollutants (POPs), such as polyaromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyl (PCBs), are sequestered in the total organic carbon (TOC) fraction of sediments (USEPA 2003a; 2003b; 2003c). Similarly, heavy metals are sequestered by AVS and the TOC fraction of marine sediments (U.S. Environmental Protection Agency 2005; Johnson et al. 2008). For POPs hydrocarbons, like PAHs, the ratio of the concentrations of these contaminants relative to those of the fractions governs bioavailability and hence toxicity (USEPA 2003b). In the case of metals, bioavailability is governed by an excess of AVS concentrations relative to the metal concentrations as normalized by TOC (USEPA 2005). Sand and gravel sediments typically contain low TOC and AVS concentrations, and where there is a prominent source of POPs and metals, such as at dumpsites, these coarser sediments could in fact release such contaminants when disturbed or oxidized (Johnson et al. 2008).

Residual oil in the sediment as a result of oil spills is of concern mostly in waters close to the shoreline. In 1996, more than 3 million liters of No. 2 fuel oil was spilled into Rhode Island Sound after the tank barge *North Cape* and tug *Scandia* grounded on Moonstone Beach, RI. The toxicity and chemistry of this oil in subtidal sediments were followed for nearly a year after the spill. Maximum concentrations of polycyclic aromatic hydrocarbons (PAHs) in the sediments reached 730 μg/g dry weight (DW) but returned to background levels of 10 μg/g after 6 months

(Ho et al. 1999). In the four months following the spill, samples from the water column showed maximum concentrations of PAHs and total petroleum hydrocarbons were 155 and 3940 µg/L, respectively (Reddy and Quinn 2001).

In the Gulf of Maine, sediment samples have been analyzed for 16 PAH compounds. The majority of the compounds were widely distributed, with total concentrations ranging from 10 to 512 ppb (dry weight). These values are an order of magnitude lower than observed values in the coastal zone, but greater than those on Georges Bank. Observed PAH distributions decrease rapidly with distance from shore and indicate that the principal transport mechanism is through the atmosphere with localized augmentation by sediment resuspension and transport from coastal embayments (Larsen et al. 1986; Windsor and Hites 1979; Hites and Laflamme 1978).

Polychlorinated biphenyls (PCBs) were a product of paint, plastic, coating compounds and many other manufacturing processes until the 1970s. However, they are persistent in the environment and are still of interest because of the detrimental health effects they cause if they enter the food chain. The geographic extent of the PCB contamination in the Gulf of Maine showed detectable levels of PCBs found at concentrations ranging from trace amounts to 0.13 ppm (dry weight) (Larsen et al. 1985).

Dioxins naturally occur as byproducts of combustion, such as forest fires, and of manufacturing processes such as paper manufacture. Evaluation of sediment quality in Casco Bay (CB), ME, revealed that dioxins were present in all sedimented areas of Casco Bay. The concentrations were highest near potential input sources. Dioxins had higher concentrations near the Presumpscot River, 10 miles downstream of a pulp and paper mill and in the East Bay. These high concentrations are thought to be the result of transport into the bay from sources in the Kennebec/Androscoggin River or localized combustion sources (Wade et al. 1997).

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5. GEOLOGICAL OCEANOGRAPHY

The geological oceanography section of this synthesis report focuses on the bathymetry, surficial sediment data, and potential geohazards of the North and Mid-Atlantic Coast. The Atlantic coast does not experience heavy sediment deposition from river estuaries, as is the case with the Gulf of Mexico and the Mississippi River Delta, nor is it situated on a tectonic boundary (as is the Pacific Coast). Therefore, the Atlantic Coast is typically considered to be a passive margin with a relatively stable sediment regime. The main source (present-day) of sediment influx is storm events (e.g. hurricanes and nor'easters) that supply sediment via increased storm-wave beach erosion, inland runoff, and deposition from deepwater regions into the nearshore environment. Due to the aleatory nature of these events and the lack of alternative sediment loading mechanisms, the Atlantic Continental Shelf (ACS) is typically considered a relatively stable, wide, and relatively flat margin with few regions that exhibit conditions for erosional transgression. In addition, the ACS (up to the 100-m isobath) has few geological structures that could potentially impact alternative energy development.

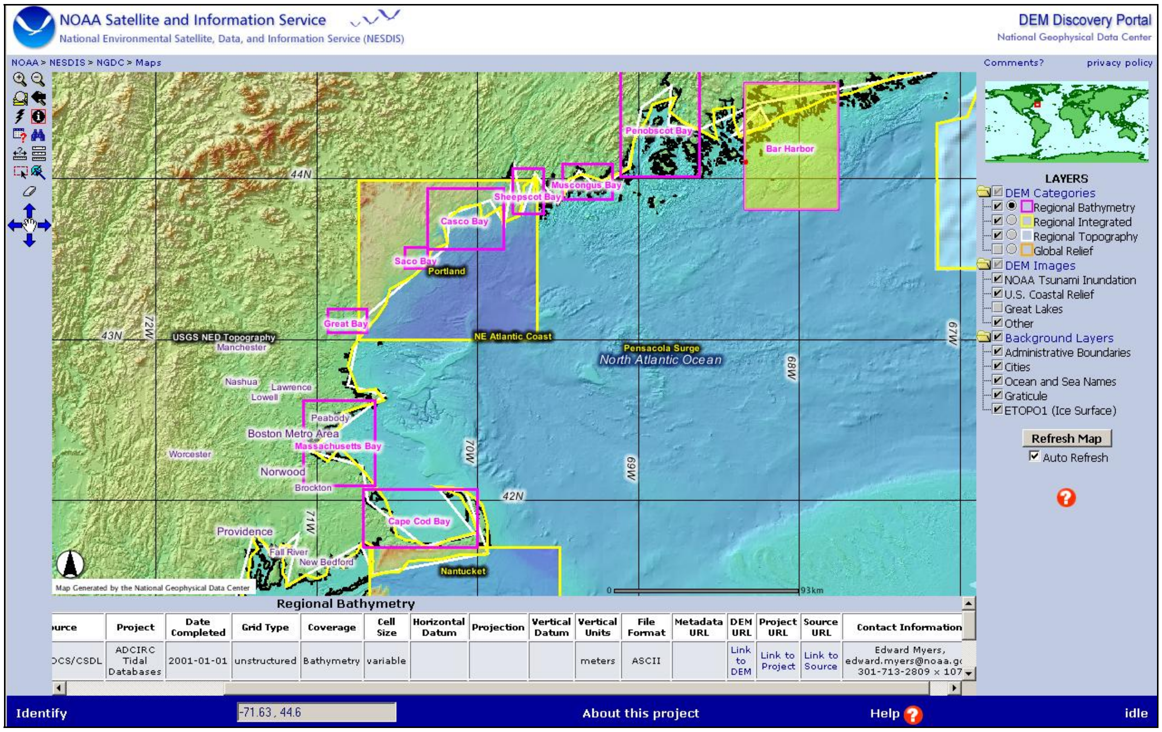
For the purpose of this synthesis, the geological oceanography characterization is limited to the region of ACS from the coastline to the 100-m isobath. Due to the passive nature of the ACS there are limited quantities of information regarding geological structures, bathymetry, etc. available within the 100-m isobath limitation. However, there are substantially more scientific investigations in water depths greater than 100 m focusing mainly on the U.S. Atlantic continental slope and are of limited use in this report. While each topic presented within this section can easily be expanded into greater depth, the focus of this synthesis is to present information relevant for the siting and design of renewable/alternative energy structures.

For specific locations within the study region a detailed bathymetric image or dataset can be obtained from the National Oceanic and Atmospheric Administration National Geophysical Data Center database (Amante and Eakins 2008; Divins and Metzger 2008) in a format compatible with standard Geographic Information System (GIS) software. Similarly, for detailed or site-specific surficial sediment data both the Continental Margin Mapping database (Poppe et al. 2005) and the usSEABED database (Reid et al. 2005) produce output files compatible with GIS software. Grilli et al. (2009) illustrate how the data presented within the bathymetry and sediment databases can be utilized for site-specific studies.

5.1 BATHYMETRY

The most comprehensive source for topographic and bathymetric data for the study region is the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) database (Booth et al. 1984; USDOC, NOAA 2008; USDOC, NGDC 2008; Amante and Eakins 2008; Divins and Metzger 2008) Figure 5.1. The NOAA database is a collection and integration of multiple bathymetric data sources that include the U.S. National Ocean Service Hydrographic Database, the U.S. Geological Survey (USGS), Monterey Bay Aquarium Research Institute, U.S. Army Corps of Engineers, and multiple academic institutions. Additionally satellite surveys (3-arc-second grids) along with USGS topographic surveys describe the topography for the U.S. East Coast. This data is compiled into a singular, interactive Coastal Relief Model (CRM) in a 3-arc-second (about 90-m) grid that integrates land elevations and ocean depths, providing a comprehensive view of the U.S. coastal zone, and allows the user to generate specific GIS relief files (Divins and Metzger 2008). Additionally, the USGS provides similar imagery and downloadable Metadata files for all U.S. East Coast regions (USDOI, GS 2008a).

The distance to the 100-m isobath closely corresponds to the contours of the Atlantic continental shelf-slope break (USDOC, NOAA 2008; Divins and Metzger 2008; Amante and Eakins 2008). The ACS is approximately 23 km wide to a water depth of approximately 55 m at its narrowest region near Cape Hatteras North Carolina, and approximately 150 km wide to a water depth of approximately 160 m at its widest extent off the New Jersey coastline (Reidenauer et al. 1999). Additionally, the ACS has gentle bathymetric gradients, with typical inclinations of less than 4 degrees (Reidenauer et al. 1999; Goff et al. 2004; Locat et al. 2003; Nordfjord et al. 2005). In the Mid-Atlantic Bight, the gradient of the slope is relatively flat, with inclinations of less than 0.02 degrees (Reidenauer et al. 1999; Nordfjord et al. 2005). This gradient remains relatively constant until the Atlantic continental shelf-slope break.



LAYERS

- ☑ DEM Categories
  - ☑ ● Regional Bathymetry
  - ☑ ○ Regional Integrated
  - ☑ ○ Regional Topography
  - ☐ ○ Global Relief
- ☑ DEM Images
  - ☑ NOAA Tsunami Inundation
  - ☑ U.S. Coastal Relief
  - ☐ Great Lakes
  - ☑ Other
- ☑ Background Layers
  - ☑ Administrative Boundaries
  - ☑ Cities
  - ☑ Ocean and Sea Names
  - ☑ Graticule
  - ☑ ETOPO1 (Ice Surface)

☑ Auto Refresh

Regional Bathymetry

urce	Project	Date Completed	Grid Type	Coverage	Cell Size	Horizontal Datum	Projection	Vertical Datum	Vertical Units	File Format	Metadata URL	DEM URL	Project URL	Source URL	Contact Information
CS/CSDL	ADCIRC Tidal Databases	2001-01-01	unstructured	Bathymetry	variable				meters	ASCII		Link to DEM	Link to Project	Link to Source	Edward Myers, edward.myers@noaa.g 301-713-2809 x 107

Figure 5.1. Bathymetric imagery of the Gulf of Maine, from the NOAA Digital Elevation Model database (USDOC, NOAA 2008). Highlighted regions depict areas of detailed sonar surveys.

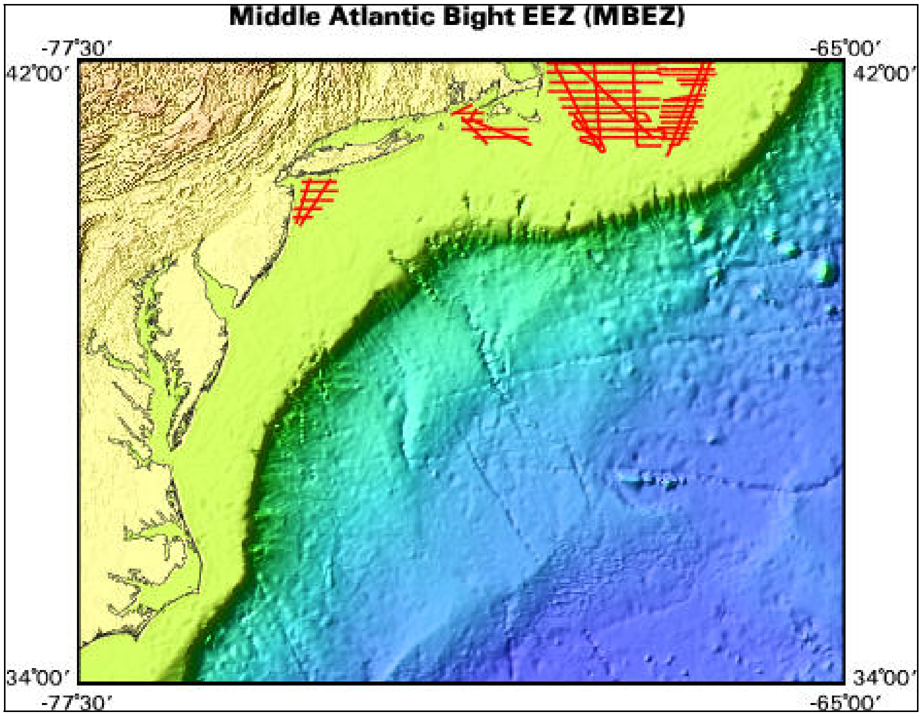


Figure 5.2. Bathymetry of the Mid-Atlantic Bight, from the USGS topographic database (USDOI, GS 2008a). This figure is from the USGS Coastal & Marine Geology InfoBank website and is an illustration as to the resolution of bathymetric imagery that can be obtained from their database. No reference to depth values are given or inferred from this figure. Depth values can be obtained by incorporating the available data into GIS software.

5.2 MARINE GEOLOGY

The ACS is typically considered to be a sediment-starved passive margin with a low degree of seismic activity due to movement of the North American Plate in a westerly direction. Unlike the sediment-rich continental regions (e.g. Gulf of Mexico) there are no major present-day fluvial sediment systems producing large sediment influx to the ACS (Riggs et al. 1998). Because of this, the ACS relies on physical and biological processes for sediment "production" and transport. However, significant coastal subsidence up to 3,000 m over the last 150 million years has led to the formation of deep sediment layers (Reidenauer et al. 1999). Additionally, most regions of the U.S. Atlantic coast are submerging at a rate of approximately 1.94 ± 0.6 mm per year (Peltier 1996) with specific submergence rates varying between 2-4 mm/yr (Newman and Rusnak 1965; Riggs et al. 1998; USDOI, GS 1998; Kearney and Stevenson 1991, Peltier 1996). However, recent studies by Pfeffer et al. (2008) indicate that sea-level rise over the next century may range between 0.8 and 2.0-m due to rapidly melting glacial ice.

The greatest impact to the formation of the present-day continental margin is the movement of the Laurentide Ice Sheet during the last glaciation. This glacial ice sheet extended from Canada to the New York Bight region of the Atlantic coast (Ives 1978; Dyke et al. 2002). Along this frontal edge terminal moraines were deposited, forming much of present day Long Island, NY, and Cape Cod, MA. The remnants of the terminal moraine yield unstratified glacial till sediments, ranging from boulder-size particles to fine-grained sediment such as silts and clays. Bedrock formations north of the New York Bight are hard, dense, and erosion-resistant formations that were shaped by the Wisconsinian glaciation. Additionally, the Gulf of Maine is in a state of isostatic rebound since the retreat of the Laurentide Ice Sheet. This increases the load-bearing potential of foundation strata in this region. However, the bedrock formations to the south of New York were not subjected to the pressures of the Laurentide Ice Sheet and tend to weather and erode more readily. This weathering increases the volume of sand loading within the sediment transport scheme, resulting in increasing numbers of beaches along the coastline.

During glaciations, sea levels decreased worldwide as significant quantities of water were trapped in the ice sheets. As the climate transitioned from glacial to interglacial and back to glacial conditions the sea level fluctuated (increased then deceased). This fluctuation of sea level caused periods of decreased then increased fluvial deposition (Reidenauer et al. 1999). The periods of increased fluvial deposition (corresponding to decreased sea levels) are the primary influence of the geology of the Mid-Atlantic Bight (Greenlee et al. 1992; Reidenauer et al. 1999; Duncan et al. 2000; Gulick et al. 2005; Mallinson et al. 2005). The resultant geology is a series of downward-dipping wedge-shaped fluvial deposits (which increase in depth as the distance from the shoreface increases) (Miller et al. 1996; Gulick et al. 2005). Each of these wedge shapes corresponds to a different time period of decreased sea level. During transitional periods from glacial to interglacial conditions, there is little sediment deposition from coastal river systems as the fluvial influx is either non-existent, effectively trapped within the coastal zone, or transported across the shelf and deposited along the slope (Riggs et al. 1998). As such, the dominant influx of sediment in the present-day regime is the result of storm events and strong longshore currents in a southwest direction (Gulick et al. 2005), and the bioerosion of exposed Pleistocene and Miocene outcroppings (Riggs et al. 1996; Riggs et al. 1998).

5.2.1 Geologic Structures

Along the ACS there are few major geologic structures from the shoreline to the 100-m isobath. The most dominant features are sand ridges (Stubblefield and Swift 1976; Swift and Freeland 1978; Swift and Field 1981; Snedden et al. 1994; Goff et al. 1999; Reidenauer et al. 1999; Nordfjord et al. 2005; Goff et al. 2005), or shoals (Duane et al. 1972). Sand ridges are created within the nearshore environment by storm activities, typically within water depth of 20 to 60 m, but have been witnessed in water depths up to about 400 m. These ridges are oriented at an angle of 10 to 50 degrees relative to the present coastline (Swift and Field 1981; Goff et al. 1999). Their amplitude varies between 1 and 10 m, with lengths of up to 5 km, and both the amplitude and spacing increase with water depth. Additionally, these sand ridges become asymmetrical, and their seaward flanks become steeper with increasing water depths. However, there is significant scientific debate over the evolution of these sand ridges in water depths greater than 20 m (Duncan et al. 2000). The two prevailing theories on the evolution of these ridges in water depths between 20 and 40 m are: (1) that these ridges are not evolving and can be considered “inactive” (Stubblefield and Swift 1976; Swift and Field 1981); and (2) the ridges are “active” or modified in this region (Snedden et al. 1994). In regions where the water depth exceeds 40 m, it is widely accepted that these ridges are historic remnants of periods of lower sea levels (Goff et al. 1999; Duncan et al. 2000).

Duane et al. (1972) identify the presence of these ridges, or shoals, from Sandy Hook, NJ, to Palm Beach, FL. However, three major regions were identified, from Sandy Hook to Cape Hatteras, which do not exhibit these features: northern region of Cape Charles, northern region of Cape Hatteras, and the southern region of Cape Hatteras.

There is also evidence of sand ribbons along the outer shelf region (Reidenauer et al. 1999, Goff et al. 2005; Nordfjord et al. 2005). Ribbons are typically northeast-to-southwest-trending striations that are parallel to the southwest current. These ribbons are formed near clusters of smooth-sided ridges (Goff et al. 2005). These ribbons indicate ongoing erosion of the outer ACS. Due to the apparent lack of development and evolution of these ribbons in the nearshore, Goff et al. (2005) hypothesize that negligible quantities of eroded sediment are being added to the sediment load within the nearshore environment. Further, Goff et al. (2005) suggest that changes to these ribbons primarily occur during storm events.

There is also evidence of buried fluvial channels, remnants of the retreat and melting of the Laurentide Ice Sheet (Reidenauer et al. 1999, Nordfjord et al. 2005) off the New Jersey coast. These buried channels are considered dormant since the last glaciation, and as such do not have a role in the present sediment regime along the ACS. Similar buried channels have been identified off the North Carolina coast (Hine and Snyder 1985; Reidenauer et al. 1999) and likewise, do not have a significant role in the present-day sediment regime (Mearns et al. 1988; Reidenauer et al. 1999).

There are several major geologic structures (e.g. Hudson Canyon, Washington Canyon, Norfolk Canyon, etc.) located along the continental slope that begin in water depths greater than the 100-m isobath (USDOI, MMS 1999; Mitchell 2004; USDOI, GS 2008a; Divins and Metzger 2008). These include the Hudson Canyon, Washington Canyon, and Norfolk Canyon, but due to their respective deeper-water locations they are not considered within this report. However, within the Mid-Atlantic Bight, there are geologic structures identified by Swift et al. (1972) and Uchupi et al. (2001) that are either remnants of periods of low relative sea levels or subsequent breaches of the terminal moraines from the last glaciation formed in Long Island, NY, and southern New England (Figure 5.3). These are the Hudson Shelf Valley, Block Island Valley, Long Island Valley, Hudson Valley, Great Egg Valley, Delaware Valley, Susquehanna Valley, Virginia Beach Valley, and Albemarle Valley. The Hudson Shelf Valley, Delaware Valley, and Albemarle Valley are northwest-to-southeast-trending valleys, while Block Island Valley and Great Egg Valley trend north to south. The Susquehanna Valley and the Virginia Beach Valley are orientated southwest to northeast. The Long Island Valley is a series of three tributaries, two southwest to northeast and one north-south, which merge into a main north-south trending valley.

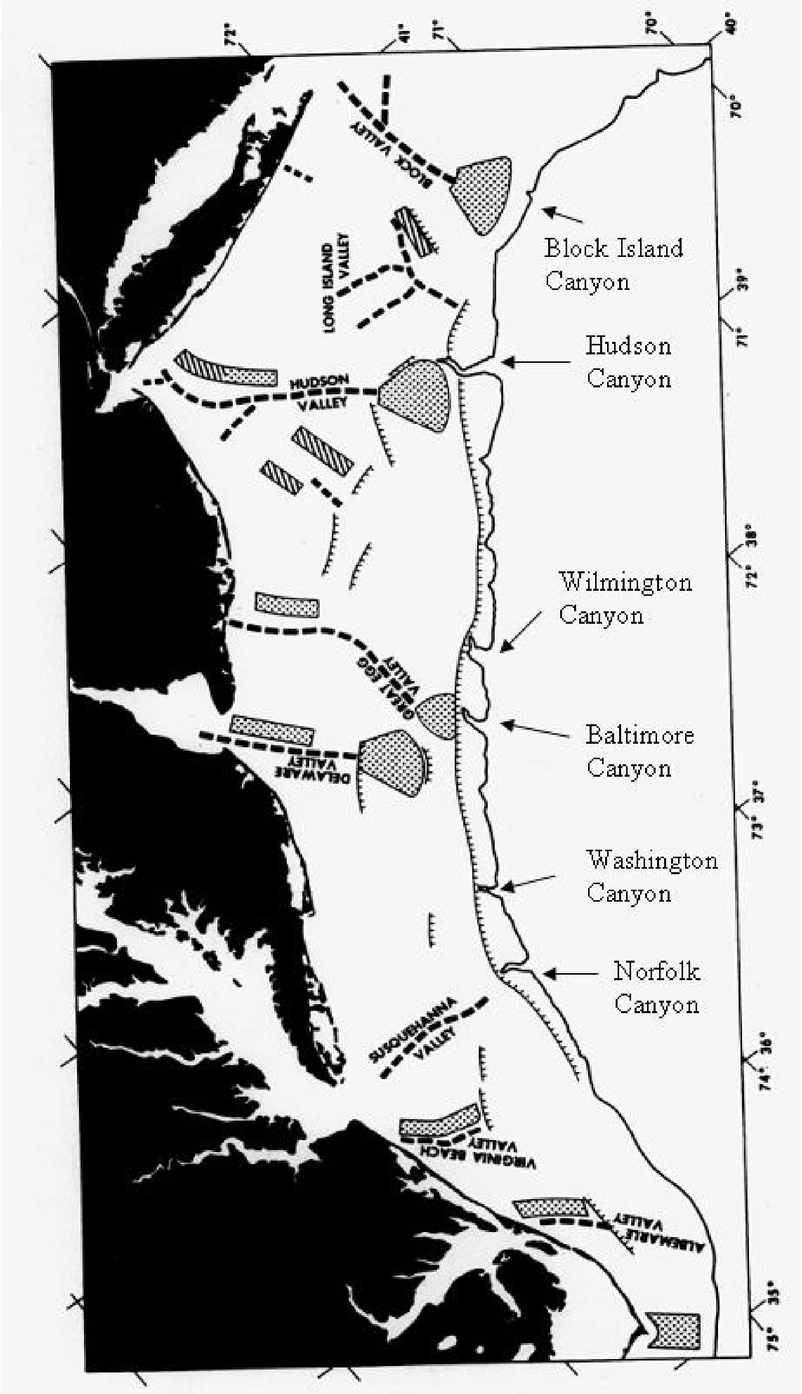


Figure 5.3. Major features within the Mid-Atlantic Bight (modified from Swift et al. 1972). The dashed [**---**] lines represent shelf valleys and hatchured lines represent scarps. Stippled areas are highs of probable construction origin, including shoal-retreat massifs and stillstand deltas. Diagonally ruled areas are probable erosional origin.

5.2.2 Sediment Data

Sediment types vary significantly with respect to their grain size, texture, shape, plasticity, and origin, along the U.S. East Coast. In the past five decades there has been increased scientific effort in gathering sedimentary data for the ACS. Until recently these efforts were relatively independent and few collaborative assimilations of the data were publicly available. The primary means for determining ACS sediment data were published maps and reports by government agencies, primarily the USGS and the U.S. Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE).

The USGS and Woods Hole Oceanographic Institute (WHOI) began the Continental Margin Mapping (CONMAP) database in 1962 to identify and catalog sediment types by grain-size distributions along the continental margin off the U.S. Atlantic coastline (Poppe et al. 2005). The sediment data collected in this effort was classified on the Wentworth grain-size scale and the Shepard classification systems. The resulting classifications denote the dominant grain-size/sediment type and do not account for local (small-scale) variability. Additionally, the database depicts only the surficial sediment and makes no reference to the potential variability of the soil type with depth.

The type of data available in CONMAP is illustrated in Figure 5.4. Figure 5.4 shows that surficial sediments in the Gulf of Maine consist of predominately fine-grained materials, ranging from sandy to silty clays as a result of fluvial deposition from the Wisconsinian glaciation approximately 15,000 years ago (Milliman et al. 1972). To the south in Massachusetts Bay the predominant sediment type is classified as a glacial-marine sand. However, detailed investigations by Butman et al. (2008) and Uchupi (2004) state that this sand is actually sand and gravel with ridges of boulders underlain by coastal plain erosional remnants and glacial till from the Wisconsinian or pre-Wisconsinian glaciation. A detailed geologic map of the Massachusetts Bay region has been developed by Uchupi (2004).

The distribution of surficial sediment types within the Mid-Atlantic Bight is shown in Figure 5.5. The predominant sediment type in this area is sand. Unlike in the Gulf of Maine, this sand is not from a terminal moraine or glacial outwash. Rather generation of this sand is either the product of fluvial deposition during sea-level transgression or from bedrock weathering (Milliman et al. 1972; Riggs et al. 1996; Riggs et al. 1998; Reidenauer et al. 1999; Byrnes et al. 2000) of shallow hardbottom reliefs. In both cases the surficial sediment is exported by major storm activities to the shelf edge.

The current sediment loading is dominated by storm-driven deposition, which creates a relatively sediment-starved environment (Riggs et al. 1996; Riggs et al. 1998; Duncan et al. 2000). The surficial sediments along the Long, Block, and Rhode Island Sounds vary from gravel to fine-silty clays (Uchupi et al. 2001) (Figure 5.5). Along the New Jersey shelf, grab samples indicate that the surficial sand sediments are composed primarily of well-sorted medium-to-coarse sand with significant shell content (Goff et al. 2004). However, Goff et al. (1999) observed outcrops of stiff clays in the Hudson Apron region that show evidence of iceberg scour, suggesting that these areas are resistant to the present-day erosion process.

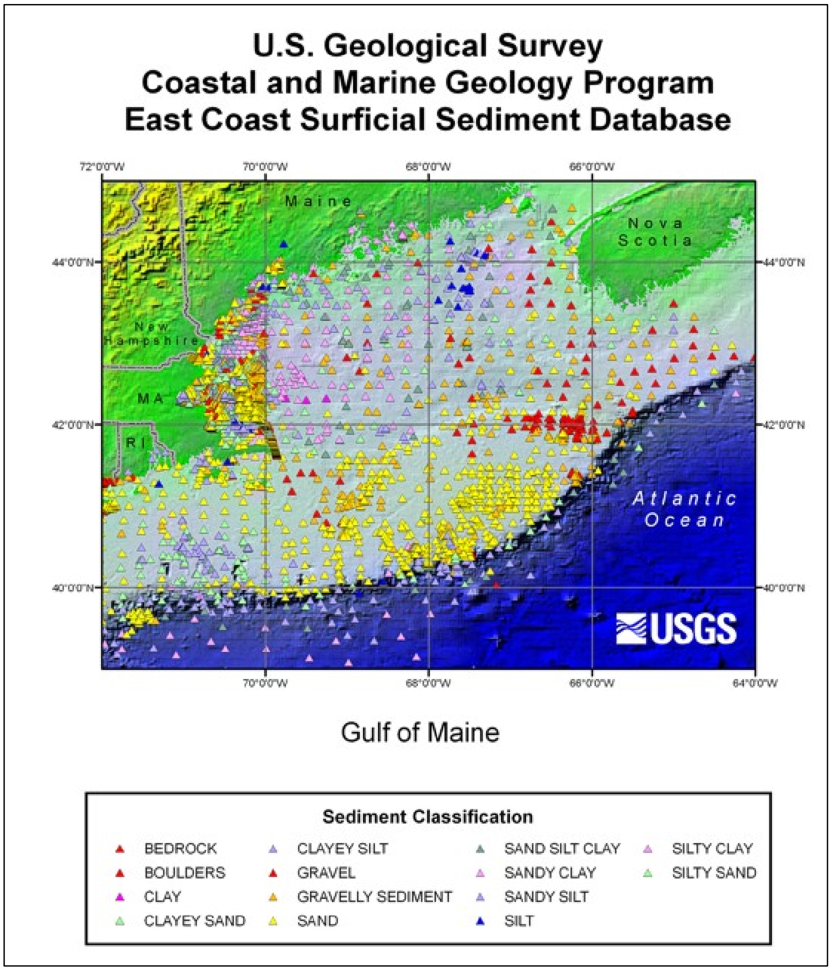


Figure 5.4. CONMAP sediment data for the Gulf of Maine (Poppe et al. 2005).

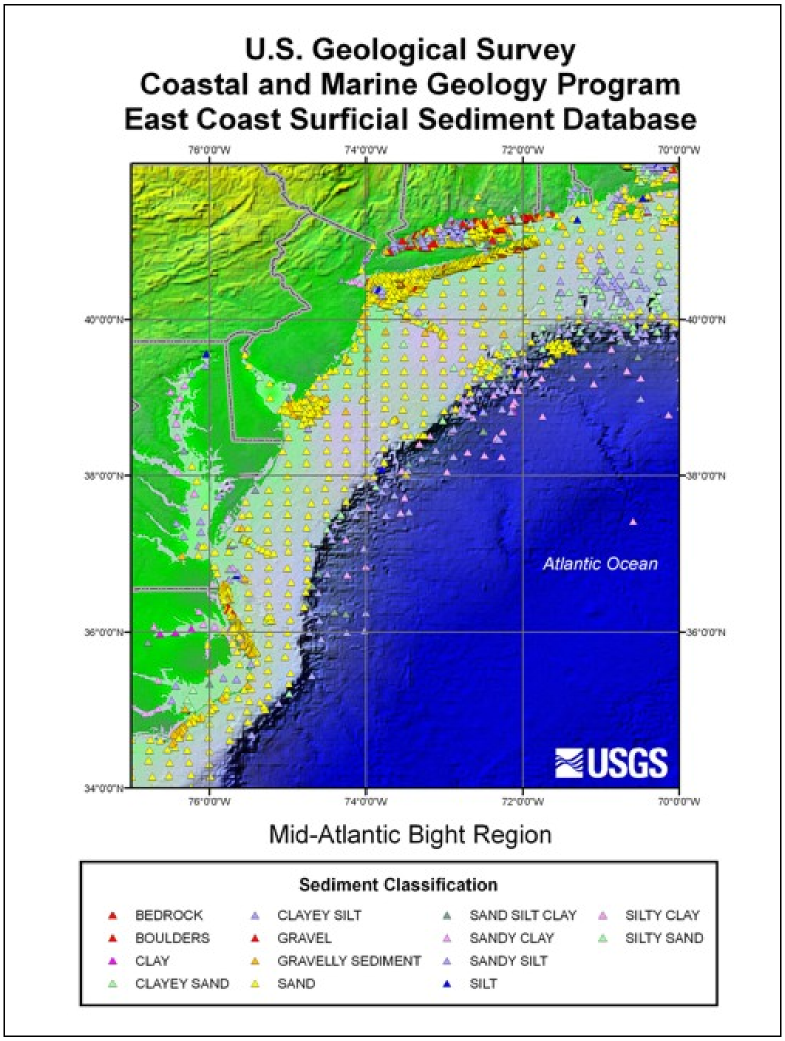


Figure 5.5. CONMAP sediment data for the Mid-Atlantic Bight (Poppe et al. 2005).

Within the past decade, the USGS, the Office of Naval Research (ONR), NOAA, coastal states, and local academic institutions have collaborated to gather information on potential offshore aggregate resources and to improve and update the CONMAP database. The findings of this effort were assembled by Reid et al. (2005) to generate the usSEABED database. Reid et al. (2005) compiled over 150 different data sources, including the CONMAP data, with over 200,000 individual data points into an online coastal database. Like the CONMAP database, usSEABED contains the most recent surficial sediment data and is continually updated as the data become available. The concentration of the data is shown in Figure 5.6. As illustrated in Figure 5.6, the magnitude of actual laboratory data decreases from the Gulf of Maine to Cape Hatteras. Therefore, an increasing amount of sediment data is interpolated for the Mid-Atlantic Bight and the level of uncertainty increases. In addition to the usSEABED and CONMAP databases, the BOEMRE has funded extensive investigations into offshore sand resources for beach and coastal restoration (Reidenauer et al. 1999; Byrnes et al. 2000).

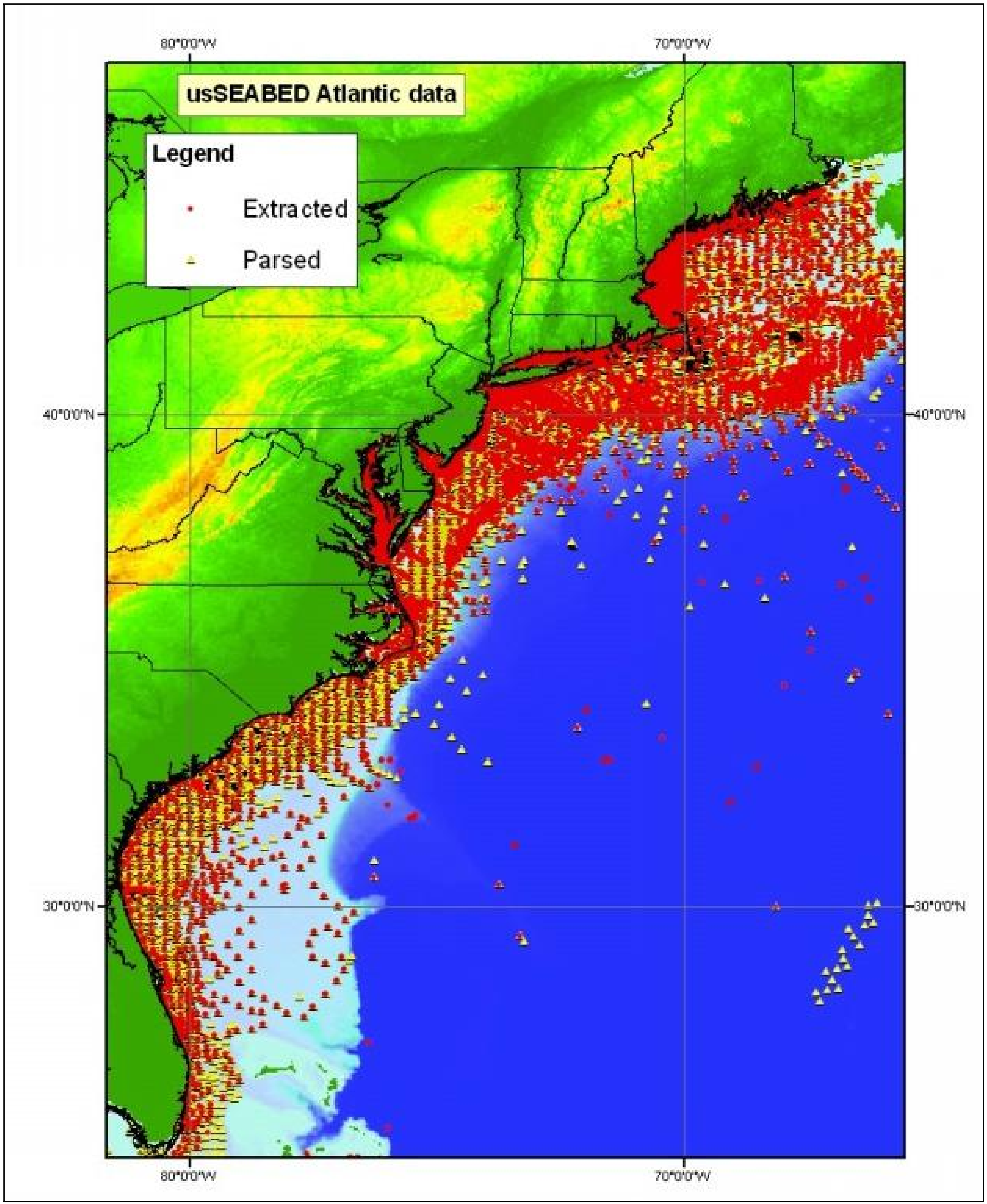


Figure 5.6. Distribution and location of sediment data points for the U.S. Atlantic Coast within the usSEABED database (Reid et al. 2005). Note that the extracted (red) points indicate data that was obtained via laboratory methods and parsed (yellow) points indicate data that was obtained by other means (e.g. verbal logs, shipboard notes etc.).

It must be noted that there are no references summarizing geotechnical strength properties (e.g. undrained shear strength or friction angle) of the identified surficial sediment types. Approximated ranges for individual properties can be inferred from typical geotechnical values; however, these values should not be used for determination of alternative energy foundation design. Site-specific geotechnical investigations would be required in any region or regions selected as potential alternative energy sites.

5.2.3 Depth to Bedrock

Bedrock depths vary along the ACS. In the majority of cases the depth to bedrock is inferred from seismic lines where available. In some regions of the Gulf of Maine and Massachusetts Bay the depth to bedrock is known from seismic surveys, surficial sampling, or borings. Uchupi (2004) indicates the presence of bedrock at a depth of approximately 120 m within Massachusetts Bay. From usSEABED (Reid et al. 2005) and CONMAP (Poppe et al. 2005) bedrock outcrops have been encountered at the seafloor within the Gulf of Maine. However, in both of these regions, the depth to bedrock can substantially vary due to the advance and retreat of the Laurentide Ice Sheet and subsequent glacial outwash.

Seismic lines, such as those off the Rhode Island coast southwest of Fishers Island (Needle and Lewis 1984; Poppe et al. 2006), indicate the presence of dense sediment layers and exposed bedrock, which are products of the advance and retreat of the Laurentide Ice Sheet.

Within the Mid-Atlantic Bight, the depth to bedrock is generally unknown. However, an ocean drilling survey, as part of the Ocean Drilling Program (ODP) Leg 150X, was performed along the New Jersey coastline (Miller et al. 1996). Borings in Cape May were terminated at depths greater than 380 m (Miller et al. 1996) without encountering bedrock. Further, Owens et al. (1996) interpreted the data for the northernmost borehole along the New Jersey shore (Island Beach Borehole) that was part of the ODP Leg 150X survey, and did not encounter bedrock at similar depths. Maguire et al. (2004) identified the bedrock topography as increasing in depth from 300 m in the northwest (inland New Jersey) to greater than 1.0 km in the southeast (coastal New Jersey, Cape May region).

Between 1972 and 1982 the MMS conducted an investigation on Georges Bank related to petroleum resources. Ten offshore borings were completed during this time (Edson et al. 2000), Figure 5.7. These boring were performed in water depths ranging between 48 m and 138 m. In the two geological investigation bore holes, COST No. G-1 and COST No. G-2, the top of bedrock was encountered at 1511 m and 335 m (USDOI, MMS 1980a; USDOI, MMS 1980b), respectively.

In the southern Mid-Atlantic Bight there are an abundance of hardbottom regions (Riggs et al. 1996; 1998). Riggs et al. (1996) define hardbottoms as: “an indurated surface on the seafloor with no implications of synsedimentary cementation or growth of reef-building organisms; the term refers to all hardgrounds, reefs, and rock outcroppings on the seafloor.” These hardbottoms are typically Pleistocene Limestone overlaying Miocene Muddy Fine Sandstone. The depth of the Limestone varies dependent on the degree of bioerosion in the specific region. The surficial sand overlaying the hardbottom varies from millimeters to tens of meters in thickness (Riggs et al. 1998). Similar to that in the North Atlantic, the BOEMRE conducted a petroleum investigation along the Mid-Atlantic shelf. A total of 34 borings were completed; however only information from ten were released. One available geological investigative boring was performed within the limits of this study region, COST No. B-2 (Smith et al. 1976). COST No. B-2 was drilled in water depth of 91 m, with bedrock encountered at 775m (Smith et al. 1976).

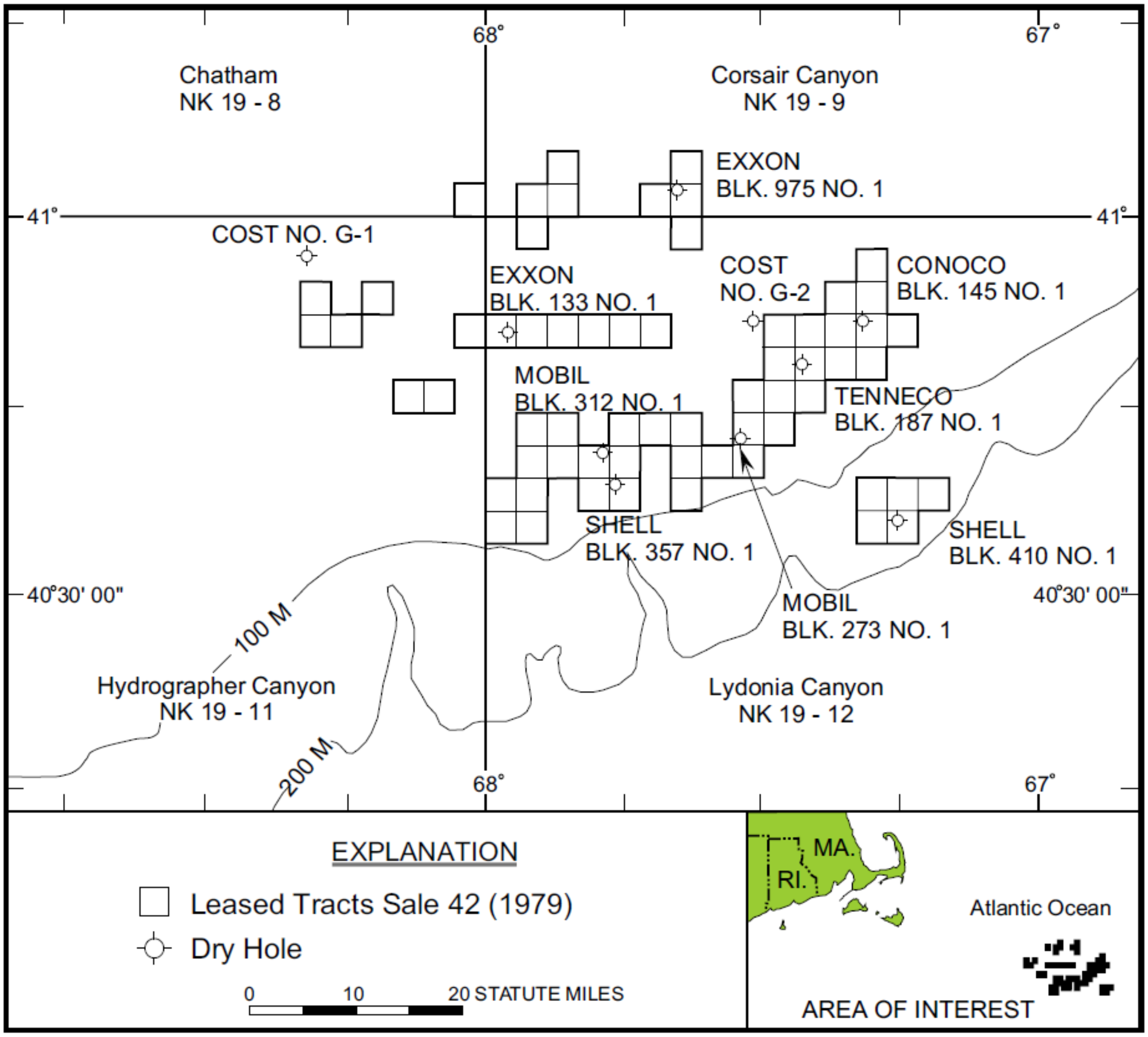


Figure 5.7. Map of the North Atlantic offshore petroleum exploration (from Edson et al. 2000).

5.3 SEDIMENT TRANSPORT

Sediment transport and beach replenishment occur from direct littoral, fluvial, glacial, and aeolian transport; coastal erosion and deposition; in situ sediment production (by either organic or inorganic means); and onshore sediment transport (Pilkey and Field 1972).

The Gulf of Maine and northern Mid-Atlantic Bight rely primarily on storm events for sediment transport and deposition (Duane et al. 1972; Li et al. 1997; Li and Amos 2001; Goff et al. 2005; Butman et al. 2008). Li et al. (1997) predict that the net daily sediment transport for the Scotian Shelf from storm-driven events is 2 to 3 orders of magnitude greater (approximately 822 kg/m^{-} day) higher than non-storm-driven transport.

In the Mid-Atlantic Bight, off the New Jersey coast, major storm events are essential to the present-day sediment transport. Stubblefield et al. (1975) suggested that during periods of fair weather conditions (the predominant weather condition) there is negligible erosional or depositional activity of the sand ridge systems. In moderate weather conditions winnowing of the ridge crests was observed but there was no significant erosion of the troughs. Only during major storm events is the entire ridge system affected.

Riggs et al. (1996; 1998) indicate that the intensity and frequency of individual storm events control the accumulation and erosion of sediment in hardbottom regions off the coast of North Carolina. These storm events control the benthic community structure and thus control the hardbottom bioerosion rate and the quantity of available sediment for transport. Typically the bioerosion rate varies from 5.5 kg/m^2/yr (Miolcene Muddy Sandstone) to 0.4 kg/m^2/yr (Pleistocene Limestone) and, as such, the sediment available for transport is more abundant in this region than the northern Mid-Atlantic Bight (Riggs et al. 1998).

5.3.1 Scour

Pile foundations are quite common within the marine environment (typically seen in offshore platforms, jetties, and wind turbine monopile foundations); however scour effects have not been studied as extensively on marine-based piles as on river-based piles (e.g. bridge piers), due to the complexities of combined wave action and currents (Sumer and Fredsoe 2002). However, scour processes can be explained as two basic regimes: scour around slender piles and scour around large piles. The amount of scour depends primarily on the magnitude of the bottom currents and sediment type. Cohesionless sediments (e.g. sands and silts) are more prone to large scour effects while cohesive sediments tend to have low degrees of scour.

Scour is considered to occur in the slender regime when the pile diameter is small in comparison to the wave length, specifically when the ratio of pile diameter to wave length is less than 0.2, resulting in an increased current velocity and turbulence, generating localized scour zone around the pile (Sumer and Fredsoe 2002).

A large-pile regime is considered when the ratio of pile diameter to wave length exceeds 0.2. In this case vortex shedding and the frontal horseshoe vortex--two of the three main scour mechanisms for slender piles--do not occur. However, scour still occurs around these piles, but more uncertainty exists in the current prediction methods (Sumer and Fredsoe 2002).

5.3.2 Scour Mitigation

Scour protection methods are often used to mitigate scour around offshore structures. Typically the area around a pile is covered by a stone or concrete protection layer (e.g. riprap) or a protective mattress (e.g. artificial sea grass) (Sumer and Fredsoe 2002). However, as water depths, current velocities, etc. increase, so does the difficulty to adequately place and anchor scour mitigation measures.

5.4 GEOHAZARDS

The primary geohazard along the U.S. Atlantic coast is seismic activity. The seismicity of the coast is characterized by the USGS earthquake database (USDOI, GS 2008b; Petersen et al. 2008), which yields an estimated peak horizontal ground (bedrock) acceleration (PHA) corresponding to a desired exceedance probability. The generated seismic hazard maps include onshore and offshore seismic sources and are applicable to an easterly longitudinal limit of 65 degrees; thus the region shoreward of the 100-m isobath is included within these maps. As the accelerations estimated by the USGS are bedrock motions, a site-specific analysis would be required for final design of alternative energy foundations to account for propagation of ground motions up through overlying sediment to the seafloor. The seismicity along the ACS increases the closer a potential site is to Quebec, Canada, and Charlestown, SC, and decreases in other regions (e.g. MA, RI, NJ, NY, etc.).

The seismic energy that propagates vertically through the sediment during an earthquake is primarily in the form of shear waves. These induce shear stresses in the sediment, which during rapid loading cause increases in pore pressure above hydrostatic conditions. If these pore pressures become equal to the total overburden stress of the sediment, then liquefaction, or complete loss of strength, can occur. Liquefaction potential is dependent on the level of ground motions and the density of the sediment, and it can be evaluated using geotechnical in situ tests such as the standard penetration and cone penetration tests (Youd et al. 2001).

Liquefaction can also be caused in some cases by large period waves during severe storms and hurricanes (Sumer and Fredsoe 2002). Less is known about this phenomenon than earthquake-induced liquefaction; however, recent work has identified mudslides in the Gulf of Mexico caused by wave-induced liquefaction during hurricanes (Nodine et al. 2009).

In addition to seismicity, two other potential geohazards exist within the region: submarine mass movements (i.e. slope failures) and localized tsunamis.

5.4.1 Submarine Mass Movements

Submarine mass movements (e.g. submarine landslides, slumps, and debris flows) can be triggered along the U.S. Atlantic Coast by local or regional earthquakes of moderate to large magnitudes (Grilli et al. 2009). Within the Mid-Atlantic Bight, there is evidence of 179 past individual movements (Booth et al. 1985; Booth et al. 1993; Chaytor et al. 2009) along the outer continental margin. The only definitive case of a known seismically-induced event is the 1929 Grand Banks failure, located off Newfoundland, Canada, which was triggered by a magnitude 7.2 earthquake. The resulting debris flow generated a tsunami that caused extensive damage in Newfoundland and extended to northern Maine (Piper et al. 1999; Ruffman 2001) resulting in 27 fatalities. The failure mechanism for the remaining individual movements and their respective ages are unknown. However, all identified submarine mass movements along the U.S. Atlantic coast occur in water depths greater than 100 m. Typically these events originate along the Atlantic mid-continental slope at water depths between 800 m and 1000 m (Booth et al. 1993).

An extensive review of known submarine mass movements along the U.S. Atlantic Continental Slope can be found in Chaytor et al. (2009).

5.4.2 Local Tsunamis

Localized tsunamis can be caused by submarine mass movements along the Atlantic continental slope. As the Atlantic coast is a relatively passive margin and the probability of a submarine mass movement along the Atlantic continental slope is very low, the threat of localized tsunamis is minimal (Driscoll et al. 2000; ten Brink et al. 2009; Geist and Parsons 2009; Grilli et al. 2009). Further, the first-order estimate of resulting tsunami magnitudes, for design considerations, is less than the 100-yr hurricane storm surge within the New York Bight region (Grilli et al. 2009). As such the design of alternative energy foundation systems will most likely be controlled by storm surge loading as opposed to potential tsunami impact.

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6. SOCIOECONOMIC RESOURCES

6.1 OVERVIEW OF THE SOCIAL AND ECONOMIC CHARACTERISTICS OF THE STUDY AREA

6.1.1 General Characteristics

The purpose of this socioeconomic analysis is to focus on those socioeconomic resources that are most likely to be impacted by offshore alternative energy development, based on a review of current literature on the socioeconomic impacts of offshore wind installations. These issues include employment, economic output, recreation and tourism, commercial fishing and other maritime industries, land use patterns, property values, visual/aesthetic values, at-risk populations, and public acceptance. This section provides an overview of the socio-economic environment that provides the baseline conditions for the analysis in the study.

Coastal counties of the Atlantic seaboard were utilized as the units of analysis for basic socioeconomic and demographic data for the project area. As defined by the National Oceanographic and Atmospheric Administration (NOAA), coastal counties are those meeting the following criteria: (1) at least 15 percent of a county's total land area is located within the Nation's coastal watershed; or (2) a portion of or an entire county accounts for at least 15 percent of a coastal cataloging unit. Any U.S. county that meets these criteria is classified as coastal (USDOC, NOAA 2009a). Almost all of this project's study area falls within NOAA's Northeast Region. Only one state, North Carolina, is in the Southeast Region. While these NOAA regions do not coincide with the BOEMRE Planning Area definitions, they provide a more suitable platform for collection and analysis of socioeconomic data, and accurately portray the potential impact areas of offshore wind park construction on land-based populations.

The coastal counties of the study area include more than 20,000 miles of coastline, with a population of more than 46 million. Characteristics range from the highly urbanized areas of Boston, New York, Philadelphia, and Baltimore/Washington, D.C. to the less densely populated and more rural areas of Maine and North Carolina (see Figure 6.1). The coastal counties include numerous beaches and parks, estuarine research reserves and nature preserves, tourist destinations, maritime ports, commercial fishing areas and military installations (see Table 6.1).

The Northeast Region coastal area, as defined by NOAA's Coastal Zone Program, includes the states of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Virginia. It is the most populated coastal region in the United States. Ten of the states in this region have the majority of their population in coastal counties; three of those states—Rhode Island, Connecticut and Delaware—have their entire population in coastal counties. Coastal counties account for 40 percent of the region's total land area and four of the nation's ten largest metropolitan areas are located there: New York, Washington DC/Baltimore, Philadelphia, and Boston (Crosset et al. 2004).

Figure 6.1. Metropolitan Statistical Areas and major ports within the project study area.

Table 6.1

Geographic, Population and Housing Characteristics of Coastal Counties in Study Area States – 2007

STATE		POPULATION				HOUSING	
	Miles of Coast	Coastal Population 2007	Percent of State Total	Percent Change 2000-2007	Persons per sq. mile 2007	Number of Units 2007	Percent Change 2000-2007
ALL U.S.		156,601,000	-	5.6	176	65,211,000	8.7
ME	3,478	1,228,000	93.2	3.7	61	643,000	7.3
NH	131	1,077,000	81.9	7.0	256	471,000	9.2
MA	1,519	6,225,000	96.5	1.6	942	2,628,000	3.8
RI	384	1,058,000	100.0	.9	1,012	451,000	2.5
CT	618	3,502,000	100.0	2.8	723	1,438,000	3.8
NY	2,625	13,950,000	72.3	2.8	1,800	5,478,000	3.7
NJ	1,792	8,576,000	98.7	3.2	1,215	3,454,000	5.7
PA	57	5,922,000	47.6	3.0	860	2,448,000	4.8
DE	381	865,000	100.00	10.4	443	389,000	13.3
MD	3,190	5,146,000	91.6	5.8	679	2,120,000	7.6
VA	3,315	5,233,000	67.8	9.1	376	2,158,000	12.9
NC	3,375	2,110,000	23.3	6.3	108	1,031,000	14.0
Total	20,896	46,659,000	-	-	-	26,902,000	-

Source: USDOC, Bureau of the Census 2009; USDOC, NOAA 2009a

Among all of the states in the country with coastal counties, the average percent population change between 2000 and 2007 was 5.6 percent. In the project study area, states where coastal counties experienced population changes greater than the national average were Delaware (10.4 %); Virginia (9.1%); New Hampshire (7.0%); North Carolina (6.3%) and Maryland (5.8%) (see Table 6.1).

Three states in the study area experienced significant changes in the number of housing units in coastal counties between 2000 and 2007: North Carolina in the Southern Region (14.0 percent), and Delaware (13.3 percent) and Virginia (12.9 percent) in the Northeast Region (see Table 6.1).

North Atlantic

As the northernmost state in the study area, Maine's coastal zone includes all of the political jurisdictions in Maine that have land along the coast or a tidal waterway, such as a river or bay, including 136 towns, two plantations, ten unorganized townships, and one Indian reservation, as well as 4,613 islands. Nearly one of every two Mainers lives near the coast, while over six million people visit each year. Over 25 percent of Maine's population—254,429 residents—live in the Casco Bay area of southern Maine. The area leads Maine in population growth (ANEP 2009). Federal lands in coastal Maine include numerous National Wildlife Refuges, Acadia National Park, and the Brunswick Naval Air Station (nationalatlas.gov 2003).

There are seven federally-recognized tribes in the Atlantic coastal area between Cape Hatteras and the Canadian border, located in Maine, Massachusetts, Rhode Island and Connecticut. Only three—the Passamaquoddy and the Penobscot in Maine, and the Mashantucket in Connecticut, have reservations.

Most Passamaquoddy live in two communities along the Passamaquoddy Bay in Maine, as well as across the U.S.-Canadian border in New Brunswick. About 3000 Penobscot Indians also live in Maine. Maine's four Indian tribes—Maliseet, Micmac, Passamaquoddy, and Penobscot—are known collectively as the Wabanaki. Acadia National Park lies in the center of the Wabanaki "homeland", which stretches from Newfoundland, Canada, to the Merrimac River Valley in New Hampshire and Massachusetts (Native Languages of the Americas 2009).

New Hampshire's coastal watersheds span 990 square miles and 46 towns, and "harbor exceptional and irreplaceable natural, cultural, recreational and scenic resources" (Zankel et al. 2006). Land use along the New Hampshire coast is changing rapidly. Over the past 36 years, in Rockingham and Strafford Counties, an average of 2,230 acres per year has been converted from undeveloped land to developed land. These counties are projected to add more than 100,000 new residents between 2000 and 2025, and land values are expected to rise steeply (Zankel et al. 2006).

More than 3.8 million people live in the Massachusetts Bay region, which covers over 800 miles of coastline from the tip of Cape Cod Bay to the New Hampshire border and encompasses 49 coastal communities. Water-based activities such as tourism, boating, and commercial fishing are a major factor in the local economies. Boston Harbor is a center for shipping, marine research, and whale watching, while Cape Cod, Nantucket, and Martha's Vineyard are important tourist destinations.

Buzzard's Bay is on the southern coast of Massachusetts. It is a major thoroughfare for both commercial and recreational vessels. Nearly 20,000 vessels pass through the bay annually, and more than 10,000 vessels anchor there each summer. Buzzard's Bay is also home to the world-renowned Woods Hole Oceanographic Institute (ANEP 2009). In addition to numerous tourist destinations and wildlife refuges, Cape Cod is home to a federally-recognized Indian tribe, Cape Cod National Seashore, and Otis Air Force Base (nationalatlas.gov 2003).

The Wampanoag is the only federally-recognized tribe in Massachusetts. Currently 1099 members are enrolled, of which 68 live on tribal lands in the Town of Aquinnah and 298 live within the Tribe's service area of Dukes County. Wampanoag trust lands are located in the southwest portion of Martha's Vineyard Island in the town of Gay Head. Other land owned by the Tribe includes parcels in Christiantown and Chappaquiddick (Native Languages of the Americas 2009). Aquinnah Tribal Lands are located at the southwestern portion of Martha's Vineyard, a 93-square-mile island located six miles south of mainland Cape Cod, Massachusetts, and 80 miles directly south of Boston. The Tribe owns approximately 481 acres of land, including approximately 160 acres of private and 325 acres of common lands (Native Languages of the Americas 2009).

National Wildlife Refuges make up much of the Atlantic coastline of Rhode Island, including Ninigret, Truston Pond, John H. Chafee, and Sachuest Point. Newport, on Naragansett Bay, is home to the Newport Naval Educational and Training Center. Access to the shore is an important value in Rhode Island, as enshrined in the Rhode Island Constitution, which specifically protects citizens' rights to fish from the shore, to gather seaweed, to leave the shore to swim in the sea, and to walk along the shore (Allard 2004).

The Connecticut coast is also the location of the New London Submarine Base and the Mashantucket Pequot Indian Reservation. Two federally-recognized tribes are found in Connecticut—the Mohegans and the Mashantuckets. The Mohegan tribes for the most part have assimilated into New England society, while the Mashantuckets maintain a reservation in southeast Connecticut (Native Languages of the Americas 2009).

Between Connecticut and New York is Long Island Sound, one of the region's largest estuaries, with a coastline of more than 600 miles. More than 8 million people live in the Long Island Sound watershed, and the activities that take place there—boating, fishing, tourism, and swimming—contribute an estimated $5.5 billion per year to the regional economy (Connecticut Dept. of Environmental Protection 2009). More than 200,000 boats are registered on Long Island Sound. The Peconic Bays, which make up the tip of Long Island, were designated by the Nature Conservancy as one of the "Last Great Places" in the Western Hemisphere. The population of the area's five eastern towns is 106,000, but it triples in the summer, when visitors arrive for swimming, boating, fishing, and bird watching (ANEP 2009).

New York Harbor includes the largest port on North America's East Coast, the third largest container and petroleum port in the United States, a major passenger port, and a major vehicle port. Waterfront access for recreation is also a high priority in this area, as is recreational fishing (ANEP 2009).

New Jersey has a long coastline of over 1000 miles, as well as two major tidal rivers, the Hudson and the Delaware, and numerous estuaries inside its barrier islands and embayments (McCay and Cieri 2000). It is also the most densely populated state in the United States, with over 8.6 million people on 19,210 km (Cooper et al. 2005). Structural development along the coast varies from heavily urbanized centers, such as Atlantic City, to sparsely populated agricultural communities on the Cape May peninsula. The state's coastal counties account for nearly all of the total population of the state (Cooper et al. 2005).

Barnegat Bay and Little Egg Harbor are important estuaries on the coast of New Jersey. The watershed has a year-round population of 500,000, which increases to more than 1 million during the summer. The area is a recreational playground for tens of thousands of boaters and anglers, but it also supports a significant commercial fishing industry. New Jersey is home to numerous military installations, such as Fort Monmouth, McGuire Air Force Base, Lakehurst Naval Air Station, Fort Dix, and the U.S. Coast Guard Station at Cape May. In addition, there are extensive wildlife reserves at Cape May, along the southern Atlantic Coast, and on Delaware Bay (nationalatlas.gov 2003).

Central Atlantic

The Delaware Estuary region, which includes the states of New Jersey and Delaware, supports one of the world's largest concentrations of heavy industry, including the port of Philadelphia, and the nation's second largest refining petrochemical center, which receives nearly 70 percent of all oil shipped to the East Coast (ANEP 2009). It is also the second largest staging area in the Western Hemisphere for migrating birds. Delaware is also home to Dover Air Force Base (nationalatlas.gov 2003).

Maryland's coastal zone includes 16 counties and the city of Baltimore, encompasses two-thirds of the state's land, and is home to more than 90 percent of its residents. An additional 3 million people are expected to move to the Chesapeake Bay watershed by 2020 (Surfrider Foundation 2009).

Virginia's coastal zone includes four tidal rivers reaching as far as 100 miles inland, and the Chesapeake Bay and Albemarle-Pamlico Sound watersheds. Virginia's open ocean shoreline lies mainly in the Virginia Beach area and the barrier islands of the Eastern Shore in Accomack and Northampton Counties (Surfrider Foundation 2009). Virginia is the leading state in the country in ship and boat building, with its shipyards and related facilities at Newport News (Kildow et al. 2009).

North Carolina's coastal area consists of 3,375 miles of coast and twenty counties but unlike most of the Northeast Region, the majority of North Carolina's population does not live on the coast. However, North Carolina experienced a large population change between 2000 and 2007 (6.3%), and an even larger increase in housing units during the same period (14.0%) (see Table 6.1).

According to a recent report from the National Ocean Economics Program, "…the coastal economy makes up a disproportionately large share of the American economy. The spatial dimensions of the coastal economy have pushed population inland, but jobs more and more towards the shore" (Kildow et al. 2009) (see Table 6.2).

Table 6.2

Employment Change in Study Area Shore Adjacent Counties by State – 1997-2007

State	1997	2007	Change	Percent Change
ME	293,285	330,607	37,322	13%
NH	157,361	183,956	26,595	17%
MA	1,601,411	1,712,937	111,526	7%
RI	433,802	473,380	39,578	9%
CT	949,972	989,478	39,506	4%
NY	3,201,178	3,449,423	248,245	8%
NJ	3,190,495	3,463,405	272,910	9%
PA	124,286	128,291	4,005	3%
DE	370,855	417,151	46,296	12%
MD	1,129,029	1,629,448	500,419	44%
VA	1,362,345	1,748,162	385,817	28%
NC	240,985	300,337	59,352	25%

Source: USDOL, Bureau of Labor Statistics 1997–2007, in Kildow, et al. 2009

6.1.2 Commercial Shipping

There are five major commercial shipping centers in the study area: Boston, New York/New Jersey, Camden/Philadelphia, Baltimore/Washington, D.C., and Norfolk/Hampton Roads. The Ports of New York/New Jersey, Philadelphia, Baltimore and Norfolk have been listed by the Research and Innovative Technology Administration (RITA) among the top 50 U.S. Freight Gateways in the nation based on the value of shipments in 2006 (see Table 6.3).

Table 6.3

Study Area Ports in the Top 50 Freight Gateways* in the U.S.,
based on Value of Shipments – 2007

PORT	RANK	TOTAL TRADE ($billions)	EXPORTS ($billions)	IMPORTS ($billions)
Port of NY and NJ	2	165.2	40.6	124.6
Port of Norfolk, VA	16	49.5	20.7	28.8
Port of Baltimore, MD	18	42.0	14.0	28.0
Port of Philadelphia	38	18.5	1.9	16.6

Source: USDOD, Army Corps of Engineers, Navigation Data Center, special tabulation, December, 2008. (RITA 2009)

*rankings based on total value of air, water and land freight

All of these ports are among the top ten ports in the United States, based on the vessel call rankings in 2008 as reported by the U.S. Department of Transportation (USDOT) (see Table 6.4).

Table 6.4

Top Ten National Vessel Call Rankings for Study Area Ports – 2008

	Number of Vessel Calls and U.S. Rank, by Call Type*									
Port	**Tanker**		**Container**		**Gas**		**Dry Bulk**		**All Types**	
	#	**Rank**	**#**	**Rank**	**#**	**Rank**	**#**	**Rank**	**#**	**Rank**
Boston					59	4				
New York	1,469	4	2,419	2			253	10	4,823	2
Philadelphia	1,549	2			43	7	261	9	4,006	6
Baltimore							410	7		
Virginia ports			1,752	4			608	4	2,759	7

Source: USDOT 2009a

*only top ten ports ranked for each call type

North Atlantic

The Port of Boston handles more that 1.3 million tons of general cargo, 1.5 million tons of non-fuels bulk cargo, and 12.8 million tons of bulk fuel cargo yearly. Boston also has a rapidly growing cruise market, and between December 2007 and November 2008 it served 282,948 cruise passengers (MASSPORT 2009).

The coastal waters of Massachusetts include Buzzards Bay (between southeastern Massachusetts and Cape Cod), Nantucket Sound (south of Cape Cod, between the islands of Nantucket and Martha's Vineyard and Cape Cod), Cape Cod Bay, and Boston Harbor. There are major shipping lanes into Boston Harbor, through Buzzards Bay, Nantucket Sound, and the Cape Cod

Canal. In addition there are numerous smaller channels and routes used by fishing boats, ships of smaller tonnage, seasonal ferries, and pleasure craft. Massachusetts also has significant dock, dry-dock and shipyard facilities in New Bedford and Quincy. These ports and other nearby ports that have been central to the New England fishing industry have experienced economic declines recently due to increasing catch restrictions (Rogers et al. 2000).

Although it is not considered a major port-of-call, the total cargo brought into Rhode Island ports exceeds 8 million tons annually. Narragansett Bay has three public ports: Providence, Quonset Point-Davisville, and Fall River. Several dredged channels allow large vessels to reach these ports. In 1999, 84 percent by weight of the total cargo delivered to Narragansett Bay ports consisted of petroleum products (gasoline, heating oil, diesel, kerosene, and natural gas). Most commercial vessels using the Bay are barges, tugs, and tow vessels (Ely 2002).

Together, the New York/New Jersey port and the Camden/Philadelphia port represent one of the largest import/export areas in the country. The Port of New York/New Jersey ranks third among the top ten U.S. and Canadian ports after Los Angeles and Long Beach, California. In 2008 its total cargo tonnage was 88.9 million metric tons, with a total value of $190 million. The port's leading trading partners, based on general cargo tonnage, were China, India, Italy, Germany, and Brazil. There were 5,251 ship calls in the port in 2008, compared to 5,465 in 2007 (Port Authority of New York and New Jersey 2009).

Central Atlantic

Baltimore is one of only two Eastern U.S. ports where the main shipping channel reaches a depth of 50 feet with a channel 800 feet wide. The Port serves more than 700 ocean carriers whose vessels make nearly 2,300 annual port visits, and it is the largest automobile exporter in the country. The total value of cargo that moved through the port in 2007 was $41.9 billion, with a volume of 8.7 million tons (Maryland Department of Business and Economic Development 2009).

The Port of Virginia reports 3,033 vessel calls during 2007, with a total cargo tonnage of about 17.7 million. The port's five top trading partners were Italy, Brazil, Egypt, France, and the Netherlands (Virginia Port Authority, 2008). The Port of Virginia is part of a larger public/private commercial shipping complex known as Hampton Roads. Hampton Roads is known as "the world's largest harbor," as well as one of the world's deepest and naturally ice-free harbors. It is a Mid-Atlantic leader in waterborne foreign commerce, and it provides a location for extensive shipbuilding and cargo-handling facilities and many smaller facilities and recreational boating marinas (Global Security Org 2009).

Hampton Roads is also home to the world's largest naval base. The Navy owns 36,000 acres and more than 6,750 buildings in the area. There are approximately 108,000 Navy and Marine Corps personnel stationed there, as well as 41,000 civilians who are employed by the Navy. The entire Hampton Roads Navy community, including active-duty military, civilian employees, and dependents, numbers approximately 318,000 (Global Security Org 2009).

There are no major shipping routes to North Carolina, but North Carolina has two primary ports: The Port of Wilmington in New Hanover County and Morehead City in Carteret County. Together they support 48,388 jobs and contribute more than $30 million in state and local tax revenues. Both ports engage in international commerce, processing over 5.4 million tons of cargo per year (Environmental Defense Fund 2007).

The major shipping ports of the study area also play a major role in cruise ship traffic to the Caribbean, Bermuda, Mexico and other destinations. The Ports of Boston, New York, Norfolk, Baltimore and Philadelphia, all have significant cruise ship traffic, based on departures during 2007 and 2008 (see Table 6.5).

Table 6.5

North American Cruise Passengers by Departure Port – 2007 and 2008

Port	Number of Passengers 2007 (thousands)	Number of Passengers 2008 (thousands)
New York	525	477
Boston	52	69
Norfolk	31	41
Baltimore	62	46
Philadelphia	30	14

Source: USDOT 2009b

6.1.3 Commercial Fishing

Leading fishing ports in New England, based on landing weight and value in 2007 include Portland, Rockland and Stonington in Maine; Boston, Gloucester and Provincetown-Chatham in Massachusetts; Point Judith and Newport in Rhode Island; and Stonington in Connecticut (see Table 6.6).

North Atlantic

Commercial fishing and marine trades are significant aspects of the Maine economy. They contribute more than $800 million annually, and employ about 30,000 people, “giving fishermen and others both a livelihood and a valued way of life” (Maine.gov 2006) (see Table 6.6).

Leading fishing ports of the Mid-Atlantic, based on landing weight and value in 2006 are Montauk in New York; Cape May-Wildwood, Atlantic City, Point Pleasant and Long Beach-Barnegat in New Jersey; and Reedville, Hampton Roads and Chincoteague in Virginia (see Table 6.7).

Table 6.6

Top Fishing Ports for New England in 2007

Rank	Landing Weight		Landed Value	
	Fishing Port	Pounds (000s)	Fishing Port	Landed Value ($millions)
1	New Bedford, MA	149,500	New Bedford, MA	$268.0
2	Gloucester, MA	94,400	Gloucester, MA	$46.8
3	Point Judith, RI	37,600	Point Judith, RI	$36.7
4	Portland, ME	34,600	Portland, ME	$24.1
5	Rockland, ME	33,400	Stonington, ME	$23.5
6	Provincetown-Chatham, MA	14,300	Provincetown-Chatham, MA	$18.2
7	Stonington, ME	12,300	Newport, RI	$12.4
8	Boston, MA	10,500	Boston, MA	$12.2
9	Newport, RI	8,700	Rockland, ME	$9.7
10	Stonington, CT	3,000	Stonington, CT	$4.4
	Total	398,300	Total	$456.0

Source: NOEP 2009c from USDOC, NMFS

Table 6.7

Top Fishing Ports for the Mid-Atlantic in 2007

Rank	Landing Weight		Landed Value	
	Fishing Port	Pounds	Fishing Port	Landed Value ($millions)
1	Reedville, VA	421,000,000	Hampton Roads Area, VA	$70.2
2	Cape May-Wildwood, NJ	68,400,000	Cape May-Wildwood, NJ	$58.8
3	Atlantic City, NJ	40,700,000	Atlantic City, NJ	$27.5
4	Point Pleasant, NJ	23,600,000	Reedville, VA	$27.3
5	Hampton Roads Area, VA	20,000,000	Point Pleasant, NJ	$23.1
6	Montauk, NY	12,000,000	Long Beach-Barnegat, NJ	$23.1
7	Ocean City, MD	10,100,000	Montauk, NY	$15.7
8	Long Beach-Barnegat, NJ	7,800,000	Ocean City, MD	$10.4
9	Chincoteague, VA	3,900,000	Chincoteague, VA	$4.1
	Total	607,500,000	Total	$260.2

Source: NOEP 2009c, from USDOC, NMFS

New York's commercial fisheries are concentrated on Long Island, which extends from Brooklyn, a borough of New York City, to the far eastern ports of Montauk and Greenport

(McCay and Cieri 2000). This region sustains a $50-billion maritime industry centered at the Port of New York and New Jersey, and a $100-million commercial fishing industry (Cooper et al. 2005) (see Table 6.7).

New Jersey has a long history of commercial fishing. Directly or indirectly, New Jersey's commercial fisheries provide employment to more than 21,000 people and have an economic impact on the state's economy of $590 million annually. Commercial fishery landings in 2003 had a dockside value of $121 million. There are five active fishing ports and 14 fish and shellfish processing plants employing more than 1,000 people in New Jersey. The ports of Cape May-Wildwood, Atlantic City, and Point Pleasant rank in the top 30 most important fishing ports in the United States. Commercial fishermen harvest over 60 species of finfish and shellfish annually, and New Jersey is among the leading states in terms of shellfish landings. The state's surf clam, ocean quahog, and sea scallop fisheries are also important contributors to the its commercial fishing industry (New Jersey Department of Environmental Protection 2005) (see Table 6.7).

Central Atlantic

Although recreational fishing dominates in Delaware, five commercial ports are recognized by the National Marine Fisheries Service (NMFS): Lewes, Indian River, and Port Mahon in Sussex County; and Bowers Beach and Mispillon in Kent County. These commercial fisheries are almost entirely focused on blue crab, quahogs, and horseshoe crabs (McCay and Cieri 2000).

Maryland has two different fishing regions: the seaward coast of the Delmarva Peninsula and the Chesapeake Bay. Ocean City, on the sea coast, is the major port for ocean fisheries (McCay and Cieri 2000) (see Table 6.7).

According to a recent study of commercial fishing ports on the Mid-Atlantic Coast:

> Virginia has one of the highest fish landings in the United States, largely because of the menhaden which are landed and processed in Reedville, Northumberland County, on the western shore of the Chesapeake Bay. Virginia is also known for its waterman fisheries for oysters, blue crabs, etc., mainly in the Chesapeake Bay and its tributaries but also in numerous small bays along the Atlantic coast of the Southern Delmarva peninsula. There are six major ports where large, ocean-going fishing vessels unload their catches: Hampton, Newport News, Virginia Beach, Seaford, and Chincoteague. Chincoteague is one of several ports where local seafood businesses depend on migratory fishing vessels from other regions, such as North Carolina or Massachusetts, for landings. (McCay and Cieri 2000) (see Table 6.7).

Four of the top ten fishing ports for the South Atlantic in 2007 are in the Cape Hatteras area: Wanchese-Stumpy Point, Beaufort-Morehead City, Engelhard-Swanquarter, and Oriental-Vandemere (see Table 6. 8).

Table 6.8

Top Fishing Ports for the North Carolina Coast (Cape Hatteras area and North) in 2007

Rank	**Landing Weight**		**Landed Value**	
	Fishing Port	Pounds	Fishing Port	Landed Value ($millions)
1	Wanchese-Stumpy Point	22,400,000	Wanchese-Stumpy Point	$20.6
2	Beaufort-Morehead City	6,600,000	Beaufort-Morehead City	$10.9
3	Engelhard-Swanquarter	6,400,000	Engelhard-Swanquarter	$9.5
4	Oriental-Vandemere	4,800,000	Oriental-Vandemere	$7.9
	Total	40,200,000	Total	$48.9

Source: USDOC, NMFS, in NOEP 2009c

The major commercial finfish catches in the Northeast include monkfish, Pollock, cod, haddock, and silver hake, with smaller total catches (less than 2,200 metric tons) of winter flounder, yellowtail flounder, white hake, American plaice, redfish, and witch flounder (see Table 6. 9).

Table 6.9

Preliminary Landings of Top Five Commercial Fish by Major Ports and States,
May 2008 – January 2009 (metric tons)

Port/State	**Monkfish**	**Pollock**	**Cod**	**Haddock**	**Silver Hake**
Portland, ME	348	1,604	502	352	0
Gloucester, MA	930	3,628	2,909	887	140
Boston, MA	414	831	263	439	9
New Bedford, MA	2,159	445	1,182	2,636	1,054
Point Judith, RI	679	8	40	42	802
Maine	361	1,669	521	355	0
New Hampshire	97	997	605	13	81
Massachusetts	3,903	5,272	5,448	4,348	1,353
Rhode Island	1,048	8	56	87	818
Connecticut	120	0	0	0	375
New York	779	0	2	0	1,358
New Jersey	1,477	0	0	0	255
Other Northeast	333	0	0	0	16
Total	8,118	7,945	6,632	4,802	4,256

Source: USDOC, NMFS, 2009

Scallops are also an important commercial harvest in this area, particularly in Massachusetts, with lesser harvests in New Jersey and Virginia (see Table 6. 10).

Table 6.10

Preliminary Commercial Scallop Landings (metric tons) by Major Ports and States, March 2008 – January 2009

Port/State	**March 2008 – January 2009 Metric Tons**
New Bedford, MA	11,396
Cape May, NJ	3,545
Norfolk, VA	4,338
Maine	24
New Hampshire	0
Massachusetts	11,632
Rhode Island	121
Connecticut	502
New Jersey	5,679
Virginia	4,381
Other Northeast	626
Total	22,966

Source:USDOC, NMFS, 2009

The many estuaries of the study area provide an important source for both commercial and recreational fishermen. According to a study conducted under the auspices of the National Marine Fisheries Service (NMFS): “Approximately 77% of these landed pounds, and 83% of their dollar value, are attributed to estuarine fish and shellfish.” In the Chesapeake Region, the study continues, approximately 98% of the landed pounds, and 97% of their dollar value, are attributed to estuarine fish and shellfish (Lellis-Dibble et al. 2008).

6.1.4 Recreational Fishing

Recreational fishing is a popular vacation destination as well as an important part of the coastal economy. Economic impacts are felt through expenditures on vacation accommodations, boat rentals and boat maintenance, fishing equipment, and other related supplies (see Table 6.11).

Table 6.11

Marine Recreational Fishing Impacts on Study Area States

State	Angler Expenditures	Sales Impacts	Income	Jobs
Connecticut	$298,727,310	$203,953,751	$92,361,120	2,370
Delaware	$182,167,310	$128,298,991	$50,050,868	1,682
Maine	$83,668,979	$64,695,471	$27,228,130	1,092
Maryland	$461,213,196	$372,063,673	$158,937,028	4,922
Massachusetts	$753,835,438	$561,973,061	$247,108,557	7,266
New Hampshire	$69,426,405	$57,146,884	$24,866,954	774
New Jersey	$864,864,195	$841,045,986	$341,116,412	9,583
New York	$610,114,755	$458,411,993	$192,380,198	5,494
North Carolina	$1,985,719,275	$1,776,718,793	$707,977,518	28,409
Rhode Island	$143,845,018	$93,189,234	$39,505,198	1,411
Virginia	$479,100,912	$364,164,892	$148,313,216	5,110

Source: Southwick Associates, 2006

North Atlantic

Recreational fishing makes up an important part of the Maine tourist economy. In 2005, it was estimated that over 380,000 sport anglers fished in Maine saltwater. Of that number, 46% (173,349) were from out of state (Maine Department of Marine Resources 2007).

Recreational saltwater fishing is also popular in the waters off the New Hampshire coast. In 2007, saltwater anglers harvested about 500,000 fish. Saltwater fishing trips in 2005 consisted of private/rental boat (45 percent), headboat (7 percent), charter boat (2 percent), and shore access (46 percent) (New Hampshire Fish and Game Department 2009).

The economic impacts of recreational saltwater fishing are significant. In Rhode Island, saltwater recreational fishing is the state's eighth largest tourist attraction, accounting for as much as 10 percent of tourism-related spending (Ninigret Partners 2007). More than 13,000 recreational boats are berthed on Narragansett Bay, and tens of thousands more are trailered in from neighboring states (ANEP 2009). In all Northeast states except Maine and Rhode Island, total resident expenditures on recreational fishing exceeded those of non-residents (Gentner and Steinback 2008).

Statistics for recreational saltwater fishing are less precise than those for commercial enterprises because some of the data are collected via telephone interviews with anglers and depend on the accuracy of self-reporting. More accurate data are predicted when the National Marine Fisheries Service implements its Saltwater Angler Registry program in 2010. The largest harvest in the North Atlantic states is Atlantic Cod. In the Mid-Atlantic it is bluefish and in North Carolina it is dolphin (see Table 6.12).

Table 6.12

State Recreational Fish Harvest* by Top Five Species and Weight – 2008

State	Species Common Name	Weight (lbs)
Maine	Atlantic Cod	285,867
	Pollock	259,224
	Haddock	55,875
	Cusk	27,522
	Spiny Dogfish	2,632
	Total of All Fish	631,477
New Hampshire	Atlantic Cod	552,458
	Pollock	275,245
	Haddock	269,332
	Cusk	81,461
	Atlantic mackerel	17,805
	Total of All Fish	1,205,968
Massachusetts	Atlantic Cod	2,956,637
	Haddock	906,367
	Pollock	881,837
	Striped Bass	342,006
	Cusk	248,831
	Total of All Fish	5,767,897
Rhode Island	Scup	62,763
	Bluefish	62,196
	Striped Bass	32,191
	Atlantic Cod	10,005
	Black Sea Bass	8,807
	Total of All Fish	179,364
New York	Striped Bass	274,379
	Bluefish	202,681
	Tautog	67,126
	Summer Flounder	38,830
	Black Sea Bass	20,592
	Total of All Fish	627,418

Table 6.12. State Recreational Fish Harvest* by Top Five Species and Weight – 2008 (continued).

New Jersey	Bluefish	1,045,880
	Black Sea Bass	432,707
	Black Drum	341,404
	Striped Bass	270,043
	Red Hake	201,558
	Total of All Fish	2,875,491
Delaware	Atlantic Croaker	54,042
	Summer Flounder	32,411
	Dolphin	30,954
	Tautog	30,226
	Black Sea Bass	27,206
	Summer Flounder	32,411
	Total of All Fish	240,593
Maryland	Spot	57,081
	Dolphin	48,405
	Black Sea Bass	44,440
	Tautog	28,847
	Yellowfin Tuna	4,429
	Total of All Fish	193,859
Virginia	Dolphin	155,214
	Yellowfin Tuna	57,043
	Atlantic Spadefish	46,567
	Black Sea Bass	39,495
	Tautog	28,287
	Total of All Fish	363,956
North Carolina	Dolphin	3,281,659
	Yellowfin Tuna	769,461
	King Mackerel	597,706
	Greater Amberjack	307,179
	Total of All Fish	7,801,745

Source: Marine Recreational Fisheries Statistics Survey (USDOC, NOAA 2009c)

*Harvest includes:

Type A Catch-fish brought back to the dock in a form that can be identified by trained interviewers.

Type B1 Catch-fish used for bait, released dead, or filleted, identified by individual anglers.

6.1.5 Tourism

Tourism and recreation are important segments of the coastal economy and provide a livelihood for numerous hotels, restaurants, recreational fishing establishments, and other tourism-related enterprises (see Table 6.13).

Table 6.13

Tourism and Recreation Sector Characteristics for Counties Adjacent to the Atlantic Coastline by State (2004)

State	Number of Establishments	Employment	Wages	Gross Domestic Product
Maine	2,380	30,603	$470,508,366	$966,728,600
New Hampshire	578	8,337	$130,935,554	$253,422,100
Massachusetts	3,867	54,062	$1,095,816,188	$2,080,336,200
Rhode Island	1,602	23,416	$394,071,330	$869,969,700
Connecticut	2,707	36,612	$682,715,490	$1,323,004,100
New York	16,454	227,974	$5,596,826,931	$12,197,767,500
New Jersey	5,567	58,787	$1,020,732,937	2,198,637,500
Pennsylvania	1,576	23,364	$317,021,302	$625,916,500
Delaware	841	12,997	$188,532,229	$373,863,400
Maryland	2,212	35,014	$566,771,344	$1,119,400,700
Virginia	2,508	46,827	$669,121,385	$1,432,917,800
North Carolina	1,961	31,933	$387,164,508	$868,232,500

Source: NOEP, 2009b from USDOL, Bureau of Labor Statistics (BLS)

North Atlantic

The southern Maine coast is the most important region for tourist trips. In 2003, the southern Maine coast received 16 million day trips and 2.3 million overnight trips. According to a study prepared for the Maine Office of Tourism: "The ocean, and its beaches, clearly represent the key experiential attractions for visitors to the Southern Maine Coast" (Longwoods International 2004). New Hampshire, because most of its tourism is directed to the mountain and lakes regions, does not report individual tourism statistics for its coastal region.

The economy in the Cape Cod area is "heavily based on ocean and coastal tourism and fishing. Residents are a mix of workers serving these industries and the supporting economy, plus property owners who may be permanent or seasonal residents of the area" (Firestone and

Kempton 2007). Official statistics show that in 2000, 21 percent of the 98,000 jobs on Cape Cod were in tourism-related industries. If the indirect and induced effects of tourism spending are included, tourism accounts for 40 percent of the region's employment (Haughton et al. 2004).

Tourism is a critical part of New Jersey's economy, employing hundreds of thousands of state residents. It is the State's second largest industry, involving $16 billion annually, with most of the tourism dollars spent at the shore. Approximately 40 million day-trippers a year visit the shore (NJDEP 2005). The coastal urban center of Atlantic City alone draws more than 37 million visitors annually while eco-tourism in coastal natural areas continues to expand (Cooper et al. 2005).

Central Atlantic

Ten million visitors come to the coastal bays of Maryland every year to swim, water-ski, fish, crab, bird-watch and hike. Although just over 29,000 people live in the watershed year-round, the population is expected to double by 2020 (ANEP 2009). Because of their tourist appeal, coastal areas are subject to major population influxes during peak vacation periods. Ocean City, MD, for example, had almost 4 million seasonal visitors between the Memorial Day and Labor Day holidays in 2003 (Crossett et al. 2004).

Coastal sites are among the top 20 tourist attractions in North Carolina, and include state parks, Cape Hatteras National Seashore, the Wright Brothers National Monument, and other historic sites (DeBellis 2001). Most visitors come from within the state, and from the nearby states of South Carolina, Virginia, Tennessee and Georgia. North Carolina possesses some of the most well-known historical lighthouses in the United States, located on the Cape Hatteras and Cape Lookout National Seashores. The economic well-being of much of coastal North Carolina depends on the seasonal flux of beach tourism (Ellis and Vogelsong 2005).

There are 57,000 permanent residents of the Outer Banks of North Carolina (Dare and Currituck Counties) but it has been estimated that the effective seasonal daytime population of Dare County at times has surpassed 220,000. In effect, "Dare County supports services for a population that is nearly seven times the size of its resident population" (Kleckley N/D). This coastal economy is different from the economies of other parts of North Carolina, and is structured to support tourist orientation and demand—specifically in the construction, retail trade, real estate, and leisure and hospitality sectors (Kleckley N/D).

In summary, the vast expanse of the United States Atlantic coastline between North Carolina and the Canadian border of Maine is a rich tapestry of abundant natural resources, vibrant water-based economies, rural and urban areas, industrial complexes, military installations, and significant cultural resources. Its residents include all income and age groups, those actively employed and retired, as well as permanent residents and summer transients. The variety of socioeconomic environments within the study area ranges from the sparsely populated coastline areas of Maine and North Carolina to the densely populated urban areas of Boston, New York, Philadelphia, Baltimore and Washington, D.C.

6.1.6 At-Risk Populations

The definition of at-risk populations generally includes those below poverty level, the elderly, minorities and the disabled. Since these groups are most likely to be impacted by an activity that is in geographical proximity, only counties adjacent to the Atlantic Ocean are examined here for the presence of at-risk groups. The definition used here is consistent with one used by some Federal agencies and other institutions. For example, NOAA includes "common coastal aggregations" defined as "Shoreline-Based Coastal Counties" in the STICS data base (Coastal and Ocean Reserve Economics Program and USDOC, NOAA 2010). According to one analysis of shoreline definitions "Smaller coastal units, such as census block groups, and specific definitions of what makes a unit "coastal," lead to more refined estimates of populations at risk from various coastal processes" (Crowell et al. 2007).

Populations at risk in shoreline-based counties were examined for the states in the study area: North Carolina, Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire and Maine. Pennsylvania was excluded from the analysis, because it has no Atlantic shoreline-based counties. Characteristics included in the analysis were: percent 65 years of age and older, percent black, percent Hispanic, number of disabled 5 years of age and older, median housing value and percent persons below the poverty level, with projections based on U.S. Census 2000 (USDOC, Bureau of the Census 2010) (Table 6.14). Although Native Americans might also be considered an at-risk, they are discussed in detail in Section 6.1.1.

Poverty-Level Households

Poverty figures demonstrate pockets of severe poverty along the North and Central Atlantic coast. The Economic Research Service of the U.S. Department of Agriculture defines "high poverty counties" as nonmetro counties with a poverty rate of 20 percent or more based on 1999 income reported in the 2000 Census (USDA, ERS, 2004). Four of these counties are in the study area: Bertie and Tyrell Counties in North Carolina, Northampton County in Virginia, and Somerset County in Maryland. All of these counties are classified as Black poverty counties, indicating that they are "characterized by the poverty status of their Black residents" (USDA, ERS 2004).

In addition to the high-poverty counties identified by ERS, there are other counties in the study where the poverty level is higher than the poverty level in the state as a whole. These include most of the counties in the coastal study area of North Carolina, a majority of the counties along the Virginia coast, and all of the counties along the Maryland coast. There are levels of poverty significantly different from the State average in shoreline counties of New Jersey, (Atlantic, Hudson and Essex); New York (Kings and New York); Connecticut (New Haven); Massachusetts (Suffolk); and Maine (Waldo and York) (USDOC, Bureau of the Census 2009).

Most of the Virginia cities in the study area have high levels of Black populations, persons below the poverty level, and low property values. They include Hampton, Newport News, Norfolk, Portsmouth, Suffolk, and Virginia Beach. The city of Poquoson has a high proportion of elderly residents and high property values, but low minority and poverty indicators (USDOC, Bureau of the Census 2009).

Table 6.14

Populations at Risk in Atlantic Coastal Counties by State: North and Central Atlantic – 2009

County/State	65 and Over (Percent)	Black (Percent)	Hispanic (Percent)	Median Housing Value (Dollars)	Persons Below Poverty Level (Percent)
North Carolina	**12.4**	**21.6**	**7.4**	**$108,300**	**14.3**
Bertie	16.0	60.4	1.5	59,200	26.0
Camden	12.1	15.8	1.7	103,100	8.3
Chowan	18.0	35.9	2.0	85,200	17.3
Currituck	11.6	7.5	2.2	115,500	10.1
Dare	13.3	3.3	3.6	137,200	9.2
Hyde	16.7	35.5	2.7	76,500	23.1
Pasquotank	12.9	38.5	2.4	85,500	18.2
Perquimans	20.5	25.3	1.2	82,800	15.9
Tyrell	15.5	41.6	6.4	59,000	25.1
Washington	17.5	50.2	3.3	69,400	23.6
Virginia (counties)	**12.1**	**19.9**	**6.8**	**125,400**	**9.9**
Accomack	17.0	28.9	9.2	79,300	16.8
Gloucester	13.4	10.0	2.3	111,600	8.4
Isle of Wight	13.2	25.2	1.8	129,300	8.3
James City	18.7	14.0	3.1	167,300	5.7
Lancaster	31.6	26.9	0.8	131,600	12.9
Mathews	23.4	10.6	1.2	118,000	8.1
Middlesex	24.0	18.6	1.3	124,300	12.2
Northampton	20.4	38.9	6.2	78,700	20.8
Northumberland	28.5	24.7	1.6	129,100	13.6
Surry	14.5	46.6	1.0	88,100	11.0
York	12.1	13.9	4.4	152,700	4.1
Virginia (cities)					
Hampton	11.9	47.7	3.8	91,100	15.0
Newport News	10.9	42.5	5.3	96,400	14.7
Norfolk	10.1	44.8	5.0	88,400	17.9
Poquoson	16.0	2.3	2.1	153,400	4.7
Portsmouth	13.3	52.9	2.5	81,300	15.6
Suffolk	11.1	41.7	2.7	107,300	10.9
Virginia Beach	10.5	20.1	5.9	123,200	6.6
Maryland	**12.1**	**29.4**	**6.7**	**146,000**	**8.3**
Somerset	13.4	41.5	2.4	81,100	23.0
Wicomico	13.7	23.7	3.4	94,500	13.2
Worcester	22.8	14.4	2.4	121,500	9.2

Table 6.14. Populations at Risk in Atlantic Coastal Counties by State: North and Central Atlantic – 2009 (continued).

County/State	65 and Over (Percent)	Black (Percent)	Hispanic (Percent)	Median Housing Value (Dollars)	Persons Below Poverty Level (Percent)
Delaware	**13.9**	**20.9**	**6.8**	**130,400**	**10.3**
Sussex	20.2	13.6	6.8	122,400	9.7
New Jersey	**13.3**	**14.5**	**16.3**	**170,800**	**8.5**
Atlantic	14.2	17.6	14.9	122,000	11.9
Bergen	14.9	6.1	15.1	250,300	5.9
Cape May	20.8	5.1	4.7	137,600	8.9
Essex	11.8	41.9	18.9	208,400	13.3
Hudson	10.9	14.8	40.6	150,300	13.9
Middlesex	12.2	10.9	17.6	168,500	6.6
Monmouth	13.1	7.9	8.8	203,100	6.1
Ocean	20.9	3.5	7.1	131,300	8.4
Union	12.5	22.6	25.8	188,800	8.0
New York	**13.4**	**17.3**	**16.7**	**148,700**	**13.8**
Kings	12.3	37.2	19.7	224,100	21.9
Nassau	15.0	11.3	12.8	242,300	4.7
New York	12.9	18.8	24.5	1,000,001	17.7
Queens	13.3	20.2	26.7	212,600	12.2
Richmond	12.1	11.0	15.6	209,100	10.1
Suffolk	13.1	7.8	13.7	185,200	5.3
Westchester	14.2	14.6	19.5	325,800	7.7
Connecticut	**13.7**	**10.3**	**12.0**	**166,900**	**7.9**
Fairfield	13.2	10.7	15.4	288,900	6.7
Middlesex	14.5	4.8	4.2	166,000	5.2
New Haven	13.8	13.0	13.3	151,900	9.5
New London	13.4	6.4	6.7	142,200	6.9
Rhode Island	**14.1**	**1.2**	**2.0**	**133,000**	**6.3**
Bristol	16.8	1.2	1.6	164,600	6.7
Kent	14.8	1.7	2.9	118,100	6.6
Newport	16.3	3.4	3.5	164,100	8.3
Washington	14.0	1.2	2.0	158,600	6.3
Massachusetts	**13.4**	**7.0**	**8.6**	**185,700**	**10.0**
Barnstable	24.0	2.2	1.8	178,800	6.6
Bristol	13.7	3.7	5.1	151,500	9.3
Dukes	15.2	2.7	1.8	304,000	6.8
Essex	13.8	5.3	14.6	220,000	10.4
Nantucket	10.4	10.0	5.8	577,500	5.3
Norfolk	13.9	5.2	2.8	230,400	6.4
Plymouth	12.8	8.1	2.9	179,200	6.5
Suffolk	10.7	23.3	18.1	187,300	19.3

Table 6.14. Populations at Risk in Atlantic Coastal Counties by State: North and Central Atlantic – 2009 (continued).

County/State	65 and Over (Percent)	Black (Percent)	Hispanic (Percent)	Median Housing Value (Dollars)	Persons Below Poverty Level (Percent)
New Hampshire	**12.9**	**1.2**	**2.6**	**133,300**	**7.3**
Rockingham	11.8	0.9	2.1	164,900	4.6
Maine	**15.1**	**1.0**	**1.3**	**98,700**	**12.2**
Cumberland	13.9	2.1	1.8	131,200	9.7
Hancock	16.6	0.4	1.0	108,600	9.9
Knox	17.9	0.4	1.0	112,200	10.6
Lincoln	19.2	0.3	0.8	119,900	10.8
Sagadahoc	13.9	1.4	1.8	110,200	9.2
Waldo	15.1	0.4	0.8	90,100	14.5
Washington	18.6	0.5	1.5	68,700	20.1
York	14.6	0.7	1.2	122,600	8.2

Source: USDOC, Census Bureau. State and County QuickFacts. 2010

Black Populations

Data from the U.S. Census of 2000 indicate that the southern part of the Atlantic Coastal area is home to high proportions of Black residents. According to a U.S. Census publication:

> The Black population (of the United States) is still highly concentrated — 64 percent of all counties (3,141 counties) in the United States had fewer than 6 percent Black, but in 96 counties, Blacks comprised 50 percent or more of the total county population. Ninety-five of those counties were located in the South and were distributed across the Coastal and Lowland South in a loose arc. With the notable exceptions of Baltimore city (a county equivalent) and Prince George's County, in Maryland, generally these counties were nonmetropolitan. (McKinnon 2001)

On the North Carolina coast, seven of ten counties have percentages of Black populations greater than the state average, including Bertie and Tyrell, which are also high poverty counties (USDOC, Bureau of the Census 2009). In Virginia, six of eleven counties have Black populations higher than the state average, as well as all cities but the city of Poquoson. Somerset County, Maryland, which is a high poverty county, also has a high percentage of Black residents.

In the northeast portion of the study area, three coastal counties in New York—Kings, New York and Queens—have Black populations greater than the state average, as do the coastal counties of Fairfield and New Haven in Connecticut and Kent and Newport in Rhode Island (USDOC, Bureau of the Census 2009). The highest percentage of Blacks in a coastal county of Massachusetts is in Suffolk County, although Nantucket and Plymouth Counties also have higher than average numbers of Black residents (USDOC, Bureau of the Census 2009).

A significant portion of the Black population of Maine is in Portland, a resettlement area for refugees, including those from Somalia and Sudan. However, Maine's fast-growing southernmost counties have the state's other large populations of Blacks. The number of Blacks increased 29.5 percent (between 2000 and 2005 State estimates) in York County, and 31.6 percent, in Cumberland County. Sagadohoc County also has a Black population higher than the State average (Kim and Huang, 2006).

Populations 65 Years of Age and Older

Data show that high rates of population 65 years of age and older can be associated with high poverty levels as well as low poverty levels. High income elderly in coastal counties tend to be a reflection of the in-migration of retirees from other locations. According to Serow (2001), "A county's location on either the Atlantic or the Gulf coast was a consistently important predictor of the locality's attractiveness to potential in-migration." He reports that:

> Much of the retirement migration in the northernmost part of the Southeast region (in Delaware, Maryland and Virginia) had been consistently occurring just beyond the Washington and Baltimore metropolitan areas. Core retirement areas are concentrated in four small northeastern coastal counties of Virginia and in coastal areas of Maryland and Delaware. All are immediately adjacent to one or the other of these metropolitan areas. (Serow 2001)

Virginia includes a number of counties where the elderly population is high, but the minority and poverty populations are low: Gloucester, James City, Mathews, and the city of Poquoson, Sussex County, Delaware; Ocean County, New Jersey; Westchester County, New York and Middlesex County, Connecticut also have large elderly populations with low poverty levels and minority populations. The majority of the shoreline counties in Massachusetts and Maine also display similar characteristics (USDOC, Bureau of the Census 2009). One explanation is that "retirees are attracted to coastal locations whose existing populations have consistently achieved some measure of prosperity and are not dissimilar from the retirees themselves" (Serow 2001).

On the other hand, counties with high poverty levels can also have high levels of elderly, most likely residents who have lived in the county all of their lives. In addition to having high levels of poverty and high elderly populations, some counties also have high levels of Black residents. They include all of the poverty-level counties of North Carolina except for Dare County, which has a high level of residents 65 years of age and older but a smaller Black population and poverty rate. All of Maryland's shoreline counties have high populations of elderly and high poverty rates, although only one, Somerset, has a high Black population as well (USDOC, Bureau of the Census 2009).

Lancaster, Northampton, Northumberland and Surry Counties and Portsmouth city in Virginia all have high proportions of elderly, Blacks, and low-income residents, as do New Haven County in Connecticut and Kent and Newport Counties in Rhode Island. However, the data clearly indicate that shoreline counties with high levels of poor, elderly and Blacks are more likely to be found in the southern portion of the study area than in the northeast (USDOC, Bureau of the Census 2009).

Growth in the elderly population on the coast of Maine has been highlighted by a recent study of the impacts of sea level rise, citing that the growth has been most evident on the South Coast. The study also reports that "Economic growth in Maine since 1990 has been especially evident in coastal areas—fueling population growth—but retirement migration and growth of retirement communities have also contributed to the population increase in coastal communities" (Van Arsdol et al. 2001).

Hispanic Populations

High levels of Hispanic populations are more likely to be found in the northern part of the coastal study area, and in most cases are associated with high poverty levels. They include Accomack County in Virginia; Essex, Hudson and Union Counties in New Jersey; Kings and New York Counties in New York; New Haven County in Connecticut; Kent and Newport Counties in Rhode Island; and Essex and Suffolk Counties in Massachusetts. However, for some counties the Hispanic population is large, but the county is not below poverty level. This is true in Middlesex County, New Jersey; Queens and Westchester Counties, New York; and Fairfield County, Connecticut. Three shoreline counties in Maine have Hispanic populations only slightly higher than the state average. Only one, Washington County, has a high level of persons below the poverty level (USDOC, Bureau of the Census 2009).

Fishermen

Although fishermen are not traditionally considered an at-risk group, it is reasonable to consider them as such for the purposes of this study. Numerous studies and articles, including the recent Atlantic Highly Migratory Species Fishery Management Plan (USDOC, NOAA 2006) have discussed the vulnerability of the East Coast fisheries to the economy, environmental factors, management measures and policy decisions. The Fishery Management Plan in particular has called attention to the dependence of a number of East Coast communities on the fishing industry, and the integral part that fishing plays in their economies and culture. For example, in the case of Barnegat Light, New Jersey:

> Barnegat Light's small businesses rely on the summer tourist economy and the year-round fishing industry. According to local citizens, commercial fishing employs as many as 150 local people at marinas. The marinas are the major source of tax revenue for the community, according to representatives of the community's taxpayers association. In addition, small businesses are able to stay open all year because of the fishing industry, and this has stabilized the community so that it has the lowest crime rate on Long Beach Island. (USDOC, NMFS 2007)

Or the case of Gloucester, Massachusetts:

> …(W)hen support industries such as ice companies and seafood dealers are taken into consideration, 40 percent of Gloucester's economy is somehow related to fishing. (USDOC, NMFS 2007)

Cultural factors have also been found to be an integral part of the fishing industry in parts of the northeastern Atlantic coast, such as in New Bedford, where "Many of the members of this fishing community are descended from Portuguese fishing families and kinship networks are an extremely important influence on employment patterns in the fishing industry" (USDOC, NMFS 2007). In many communities, fishing has been a way of life for generations, and fishermen are limited in their ability to find other occupations. In Gloucester, for example, "The majority of active fishermen are not formally well-educated, but rather are educated in the 'school of hard knocks' as one man put it. Consequently, fishermen would generally be at a disadvantage in competition for alternative occupations" (USDOC, NMFS 2007).

Given the importance of the fishing industry to the communities of the Atlantic coast, and the economic, environmental and political impacts it has experienced in recent years, it seems logical that the potential for further impacts on this industry should be carefully examined within the same framework as other at-risk groups.

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PART II
POTENTIAL IMPACTS OF ALTERNATIVE ENERGY DEVELOPMENT

INTRODUCTION: A NOTE ABOUT IMPACTS

This literature synthesis describes the literature on potential impacts to various oceanographic resources from activities conducted as part of offshore alternative energy development. While it attempts to focus on impacts that would be felt by resources within the study area, it is not a specific analysis or prediction of effects from a given project in a given location.

In the context of environmental analyses required by the National Environmental Policy Act (NEPA), impact levels are typically characterized along a continuum, from negligible to major, by their extent, duration, magnitude, and likelihood of occurrence. Throughout Part II, where these terms are used, they have the interpretations given below. Because physical resources and socioeconomic resources are so different, different interpretation of impact terms is appropriate; both definitions are presented below.

Impact Levels for Biological and Physical Resources

Negligible

- No measurable impacts.

Minor

- Most impacts to the affected resource could be avoided with proper mitigation.
- If impacts occur, the affected resource will recover completely without any mitigation once the impacting agent is eliminated.

Moderate

- Impacts to the affected resource are unavoidable.
- The viability of the affected resource is not threatened although some impacts may be irreversible, OR
- The affected resource would recover completely if proper mitigation is applied during the life of the project or proper remedial action is taken once the impacting agent is eliminated.

Major

- Impacts to the affected resource are unavoidable.
- The viability of the affected resource may be threatened, AND
- The affected resource would not fully recover even if proper mitigation is applied during the life of the project or remedial action is taken once the impacting agent is eliminated.

Impact Levels for Societal Issues

The following impact levels are used for the analysis of demography, employment, and regional income; land use and infrastructure; fisheries; tourism and recreation; sociocultural systems; and environmental justice.

Negligible:

- No measurable impacts.

Minor:

- Adverse impacts to the affected activity or community could be avoided with proper mitigation.
- Impacts would not disrupt the normal or routine functions of the affected activity or community.
- Once the impacting agent is eliminated, the affected activity or community will return to a condition with no measurable effects without any mitigation.

Moderate:

- Impacts to the affected activity or community are unavoidable.
- Proper mitigation would reduce impacts substantially during the life of the project.
- The affected activity or community would have to adjust somewhat to account for disruptions due to impacts of the project, OR
- Once the impacting agent is eliminated, the affected activity or community will return to a condition with no measurable effects if proper remedial action is taken.

Major:

- Impacts to the affected activity or community are unavoidable.
- Proper mitigation would reduce impacts somewhat during the life of the project.
- The affected activity or community would experience unavoidable disruptions to a degree beyond what is normally acceptable, AND
- Once the impacting agent is eliminated, the affected activity or community may retain measurable effects indefinitely, even if remedial action is taken.

7. PHYSICAL OCEANOGRAPHY AND AIR-SEA INTERACTION

This section briefly addresses the potential impacts that alternative energy development on the OCS of the Mid-Atlantic and North Atlantic Regions could have on POASI characteristics and resources in these regions, as were described in Chapter 2 of the resources part of this document. Overall, in the literature regarding environmental impacts of alternative energy, effects on POASI have been the subject of far less study than have effects on ecological resources (e.g., Gill 2005). By their very nature, many of the POASI resources are interconnected with other resources and characteristics, making it difficult to discuss the potential effects separately. These issues are recognized in the series of recent reports (USDOI, MMS 2007a; 2007b; USDOE 2008 for marine hydrokinetic) that form the foundation on which much of the present material is built; these reports are representative of the most current understanding that has emerged. A primary limitation for the discussion here is that implementation of alternative energy extraction devices has not occurred in North Atlantic/Mid-Atlantic Regions to date; there are no observations from or data that are directly applicable to these geographic areas, and therefore all present understanding stems from inferring how results obtained elsewhere will generalize and be transferable to the North Atlantic/Mid-Atlantic. For wind energy, projects already implemented in Europe have resulted in a number of observation-based studies that are relevant (e.g., Elsam Engineering and ENERGI_E2 2005 and others cited below); in addition, environmental impact studies for the Cape Wind project in Nantucket Sound have been carried out (USDOI, MMS 2009). For wave and current energy, applicable observations to date are extremely limited, since the technologies suitable for the OCS are in the developmental stages.

The following discussion refers to “near-field,” “far-field,” and “remote” spatial scales. The near-field scale corresponds to an individual power extraction device, for example a wind turbine generator (WTG), wave energy conversion (WEC) device, or current energy conversion (CEC) device. The far-field scale refers to the aggregate collection of a group of such devices. The remote scale corresponds to areas extending beyond the entire group. In addition, for purposes of discussion, it is assumed that WTGs will be installed atop fixed platforms (as opposed to floating platforms). For WEC and CEC devices that require a fixed platform, the remarks made regarding WTG platforms apply, but are not repeated in the text.

The following subsections are organized by resource that could potentially be altered, following the same headings as in Chapter 1 of the first part of this document. Within each subsection, the potential impacts on that resource of WTGs, WECs, and CECs are taken up in turn.

7.1 WINDS AND THE ATMOSPHERIC BOUNDARY LAYER

Attributes of winds and the atmospheric boundary layer are resources that affect and are affected by numerous other characteristics and resources of the OCS atmospheric and oceanic environment. Two key roles that winds and the atmospheric boundary play, for example, are the generation of ocean waves and the dispersal of airborne pollutants.

Operation of wind turbine generators (WTGs) has the potential to alter winds and the atmospheric boundary layer on near-field, far-field, and remote scales. WTGs will weaken the downstream winds and increase turbulence (e.g., Barthelmie et al. 2003) and hence the height of the atmospheric boundary layer. Satellite wind measurements used to study the far-field effects of the Horns Rev (North Sea) and Nysted (Baltic Sea) wind parks (Christiansen and Hasagar 2005) showed that an 8-9 percent deficit in wind speeds relative to free stream velocity occurred immediately downstream of the wind park, while at 5 to 20 km downstream the deficit had diminished to about 2 percent. Weaker downstream winds will reduce the extractable wind energy resource. They will also reduce the generation of ocean waves in the downstream area, another extractable energy resource. Weaker winds will diminish the rate of air-sea transfers of heat and moisture, while increased turbulence will enhance them; the net effect of WTGs on heat and moisture transfers is not generally known but will depend on the relative importance of these two effects. Air-sea transfer of heat is an important factor determining oceanic thermal stratification; together with air-sea transfer of moisture, it is also is an important factor determining fog formation. The magnitude and sense of potential changes to the cycles in oceanic thermal stratification over OCS areas due to wind park influences on atmospheric processes are poorly known, as are potential changes in the frequency and intensity of fog formation. Finally, changes to the winds and atmospheric boundary layer will influence the nature of airborne pollutant dispersal (e.g., Angevine et al. 2006); decreased wind speeds will slow the horizontal dispersal of pollutants and enhanced turbulence will make vertical dispersal more rapid.

WEC and CEC devices are likely to have a negligible or very minor effect on winds and the atmospheric boundary layer, owing to the small distance by which they extend above the sea surface. If a group of WEC devices had a large areal footprint, there would be potential that it could alter air-sea exchanges and lead to some of the associated effects just listed.

7.2 WAVES

Examples of roles the wave climate plays are its control over sediment transport along nearby coastlines, and its mediation of air-sea exchanges such as heating/cooling that control density stratification/destratification. The wave environment sets the boundary condition for winds at the base of the atmospheric boundary layer and thus if altered could modify atmospheric circulation and wind shear profiles.

WTG platforms can alter wave conditions in near-field, far-field, and remote areas. In the near-field, WTG platforms can interact with waves directly, by refraction and sheltering, and also indirectly by their potential to result in current scour, which modifies waves. Conservative theoretical modeling of near-field and far-field wave modifications due to direct interactions with platforms was presented by DHI (1999) and used to estimate that, due to the multiple monopole foundations of the Horns Rev wind park, wave heights will be reduced by about 3 percent in the far-field and nearby remote areas. Similar calculations for other sites and platform types have suggested up to 15 percent reduction in the near-field and far-field (Cooper and Beiboer 2002). Where water depths are shallow enough to influence waves, waves can also be modified by scour near platforms or by the reduced water depths due to boulders installed to limit scour; the findings of studies of dredging impacts just offshore of the 3-nm state waters boundary showed waves off the Virginia and New Jersey shores are more susceptible to wave modifications than the New England shelf (e.g., Maa and Hobbs 1998), are applicable. By modifying currents through wake effects (discussed in the next section), platforms could also alter waves because waves can be, in turn, refracted by currents.

Above water, WTG towers and rotors decrease wind speeds, as described in Section 7.1 of this chapter, in the downstream remote area. Wave heights can be expected to decrease there for this reason, in addition to the effects of the platforms. Remote downstream areas where the wave heights are decreased due to a group of WTGs represent a change to the available extractable resource in that area.

WEC devices, if installed on platforms similar to those used for WTGs, present all the same potential impacts on waves as do platforms just described. Beyond the potential platform influences, by their design WEC devices will decrease the energy flux of waves passing across them. This will lead to decreased energy of waves in the near-field, far-field, and remote areas. Longshore sediment transport and associated morphological changes may decrease detectably in response to even small changes in wave energy and need to be modeled on a site-specific basis; for example, a propagating sand barrier feature in the lee of the Nysted wind park has been estimated to move at 12 m per year instead of 15 m per year (ENERGI E2 and Elsam Engineering 2004).

CEC devices, if installed on platforms similar to those used for WTGs, present all the same potential impacts on waves as do platforms just described. Beyond the potential platform influences, CEC devices are expected to have negligible or minor effects on the wave climate. Their potential influence would be primarily indirect, by change in the strength and direction of currents downstream, which refract waves. Such refraction can increase or decrease wave heights, depending on the angle of wave approach relative to the current shear (e.g., Komen et al. 1996).

7.3 CURRENTS

Currents transport heat and salt and maintain the fundamental distribution of water properties, including stratification, throughout the OCS. Alterations to currents will impact the wave climate through refraction, and the atmospheric climate through air-sea interaction.

WTG platforms and associated scour protection installed on the seafloor cause direct near-field modifications to currents. The near-field influence of blocking and drag based on simple theoretical calculations for monopiles causes current speed reduction of about 2 percent (DHI 1999). The effect increases as a function of platform radius, so will be larger for heavier jacketed-type platforms, but is still likely to be minor. Furthermore, because of the large separation distances between WTGs compared to the platform radius, far-field effects will not be magnified relative to near-field effects. Downstream from platforms there will be increased turbulence, which will have the effect of reducing stratification and hence make currents more uniform vertically. In an area with vertically sheared flow associated with strong stratification, for example near-surface currents opposed to near-seafloor currents, the installation of a group of platforms could result in less stratified conditions and a weaker current moving more nearly in the same direction at all depths.

The influence of WTG towers on currents can occur indirectly by reducing wind speeds (described above, in Section 1 of this chapter) and thus reducing speeds of wind-driven currents. This could reduce weather-band current variability, which would reduce the dispersion of waterborne materials and would have implications for pollutant pathways. To the extent that WTG towers change the atmospheric boundary layer and air-sea fluxes of heat, they could modify stratification and hence the location of tidal mixing fronts, which exert strong influence on mesoscale OCS currents (as described in Section 2.3.4). WEC devices, if installed on platforms similar to those used for WTGs, present all the same potential impacts on currents as do platforms just described. Beyond the potential platform influences, WEC devices are unlikely to modify OCS currents except in very shallow areas where divergence of wave fields is important in driving currents. For such areas, the reduced wave energy due to WEC power extraction will cause the wave-driven component of total currents to weaken.

CEC devices, if installed on platforms similar to those used for WTGs, present all the same potential impacts on waves as do platforms described above in this section. Beyond the potential platform influences, CEC devices have the potential to modify current resources in multiple ways. First, once a current has been drawn down, the potentially extractable resource of a remote downstream area will be reduced. To date only one field study has addressed this process, by measuring currents both upstream and downstream of a pilot CEC in Yell Sound, Shetland Islands (The Engineering Business Ltd 2005). The results were not conclusive but suggested that the influence of the CEC was comparable to natural variability in its importance to differences between upstream and downstream currents. Another potentially important effect of CEC devices could be the alteration of the mixing and dispersal characteristics, which could be felt in both the near-field and the far-field, as described in this section above.

7.4 WATER PROPERTIES AND DENSITY STRATIFICATION

The present geographic distribution and temporal cycles of variation in water properties and density stratification constitute a key resource. This is made clear on consideration of their influence on habitat for living marine resources at all scales.

The characteristics of density stratification result from a delicate interplay of many processes: air-sea heat flux, lateral dispersion of salt, wind-driven mixing, turbulence driven by tidal currents, and advective transport by currents. As described above, WTG, WEC, and CEC each have potential effects on at least one of these processes.

To assess potential impacts will require careful consideration of these processes collectively, tailored for each specific site and its surrounding far-field region. To attain such goals will likely require use of detailed, realistic numerical model simulations that are driven by measurements and that ideally are capable of assimilating observations.

7.5 SEA LEVEL

Outside of alteration to the waves, as addressed above, alternative energy development is not expected to impact sea level on the OCS. It may, however, alter sea level in nearby coastal areas, and thus inundation risks. This is because WTG and WEC/CEC devices, as explained above, can potentially alter the downstream wind field, to which coastal storm surge is sensitive.

7.6 DISPERSION

The nature of present dispersive processes on the OCS is intrinsically linked to the distribution of water properties and density stratification, as well as currents on all space and time scales. As noted above, there are numerous ways in which installation and operation of WTGs or WEC/CEC devices could alter dispersion. Given the present limitations to our baseline understanding of dispersive processes, assessment of potential impacts of alternative energy development on dispersion will challenge even the most advanced research methods and analysts.

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8. BIOLOGICAL OCEANOGRAPHY

Offshore alternative energy projects pose a range of potential impacts to marine biological resources of the North and Central Atlantic (the Northeast Shelf region). Information regarding these impacts is synthesized in this section.

Technologies considered include wind, wave, and ocean current. The priority for assessing these technologies was based on the likelihood of commercial application in the near future within the geographic scope of this effort. Responses to the BOEMRE's first round of nominations for offshore alternative energy projects indicated that wind projects were likely to be the first type developed in the North and Central Atlantic. Therefore, the emphasis in this review will be placed on offshore wind facilities. Other alternative energy technologies (such as tidal energy, solar energy, and ocean thermal energy conversion) will not be considered based on the priority criteria provided above. Each technology type may involve different impact-producing activities. The types of activities will also vary during the lifetime of a project, so impact-producing factors for each phase can be identified. The main project phases include: pre-construction (technology testing and site evaluation), construction, operation (and maintenance), and decommissioning.

Once impacting-producing factors for each project phase are identified, the nature of potential impacts can be assessed. Potential impacts to living marine resources from offshore alternative energy projects may be adverse or beneficial, direct or indirect, and avoidable or unavoidable. Impacts can also be characterized or quantified in terms of magnitude (level of impact), spatial extent, and duration. Hence, impact levels can be defined within a range from negligible, to minor to moderate to major. The spatial footprint of likely impacts can also be assessed and quantified. The duration of impacts can be determined. Most construction and decommissioning impacts will be temporary, occurring in a defined period of time and then ceasing. Some similar impacts may occur intermittently during routine maintenance, but they will also be temporary in nature. Operational impacts are considered long-term or permanent. Nonroutine events, such as pollutant spills or vessel collisions, can also cause impacts that may be of great magnitude if they occur, but the likelihood of occurrence is low.

In addition to assessing the environmental consequences from project-specific actions, a thorough environmental review requires that the potential cumulative impacts from project activities must also be considered. Potential cumulative impacts must be analyzed within the larger context of overall impacts to biological resources. This includes the consideration of impact-causing factors that are unrelated to project activities. The Northeast Coast is the most densely populated coastal region in the U.S., and heavy coastal development and resource use have resulted in a wide variety of environmental stressors. The following examples provide a partial list of human activities that contribute to impacts within the region: commercial fishing; contaminant and nutrient pollution from runoff (metropolitan, suburban, agricultural, forestry, and mining), industrial and municipal wastewater discharges, accidental spills, and atmospheric deposition; offshore construction (e.g., liquid natural gas facilities, subsea cables, and ocean outfalls); dredging (sand and gravel mining, and navigational dredging), dredged material disposal; power plant impacts (impingement, entrainment, and thermal discharge); and shipping activities (Langton et al. 1994; Buchsbaum et al. 2005).

The above considerations provide the basic framework through which impacts can be assessed. The discussion of impacts in the following sections on biological resources will be tailored to the specific considerations applicable to each resource.

Several key references provide information to help guide the assessment of potential impacts from offshore alternative energy projects to living marine resources in the Northeast Shelf region. The primary sources of information on the topic are reports produced by MMS including *Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf* (Michel et al. 2007); the *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternative Use of Facilities on the Outer Continental Shelf, Final Environmental Impact Statement* (USDOI, MMS 2007); and *Cape Wind Energy Project, Final Environmental Impact Statement* (USDOI, MMS 2009). Reports from other Federal and state agencies also inform the topic, including a draft report to Congress from the U.S. Department of Energy, *Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies* (USDOE 2008), and a report prepared for the California Energy Commission, *Developing Wave Energy in Coastal California: Potential Socio-Economic and Environmental Effects* (Nelson et al. 2008).

Commercial-scale offshore alternative energy projects have not yet been developed in U.S. waters. Hence, region-specific analysis of potential impacts for the Northeast Shelf is limited. The *MMS Programmatic EIS* (i.e., USDOI, MMS 2007) evaluated potential impacts of offshore alternative energy projects in the U.S. OCS (Outer Continental Shelf, including the Atlantic), and the *Cape Wind FEIS* (i.e., USDOI, MMS 2009) specifically assessed potential impacts of an offshore wind facility in Nantucket Sound, off Massachusetts. Nonetheless, monitoring results to assess actual impacts from developed projects in U.S. waters are nonexistent.

In contrast to U.S. projects, European offshore wind energy projects have been operational for nearly two decades. The *MMS Worldwide Synthesis* (i.e., Michel et al. 2007) reports that over 10 new offshore wind facilities (in Denmark, England, Wales, Ireland, and Sweden) have become operational since 2000, and many more are in the planning stages. Documents reporting impact analyses and monitoring results from these projects provide much of the information that is currently available to assess potential project impacts in US waters. A number of journal articles have also been published on the topic of impacts from offshore alternative energy projects in Europe. Finally, much of the information to assess potential impacts comes from the published literature regarding the response of living resources to other examples of anthropogenic disturbance that occur in the region. For example, offshore and coastal construction projects, as well as shipping, mining, dredging, fishing, and other activities, produce certain impacts that are similar to those associated with offshore alternative energy projects. The literature and information that describe effects of these activities can be used to assess the potential impacts from offshore alternative energy projects.

Recent reports by MMS and others listed above (e.g., Michel et al. 2007; USDOI, MMS 2007) review the information that is currently available to assess impacts to biological resources from offshore alternative energy projects. Therefore, the following sections will provide an overview of potential impacts with an emphasis on considerations that are relevant to living resources of the Northeast Shelf region. Adequate impact analyses are highly dependent upon site-specific assessments of biological resources relative to proposed actions. This overview provides guidance to help inform the site-specific impact analyses that are essential to assess potential environmental impacts of a specific project.

8.1 MARINE MAMMALS

Marine mammals could be impacted by offshore alternative energy projects in a variety of ways. Potential impacts of greatest concern include vessel collisions and anthropogenic noise. These and other impacts of offshore wind, wave, and current energy facilities will be discussed for both federally listed threatened or endangered species and for non-listed species in the following sections.

8.1.1 Threatened or Endangered Species

Eight species of federally listed endangered marine mammals may occur in the Northeast Shelf region. The potential impacts to these species can be discussed by taxonomic groups (i.e. mysticetes and odontocetes), where similar impacts are likely to be applicable across the group. Endangered mysticetes (baleen whales) in the region include the North Atlantic right whale, humpback whale, fin whale, sei whale, and blue whale. Endangered odontocetes (toothed whales) include the sperm whale and beluga whale. The Florida manatee is treated separately. The natural history of these species, including distribution and likely occurrence throughout the region, is discussed in Section 3.1.

8.1.1.1 Offshore Wind Energy

Many of the potential impacts associated with offshore wind projects would also occur with offshore wave or current projects. Potential impact-producing activities common to all three project types include: seismic site surveys, pile driving, increased vessel traffic (increased vessel noise and risk of collision), and electromagnetic fields from generators and buried cables. An overview of wind energy project activities, potential impacts, species or group affected, mitigation, and impact level is presented below (Table 8.1). Impact levels indicated may vary depending on geographic region, and are dependent on seasonal distribution. Levels indicated in Table 8.1 are the highest level of impact likely for project activities when the species of concern is in the general area.

8.1.1.1.1 Vessel Collision

Vessel strikes are a key concern for endangered marine mammals. Construction and decommissioning would both result in periods of intense activity involving vessels ranging from small crew boats to large cable-laying vessels. During facility operation, vessel traffic related to the facility would be limited primarily to one or two maintenance vessels that service the turbines on a routine basis.

Table 8.1

Potential Impacts on Marine Mammals of an Offshore Wind Project

Proposed Project Activity	Potential Impact Factor	Possible Result	Mammal Species (Group) Affected	Mitigation	Likely Maximum Impact Level[1]
SEISMIC SITE SURVEY					
Air gun array, side-scan sonar	Acoustic harassment	Injury to ears depending on proximity, abandonment of habitat	All	Time of year	Minor - moderate
CONSTRUCTION					
Pile driving	Acoustic harassment	Injury to ears depending on proximity, abandonment of habitat	All	Ramp-up/soft-start, bubble curtain, time of year	Moderate
Construction vessel traffic	Increased risk of vessel collision	Injury or death	All, Special concern: right whales	Slow vessel speed, schedule project activities at time of year with fewest animals in area	Right whales: major; others: minor
	Vessel noise	Change in behavior or swim direction, habitat avoidance	All	Slow vessel speed	Minor - moderate
Installation of wind turbine and inner array cable	Increased turbidity/ suspended solids	Negatively affect prey species, bioaccumulation	All	In-place scour control mats, jet plow, Time of year	Minor
OPERATION					
Operation vessel traffic	Increased risk of collision	Injury or death	All, Special concern: right whales	Slow vessel speed, schedule project activities at time of year with fewest animals in area	Right whales: major others: Minor
	Vessel noise	Change in behavior or swim direction, habitat avoidance	All	Slow vessel speed	Minor - Moderate
Wind turbine operation noise	Acoustic harassment	Change in behavior, abandonment of habitat	Cetaceans	Model of turbine?	Minor - moderate for seals
EMF cables	EMF effects	Change in orientation or effect on migration	Cetaceans (more information is needed)	Coated cables, buried at least 1 m deep	Minor? (more information needed)
Presence of wind turbine	Loss of horizontal, soft habitat, benthos disruption	Alteration of navigation routes, alteration of prey species abundance and distribution	All	Scour control mats with fronds	Negligible
DECOMMISSIONING					
Monopile cutting	Acoustic harassment	Injury to ears depending on proximity, avoidance of habitat	All	Ramp-up/soft time of year	Minor to Moderate
Increased vessel traffic	Increased risk of collision	Injury or death	All, special concern: right whales	Slow vessel speed, schedule project activities at time of year with fewest animals in area	Right whales: Moderate others: Minor
	Increased noise	Change in behavior, swim direction, habitat avoidance	All	Slow vessel speed	Minor
Increased turbidity/ suspended solids	Removal of WTG[2], ESP[3], and inner array cable	Negative effect on prey species, bio-accumulation	All	Temporary	Minor

Table 8.1. Potential Impacts on Marine Mammals of an Offshore Wind Project (continued).

Proposed Project Activity	Potential Impact Factor	Possible Result	Mammal Species (group) Affected	Mitigation	Likely Maximum Impact Level[1]
	Removal of offshore cable	Negative effect on prey species, bio-accumulation	All	Time of year	Moderate (temporary)

Notes: [1] See Introduction for definition of impact levels; actual impact level would be dependent on project-specific conditions.
[2] WTG: wind turbine generator
[3] ESP: electric service platform

Collisions with ships resulting in serious injury or death are not uncommon with cetaceans, and are a significant threat to the recovery of the North Atlantic right whale (Kraus et al. 2005). In particular, females with calves, critical to the recovery of the species, are known to spend significantly more time at the surface than other whales (Baumgartner and Mate 2003). With current population size, "the prevention of the deaths of only two female right whales per year would increase the growth rate to replacement level" (Fujiwara and Caswell 2001). This section discussing vessel collision focuses on North Atlantic right whales due to their critically low numbers and to the availability of literature. However, humpback, sei, fin, and blue whales within project and transit areas would also be at risk of vessel collision.

8.1.1.1.1.1 Mysticetes

Current data indicate that collisions between ships and whales are the leading cause of right whale deaths (Kraus et al. 2005). From 2002 to 2006 along the eastern seaboard of the United States and the Canadian Maritimes, North Atlantic right whales had the highest proportion of entanglements and ship strikes relative to the number of reports for a species ($n = 54$; Glass et al. 2008). Of these 54 reports involving right whales, 21 were verified mortalities, 3 due to entanglement, and 10 (7 of which were within the North and Central Atlantic region) due to ship strike, with an additional 2 reports of serious injuries from ship strike (Table 8.2; Glass et al. 2008). Vessel strikes account for 53 percent of deaths (when determinable) in necropsied whales (Campbell-Malone et al. 2008). Types of documented injuries include propeller trauma such as severed tailstocks and blunt trauma such as shattered skulls and massive bruises (Knowlton and Kraus 2001 as cited in Ward-Geiger et al. 2005).

From February 2004 to June 2005, the deaths of eight North Atlantic right whales in the Northwest Atlantic were recorded, including six adult females (three carrying near-term fetuses). Three of these whales were confirmed to be killed by ship strikes and one was most likely killed by a ship strike, but cause of death was not confirmed (Kraus et al. 2005). The deaths of these females represent a lost reproductive potential of as many as 21 animals (Kraus et al. 2005).

North Atlantic right whales spend most of their non-feeding time resting, socializing, and nursing at the surface, which increases their vulnerability to collisions. In addition, Baumgartner and Mate (2003) state that "significantly longer surface intervals were observed for reproductively active females and their calves compared to other individuals, indicating that this critical segment of the population may be at risk of ship strikes owing to their diving behavior." North Atlantic right whales will not necessarily move out of the way of an oncoming vessel, nor will they be easy to detect from the bow of a ship, since they are dark in color and they maintain a low profile while swimming.

Table 8.2

North Atlantic Right Whale Ship Strikes Eastern Seaboard, 2002 to 2006.

Date	Sex/Life Stage	Location	Mortality
22 Aug 2002	F/Yearling	Off Ocean City, MD	Yes
2 Oct 2003	F/Adult	*Digby, Nova Scotia	Yes
7 Feb 2004	F/Adult	Virginia Beach, VA	Yes
24 Nov 2004	F/Adult	Ocean Sands, NC	Yes
28 Apr 2005	F/Adult	Monomoy Island, MA	Yes
24 Jul 2006	F/unknown	*Campobello Island, New Brunswick	Yes
24 Aug 2006	F/Adult	*Roseway Basin, Nova Scotia	Yes

* Whales found in Nova Scotia and New Brunswick were included because of the proximity to Maine waters.

Source: Glass et al. 2008

Only at speeds below 11.8 kn does the risk of fatality from injury drop below 50 percent, and above 15 kn, the chances asymptotically increase toward 100 percent (Vanderlaan and Taggart 2007). At present, average vessel speeds within two critical right whale habitats (the Great South Channel off Massachusetts and the southeastern habitat off Florida and Georgia along the east coast of the United States) are 14 to 16 kn (Ward-Geiger et al. 2005). If these speeds are maintained, it is reasonable to expect the probability of a vessel strike to cause lethal injuries in these areas to remain between 70 and 85 percent (Vanderlaan and Taggart 2007).

There is concern for potential interactions between ships and whales not only with whales in the most highly used areas, but also with whales traveling to and from these areas. Right whale deaths attributed to ship strikes have been documented in and near shipping channels as well as in coastal areas that link major aggregation areas such as the waters off the mid-Atlantic United States (Knowlton and Kraus 2001 as cited in Vanderlaan and Taggart 2007). Previously, right whales were considered to be a slow-moving, nearshore species that tends to occur in restricted areas for well-defined periods of time (USDOC, NMFS 1991). However, data from satellite-tagged right whales indicate that right whales move long distances, have varied movement patterns, and appear to use much of the western North Atlantic coastline (Mate et al. 1997).

In a study using radio-tagged satellite-monitored right whales in the western North Atlantic, nine whales (six females, one pregnant and three with calves; two males; and one juvenile) were radio-tagged and tracked in the Bay of Fundy in 1990 and 1991. These data show relatively high mobility in the western North Atlantic Region and high use of the lower Bay of Fundy. On average, the nine tagged whales moved 68 km/day, and two individuals each traveled more than 3,000 km (one male and one female with a calf) in six weeks of the study. All animals tracked more than 12 days left the Bay of Fundy, and several left within a few days of tagging. From this study, it appears that movements in and out of the Bay of Fundy may be routine for many, or even most, right whales (Mate et al. 1997). This combination of high mobility in a heavily utilized area increases the potential of ship strikes for the whales.

In studies of recorded sounds, right whales reacted strongly to alert signals, mildly to social sounds of conspecifics, and showed no such responses to the recorded sounds of approaching vessels or to sounds of actual vessels passing through the area (Nowacek et al. 2004). This absence of response only increases the risk of collision for this species.

Measures to Reduce Ship Strikes to North Atlantic Right Whales

In October 2008, NMFS passed regulations on speed to protect North Atlantic right whales (USDOC, NMFS 2009a). A speed limit of 10 knots applies to all vessels 65 ft long or longer traveling within seasonal management areas (SMA, predetermined and established areas within which seasonal speed restrictions apply). Within the northeast region (from Block Island Sound, Rhode Island, north to the Canadian Border), SMA are delineated in Cape Cod Bay, off Race Point, Massachusetts, and Great South Channel, as well as recommended routes (USDOC, NMFS 2009a). There are no SMA in the Gulf of Maine and no mandatory speed restrictions (USDOC, NMFS 2009a). In the mid-Atlantic region (from Brunswick, Georgia, to Rhode Island), the four SMA and their corresponding dates for speed restriction are summarized in Table 8.3.

Table 8.3

Seasonal Management Areas and Their Speed Restriction Dates.

Region/Location	**Dates When Speed Restriction Applies**
Northeast	
Cape Cod Bay	January 1-May 15
Off Race Point	March 1-April 30
Great South Channel	April 1-July 31
Mid-Atlantic	
New York/New Jersey port entrances	November 1-April 30
Delaware Bay entrance	November 1-April 30
Chesapeake Bay entrance	November 1-April 30
Ports of Morehead City and Beaufort, NC	November 1-April 30
Block Island Sound	November 1-April 30

Source: USDOC, NMFS 2009a

Grand Manan Conservation Area, Bay of Fundy

Although the Grand Manan Conservation Area in the Bay of Fundy is outside the study area, the analysis of vessel speed and the probability of a lethal strike to right whales from vessel collision in the Grand Manan Conservation Area provides valuable information that may be applied to other species in other areas. The Grand Manan Conservation Area in the Lower Bay of Fundy was established in 1993 to raise awareness of the North Atlantic right whale, to encourage mariners to avoid this area if possible, and to provide guidance to mariners while they are in the vicinity of right whales (Canadian Whale Institute 2008). The waters of the Bay of Fundy, and especially the Grand Manan Conservation Area, are feeding and nursery grounds and migratory pathways for many whale and dolphin species. In the summer and fall months North Atlantic right whales, humpback whales, and fin whales congregate here and have been observed foraging and with calves.

Currently, protocols governing vessel traffic in the Grand Manan Canadian Right Whale Conservation Area are limited (Brown et al. 1995 as cited in Vanderlaan et al. 2008). They consist simply of warning vessel crews when they are transiting regions where right whales are likely to be present. There are no vessel regulations concerning routing or speed. Actions taken by vessel crews to minimize whale strikes as recommended on nautical charts and notices to mariners (slow down or avoid the region) are strictly voluntary.

Vanderlaan and Taggart (2007) analyzed the influence of vessel speed in contributing to either a lethal injury or a nonlethal injury to a large whale when struck by a vessel. A logical regression model fitted to the observations demonstrated that the greatest rate of change in the probability of a lethal injury to a large whale occurs between vessel speeds of 8.6 and 15 kn, where p_{lethal} increased from 0.21 to 0.79. The probability of a lethal injury drops below 0.5 at 11.8 kn (Vanderlaan and Taggart 2007).

Within the Grand Manan Basin (waters from coastal Maine including the Western Passage east to the southwestern coast of Nova Scotia) the greatest probability of observing a North Atlantic right whale occurs within the Grand Manan Conservation Area (Vanderlaan et al. 2008). It is within this area that vessels pose the greatest risk to right whales, where whales are exposed to vessels navigating at speeds near to, or in excess of 13 kn, corresponding to a p_{Lethal} of at least 0.6 (Vanderlaan et al. 2008). Additionally, the risk of a lethal collision also increases as vessels increase their speed leaving the outbound lane (as well as before entering the inbound lane) and in the waters between Grand Manan Island and the coast of Maine (Vanderlaan et al. 2008). There is no clear evidence that vessels reduce speed when navigating through the Grand Manan Conservation Area, as recommended on nautical charts. Speeds remain relatively high (greater than 14 kn) where the Traffic Separation Scheme intersects the Grand Manan Conservation Area" in the lower Bay of Fundy (Vanderlaan et al. 2008). According to the probability-of-lethal-injury-model (Vanderlaan and Taggart 2007), if a whale is struck in the area between the coast of Maine and Grand Manan Island, the probability is 72 to 84 percent that the whale will be killed (Vanderlaan et al. 2008).

In 2003, an amendment to the Bay of Fundy Traffic Separation Scheme (TSS), which relocated the shipping lanes from the middle of the Grand Manan Conservation Area to the east, outside the high-use area, was implemented. Probability analyses of risk of lethal encounters were performed under the following parameters: the original and amended TSS, a reduction of speed throughout the entire Grand Manan Basin and speed reduction only within the conservation area, and a combination of the amendment and reduction of speed.

Relative to the original TSS, the amended TSS reduced the probability of a vessel encounter and subsequent lethality by 62 percent over the entire Grand Manan Basin (Vanderlaan et al. 2008). A reduction in vessel speed to a maximum of 10 kn throughout the entire basin reduced the overall risk by 52 percent. If the vessel speed was restricted only in the conservation area with the original TSS, a small reduction in risk was achieved (7.5 percent) (Vanderlaan et al. 2008); however, if the 10-kn speed restriction was applied to the conservation area with the amended TSS, the relative reduction in risk would be 69 percent (Vanderlaan et al. 2008). The greatest reduction in risk of lethal vessel strikes to right whales in the Bay of Fundy (75 percent) was achieved with the combination of the TSS amendment and a 10-kn speed restriction over the entire basin (Vanderlaan et al. 2008).

Summary

In summary, the potential for ship strike for North Atlantic right whales is somewhat variable depending on geographic area and time of year. In the Northern Atlantic region (Maine/Bay of Fundy), the risk of vessel strikes is the highest from summer through fall (June to December) when right whales are most apt to be in the area. Off Cape Cod (Cape Cod Bay and Great South Channel) the peak occurrence of right whales is from March through May, although some whales are likely to be present from June to September and from December to January. While in the mid-Atlantic region, the risk to right whales is highest from November through April. The likelihood of a vessel strike being fatal depends additionally on vessel speed.

Vessel Collisions for other Endangered Mysticetes

In a worldwide analysis from 1975 to 2002, fin whales were the most often reported species hit by vessels (Jensen and Silber 2003). Glass et al. (2008) reported that along the U.S. eastern seaboard from 2002 to 2006, of the 51 reported fin whales events, 9 ship strikes were reported, 8 of which were confirmed, and six of which were fatal. Of the six fatal ship strikes, 5 occurred in the mid-Atlantic waters (off New Jersey, Maryland, and Virginia; Table 8.4).

Table 8.4

Fatal Fin Whale Ship Strikes along the Eastern Seaboard from 2002 to 2006.

Date	Sex/Life Stage	Location	Mortality
25 Feb 2004	F/Adult	Port Elizabeth, NJ	Yes
26 Sep 2004	unknown	St. John, New Brunswick	Yes
26 Mar 2005	F/Adult	Off Virginia Beach, VA	Yes
23 Aug 2005	M/Juvenile	Port Elizabeth, NJ	Yes
19 Feb 2003	M/unknown	Norfolk, VA	Yes
17 Apr 2006	M/Juvenile	Baltimore, MD	Yes

Source: Glass et al. 2008

Of 20 dead humpback whales (principally in the Mid-Atlantic), Wiley et al. (1995) reported that 6 (30 percent) had major injuries possibly attributable to ship strikes, and 60 percent of the whale carcasses suitable for examination showed signs that anthropogenic factors may have contributed to, or been responsible for, their death (Table 8.5). These data are noteworthy due to the increased vessel traffic during project activities.

Table 8.5

Humpback Whale Ship Strikes along the Eastern Seaboard from 2002 to 2006.

Date	Sex/Life Stage	Location	Mortality
8 Feb 2002	F/Juvenile	Off Cape Henry, VA	Yes
1 Aug 2002	M/Yearling	Long Island, NY	Yes
6 Jun 2003	F/Juvenile	Chesapeake Bay mouth, VA	Yes
19 Dec 2004	F/Calf	Bethany Beach, DE	Yes
17 Mar 2006	F/Juvenile	Virginia Beach, VA	Yes
15 Oct 2006	F/Juvenile	Fenwick Island, DE	Yes

Source: Glass et al. 2008

8.1.1.1.1.2 Odontocetes

In a worldwide analysis of large whales and ship collisions using historical and recent ship strike data, Laist et al. (2001) determined that stranded sperm whales were commonly struck by vessels in some areas. In another worldwide analysis from 1975 to 1996, Jensen and Silber (2003) concluded that ship strikes were most common in North America. This conclusion might have been biased high because there were more sources of data from North America than from other regions worldwide. However, the authors cite 17 records of sperm whale ship strikes, with sperm whales being the seventh species of eleven in numbers of ship strikes (Jensen and Silber 2003).

8.1.1.1.1.3 Florida Manatee

The single leading cause of injury or death in manatees is collision with watercraft (USDOC, NMFS 2009a). Many studies of manatees’ response and ability to localize boat noise have been done, and these have concluded that “the primary conservation action to reduce the risk of injury/death from watercraft collision is the limitation of watercraft speed” (USDOI, FWS 2007).

8.1.1.1.1.4 Mitigation

Mitigation measures to decrease the likelihood of vessel collision include decreased vessel speed (less than 10 knots) and scheduling high-vessel activities in the time of year when fewest marine mammals would be expected in the area. Additionally, trained marine mammal observers onboard project vessels could sight any animals before collisions occurred.

8.1.1.1.2 Anthropogenic Sound

The noise generated by various activities during the development of offshore wind facilities could impact endangered marine mammals. The magnitude of any impact depends on the level, frequency, and duration of sounds generated by project activities, and on the sensitivity of the various species to anthropogenic noise.

The unit of measurement for sound is the decibel (dB). The dB scale is a logarithmic measure used to quantify sound power or source pressure. A sound power level describes the acoustic energy of a sound, and is independent of the medium in which sound is traveling. As such, sound power levels are not measurable with a sound level meter, which measures only sound pressure levels. A sound pressure level is a physical measure of the pressure field a sound wave produces, and is presented in dB as the ratio of a measured pressure to a reference pressure. In air, that reference pressure is 20 micropascals (µPa) and in water the reference pressure is 1 µPa. As a result of this difference in reference pressures, a given sound will produce a sound pressure level in water that is 26 dB higher than the same sound pressure level in air, even though the actual sound power level or acoustic energy of the sound is the same in both mediums (Southall et al. 2007).

Marine mammal auditory frequencies vary between groups: Mysticetes are low-frequency cetaceans, odontocetes are mid- to high-frequency cetaceans, and pinniped hearing is sensitive to a broader range of sound frequency in water than in air. Frequency ranges for marine mammal hearing groups are summarized in Table 8.6.

Table 8.6

Functional Marine Mammal Hearing Groups and Their Auditory Bandwidth and Genera

Functional Hearing Group	**Genera represented**	**Estimated Auditory Bandwidth**
Low-frequency cetaceans	Mysticeti: *Balaenaoptera*	7 Hz to 22 kHz
Mid-frequency cetaceans	Odontoceti: *Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Grampus, Peponocephala, Orcinus, Globicephala, Physeter, Delphinapterus, Ziphius, Hyperoodon, Mesoplodon*	150 Hz to 160 kHz
High-frequency cetaceans	Odontoceti: *Phocoena, Kogia*	200 Hz to 180 kHz
Pinnipeds in water	*Phoca, Halichoerus, Cystophora*	75 Hz to 75 kHz
Pinnipeds in air	*Phoca, Halichoerus, Cystophora*	75 Hz to 30 kHz

Source: Southall et al. 2007

Behavioral Responses

In Southall et al. (2007), a group of experts in behavioral, physiological, and physical acoustic research reviewed the expanding literature on marine mammal hearing and physiological and behavioral responses to anthropogenic sound. Behavioral disturbance to mysticetes and odontocetes from various types of anthropogenic sound ranges from relatively minor or brief responses to more significant responses more likely to affect foraging, reproduction, and survival. Some examples of behavioral responses in increasing order of severity include:

Minor changes:

- Lack of observable response,
- Prolonged orientation behavior,
- Minor cessation in vocal behavior.

More substantial responses with a greater potential to affect foraging, reproduction, and/or survival:

- Moderate changes in respiration rate,
- Extensive or prolonged changes in locomotion speed, direction, and dive profile but no avoidance of sound source,
- Prolonged cessation of vocal behavior,
- Brief/minor separation of female and dependent offspring,
- Visible startle response,
- Brief cessation of reproductive behavior.

Changes with the greatest potential to affect foraging, reproduction, and survival:

- Prolonged separation of females and dependent offspring with disruption of acoustic reunion mechanisms,
- Long-term avoidance of area (longer than source operation),
- Prolonged cessation of reproductive behavior,
- Outright panic, flight, or stampede (Southall et al. 2007).

"Though it would be convenient to have a single exposure criterion for all species and sound sources, such a simplistic approach is not supported by available science. It is neither possible nor desirable to derive distinct exposure criteria for every species and sound source. Further it is impractical to apply numerous, species-specific criteria when predicting and/or attempting to mitigate effects" (Southall et al. 2007). In other words, in order to determine (and analyze) how levels of sound may affect a marine mammal's behavior or hearing, the analysis should take into account (1) sound exposure levels (dB re 1 μPa), (2) frequency range, (3) sound source (e.g. a ship) and receiver (e.g. marine mammal) variables including: proximity of sound source, received levels of sound to the marine mammal, and sound propagation for the specific area, (4) variability in behavioral response depending on the marine mammal's activity (migration, feeding, nursing, mating, communicating, etc.), and (5) that all the above are variable among individuals, same-species groups, species, and higher taxonomic groups.

Additionally, sound levels may cause behaviors in the receiver that are more problematic than the physiological effects of sound level itself. In a study on the impacts of anthropogenic ocean noise on cetaceans and implications for management, Weilgart (2007) referenced recent strandings and mortalities of beaked whales (*Ziphiidae*) that have been linked to seismic surveys and tactical sonars. The mechanisms are still unknown, but are likely related to gas and fat emboli, at least partly caused from changes in dive pattern (i.e. surfacing too quickly) in response to anthropogenic noise. The author concluded that although mortalities were evident, estimated received sound levels in these events were typically not high enough to cause hearing damage, implying that the auditory system alone may not always be the best indicator for noise impacts (Weilgart 2007).

Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS)

Noise levels ranging from 192 to 201 dB re 1 μPa can cause a temporary threshold shift (TTS) for cetaceans, or a reversible elevation in hearing threshold. Offshore project activities including seismic site surveys and pile driving are likely to reach these sound pressure levels. Exposure to noises at this level will reduce hearing sensitivity temporarily. Factors influencing the amount of threshold shift include the amplitude, duration, frequency context, temporal pattern, and energy distribution of noise exposure (Southall et al. 2007). Exposure to noise levels of 215 dB re 1 μPa and above can cause a permanent threshold shift (PTS) for cetaceans, or an unrecoverable reduction in hearing sensitivity. PTS can occur from a variety of causes, but it is most often the result of intense and repeated noise exposures.

8.1.1.1.2.1 Mysticetes

Vessel Noise

Vessel noise associated with project activities may result in avoidance of habitat for marine mammals in the waters surrounding project activities. Large ships tend to be noisier than small ones, noise increases with ship speed, and ships under way with a full load (or towing or pushing a load) produce more noise than unladen vessels. The intensity of noise from service vessels is roughly related to ship size and speed. Project construction support vessels will likely be in the size class commonly termed small ships, ranging from 5 to 85 m in length. According to Richardson et al. (1995), small ships have broadband source levels of 170 to 180 dB re 1 μPa.

Southall et al. (2007) concluded that behavioral disturbances are strongly affected by the context of exposure and by the animal's experience, motivation, and conditioning: "A behavioral response is determined not only by simple acoustic metrics, such as received level (RL), but also by contextual variables (e.g., animal activity at the time of exposure, habituation/sensation to sound, etc.). Also important is the presence or absence of acoustic similarity between anthropogenic sound and biologically relevant natural signals in the animal's environment (e.g., calls of conspecifics, predators, or prey)." Vessel noise may result in effects on marine mammal communication including masking, signal degradation, reduction of acoustically useful ranges (specific to foraging and reproduction) and physiological effects (stress and hearing impairment) (Southall and Scholik-Schlomer 2008).

Peak underwater sound detection in most baleen whales ranges from 10 to 10,000 Hz, with greatest peak sensitivity below about 1,000 Hz (Ketten 2000 as cited in Thomsen et al. 2006), and overlaps the frequency range of sound likely emitted from project vessels. Studies of low-frequency cetaceans' (mysticetes) behavioral responses to a variety of anthropogenic noise, including vessel noise, are reviewed in Southall et al. (2007). In general, mysticetes indicated no (or very limited) responses at received noise levels of 90 to 120 dB re 1 μPa and an increasing probability of avoidance and other behavioral effects in the 120-to-160 dB re 1 μPa range (Southall et al. 2007).

In a study on humpback whales' behavioral responses to vessel traffic in Alaska, Baker et al. (1982 as cited in Southall et al. 2007) determined that the whales' responses were variable. Some whales showed no behavioral response when the received level was 110 to 120 dB re 1 μPa, while others showed some behavioral avoidance from the same received levels, and clear avoidance at 120 to 140 dB re 1 μPa (Baker et al. 1982 as cited in Southall et al. 2007). The avoidance responses in this case included at least one of the following:

- Minor or moderate individual and/or group avoidance of sound source,
- Brief or minor separation of females and dependent offspring,
- Aggressive behavior related to noise exposure (e.g. tail/flipper slapping, fluke display, jaw clapping, abrupt directed movement, bubble clouds),
- Extended cessation or modification of vocal behavior,
- Visible start response,
- Brief cessation of reproductive behavior (Southall et al. 2007).

In a different study of humpback whales' response to vessel noise, whales in Hervey Bay, Australia, indicated clear avoidance at received levels between 118 to 124 dB re 1 μPa (McCauley et al. 1996 as cited in Southall et al. 2007). As with the study above, some whales showed no observable behavioral response, while others visibly responded (Southall et al. 2007).

A study was done measuring right whales' responses to passing ships by experimentally testing whales' responses to controlled sound exposures of recordings of ship noise, social sounds of conspecifics, and a signal designed to alert the whales (Nowacek et al. 2004). Nowacek et al. (2004) concluded that the right whales reacted strongly to the alert signal, mildly to the social sounds of conspecifics, and not at all to sounds of approaching vessels as well as actual vessels. The whales reacted strongly to the alert signal by swimming strongly to the surface (a response likely to increase rather than decrease the risk of collision) (Nowacek et al. 2004).

Commercial shipping noise can be a dominant component of low-frequency noise, in the 5-to-200 Hz band (Payne and Webb 1971 as cited in Parks et al. 2007b). This frequency range overlaps with the frequency range of right whale sounds of many anthropogenic noise sources, and could potentially have a negative impact on hearing localization and communication by right whales (Parks et al. 2007a). The sound levels for these whales are relevant in determining whether project activities have significant impacts on communication, migration, and feeding abilities.

Commercial vessel noise ranges from 170 to 180 dB, which, depending on source level and distance from the vessel, have the potential to overlap with source levels of North Atlantic right whale tonal calls, which range from 137 to 162 dB re 1 μPa-m and with gunshot sounds ranging from 174 to 192 dB re 1 μPa-m (Parks and Tyack 2005). These calls were recorded during surface active groups (SAG) which coincided with both reproductive and nonreproductive behaviors including play, breeding practice, and social bonding (Parks and Tyack 2005).

Seismic Site Survey

Seismic site surveys may be used during site evaluations for wind and other offshore alternative energy projects. Seismic underwater sound source levels (230 – 260 dB re 1 μPa-m) greatly exceed other activities' sound sources Madsen et al. 2006a). Some air gun components used in site surveys carry significant energy at frequencies octaves above the frequency generally modeled (0.3 to 3 kHz; Madsen et al. 2006a). Additionally, horizontal sound propagation is high, and may be audible at many tens of kilometers away (Richardson et al. 1995).

Based on indirect evidence, at least some baleen whales are quite sensitive to frequencies below 1 kHz, but they can hear sounds up to a considerably higher but unknown frequency (Richardson et al. 1995). They produce sounds for communication and possibly navigation in the frequency range from 10 Hz to 10 kHz (Madsen et al. 2006b). Ljungblad et al. (1988 as reported in Madsen et al. 2006a) reported that in two cases, some bowhead whales (in the same family, *Balaenidae*, as North Atlantic right whales) avoided air guns at ranges of 3.5 to 7.6 km with corresponding received levels of 142 to 158 dB re 1 μPa (root-mean-squared; RMS), and all whales observed in four additional cases showed avoidance at ranges of 1.3 to 7.2 km with corresponding received levels of 122 to 178 dB re 1 μPa (RMS). Using a controlled experimental design, Richardson et al. (1999) showed that most migrating bowheads avoided air guns at a range of about 20 km, at received levels ranging from 116 to 135 dB re μPa (RMS). These results suggest that right whales may show avoidance responses to air gun sound pulses above 120 dB re 1 μPa (RMS).

Various observations of bowhead whales' responses to operating seismic vessels in the Beaufort Sea have been reported. According to Richardson et al. (1995), bowheads' initial behavior changes can be observed up to 8.2 km away, with received levels of 142 to 157 dB re 1 μPa. Some behavioral reactions lasting up to 1 to 2.4 hours included: (1) whale displacement up to several kilometers away, (2) decreased surfacing and dive duration, and (3) decreased blow rate (Richardson et al. 1995). The reactions were the strongest within 5 km of the source, but were still evident from 5 to 10 km away (received levels = 105 to 169 dB re 1 μPa; Richardson et al. 1995). Received levels ranging from 142 to 169 dB re 1 μPa would overlap with mysticetes' vocalization and hearing ranges, and would therefore be likely to mask communication of any whales within tens of kilometers from the source.

Construction/Pile Driving

The installation of monopiles for wind energy facilities would require pile driving during the construction phase of the project. Sound pressure levels and propagation from pile-driving activities are dependent on many variables (e.g. pile diameter and length, water depth, and bottom type). "Pile-driving activities are of special concern, as they generate very high sound pressure levels and are relatively broad-band (20 Hz - > 20 kHz)" (Nedwell and Howell 2004 as cited in Thomsen et al. 2006). Source levels of pile driving noise during the construction of five wind facilities in the United Kingdom waters ranged from 243 to 257 (mean 250) dB re 1 μPa at 1m, and remained above background noise up to 25 km away (Nedwell et al. 2007). Broadband peak sound pressure from pile driving at Utgrunden, Sweden, measured approximately 205 dB re 1 μPa at 30 m from the source (Thomsen et al. 2006).

Noise generated from pile-driving activities may potentially result in both short- and long-term impacts to marine mammals in the project area. Short-term impacts include changes in behavior and avoidance of the project area, and long-term impacts include abandonment of habitat and injury to the hearing system. Pile driving and other activities that generate intense impulses during construction are likely to disrupt the behavior of marine mammals at ranges of many kilometers and also have the potential to induce hearing impairment at close range (Madsen et al. 2006b). According to Madsen et al. (2006b), calculated ranges clearly indicate that pile-driving sounds are audible to harbor porpoises, bottlenose dolphins, harbor seals, and North Atlantic right whales at very long ranges of more than 100 km, and possibly up to about a thousand kilometers.

Depending on the whales' activity during a sound impulse, the behavioral response may vary. For migrating bowhead whales, significant behavioral disturbance from multiple pulses (pile strikes) occurred at received levels around 120 dB re 1 μPa (Southall et al. 2007). For all other low-frequency cetaceans (including bowhead whales not migrating), the onset of behavioral reaction occurred at around 140 to 160 dB re 1 μPa (Southall et al. 2007).

"Pile driving has the potential to affect right whales over very large ranges depending on the propagation conditions" (Madsen et al. 2006b). Sound pressure levels of pile driving could overlap with North Atlantic right whale tonal calls (137 to 162 dB re 1 μPa-m) and broadband shotgun-type calls (174 to 192 dB re 1 μPa-m), possibly causing masking of these calls (Parks and Tyack 2005). Fin whale vocalizations recorded in the eastern North Pacific ranged from 159 to 184 dB, which may also be masked by pile driving (Charif et al. 2002).

Operation Noise

There is considerable variation in the reported noise levels from operating wind turbines. Wind turbine operation noise is created by vibrations in the gear box in the nacelle, and some turbines make more underwater noise than others (Madsen et al. 2006b). The sound intensity is generally dominated by a series of pure tones below 1 kHz, and in most cases is below 700 Hz (Madsen et al. 2006b). Turbine source levels were measured from four wind projects in United Kingdom waters, and were determined to be very low (ranging from 122 to 140 dB re 1 μPa at 1 m) and not likely to cause marine mammals to leave the area (Nedwell et al. 2007). Nonetheless, higher intensities were reported from the Utgrunden Wind Park in the Baltic Sea, where measurements were taken at 83 meters, as opposed to 1 meter from the source (Ingemannsson 2003 as reported by Madsen et al. 2006b). Peak noise levels from an Utgrunden turbine (at a wind speed of 13 m/s) were 122 third-octave sound pressure levels (TOL) dB re 1 μPa RMS measured at 83 m from the turbine. The ambient noise during the peak was 92 (TOL dB re 1 μPa RMS), with the strongest tonal component around 180 Hz (Madsen et al. 2006b).

In addition to sources levels, sound radiation from the source must be considered when potential impacts to marine mammals from turbine operation noise are assessed. To determine sound radiation from a wind turbine, it is necessary to know not only the source characteristics, but also the transmission-loss properties. Differences in transmission-loss between different sites can be due to variations in the water depth and acoustic properties of bottom sediment. "Generalizations in transmission properties cannot be made, and site-specific measurements and modeling are required to understand the sound radiation patterns and propagation from each wind park. Physical measurements and detailed modeling are needed for each specific construction site to reliably evaluate the effects of wind turbines on marine mammals over changing seasons and wind conditions" (Madsen et al. 2006b). Madsen et al. (2006b) also state that measurements made from turbines presently in operation are "not entirely adequate, and may not be representative of future, larger, and potentially significantly noisier turbines" (DEWI 2004 as cited in Madsen et al. 2006b).

There have not been any studies done on the impacts of wind turbine noise on baleen whales. Right whales use tonal signals in the frequency range from roughly 20 to 1000 Hz, with broadband source levels ranging from 137 to 162 Pa at 1 m (Parks and Tyack 2005). In a summary of drillship and dredge-noise playback to bowhead whales, Richardson et al. (1995) concluded that these balaenid whales may react to a tonal signal as low as 110 dB (RMS) re 1 µPa. In a different study, North Atlantic right whales showed a strong avoidance response to tonal signals at received levels ranging from 134 to 148 dB (RMS) re 1 µPa (Nowacek et al. 2004). Therefore, turbine noise may have a masking effect on communication for right whales and other baleen whales over relatively long distances (some miles), in a quiet habitat with no ship noise (Madsen et al. 2006b). "The available data on the effects of noise from operating wind turbines are sparse, but suggest that behavioral effects, if any, are likely to be minor and to occur close to the turbine" (Madsen et al. 2006b).

Decommissioning

Decommissioning activities of wind parks include dismantling and removal of the turbines, electric service platforms (or transformers) and foundations, scour protection devices, and transmission cables, as well as transport of all of the above to shore.

Potential noise impacts from decommissioning of offshore wind facilities are similar to those of the construction phase (e.g., noise from increased vessel traffic and pile demolition and removal).

8.1.1.1.2.2 Odontocetes

Mysticetes (above) are considered to be low-frequency hearing specialists, while odontocetes are mid- or high-frequency hearing specialists (see Table 8.6 above), and therefore require a separate analysis.

Vessel Noise

In a study in New Zealand, sperm whales were exposed to whale-watching boats with sound levels ranging from 109 to 129 dB re 1 µPa/Hz within 450 m. Sperm whales respired significantly less frequently, had shorter surface intervals, and took longer to start clicking at the start of a dive descent when boats were nearby than when they were absent (Gordon et al. 1992 as cited in Southall et al. 2007).

Seismic Site Survey

Low-frequency air gun pulses were previously thought to create a relatively low risk to odontocetes with high-frequency hearing abilities. However, a recent study of acoustically tagged sperm whales with received levels measured during ascent and descent through the water column in the Gulf of Mexico determined that air guns can generate significant sound energy at frequencies many octaves higher than those of interest for seismic exploration (Madsen et al. 2006a). The bulk of energy at frequencies ranging from 0.3 to 3 kHz increases the concern of the potential impacts to odontocetes, including sperm whales, dolphins, and beaked whales (Madsen et al. 2006a).

Measured received levels (131 to 167 dB re 1 µPa (peak to peak)) varied widely with range and depth of the exposed whale, precluding the reliability of the estimation of exposure zones based on simple geometric propagation. According to Madsen et al. (2006a), this study did not include measurement data for sperm whales deep-diving closer than 4 km from the source, and more data are needed at that distance.

Construction/Pile Driving

Sound pressure levels of pile driving could overlap with sperm whale calls (160 to 236 dB re 1 µPa at 1m), and may cause masking of these calls. Behavioral impact studies of pile driving specifically for sperm whales or beluga whales are not available. However, data for harbor porpoise (a non-listed odontocete) are available (see Section 8.1.2.1.2.2 below).

Operation Noise

No studies to date have directly measured the responses of odontocetes to noise from operating offshore wind turbines (Madsen et al. 2006b). Behavioral impact information is not available for sperm whales or beluga whales. Response of harbor porpoise may be an indicator for these species (see Section 8.1.2.1.2.2 below).

Decommissioning

Potential noise impacts from decommissioning of offshore wind facilities are similar to those of the construction phase (e.g., noise from increased vessel traffic and pile demolition and removal).

8.1.1.1.2.3 Florida Manatee

Due to the manatee's exceptional acoustic sensitivity, vessel noise, seismic site survey, construction pile driving, operation noise, and decommissioning have the potential to cause masking and/or behavioral responses. This species is generally found close to shore; its nearshore location may decrease the potential impacts from energy projects farther offshore with the exception of installation of transmission cables.

8.1.1.1.2.4 Noise Mitigation

Vessel Noise

Mitigation measures for vessel noise include quieting vessel technology and the reduction of vessel speed to 10 knots.

Construction/Pile Driving

Several mitigation measures may be used to reduce potential noise impacts from pile driving. The following discussion of mitigation measures includes any counter-opinions of a given measure when available.

- The ramp-up or soft-start procedure starts with relatively low levels of sound, with gradually increasing intensity. This theoretically gives the animal time to leave the area before the sound levels become potentially injurious. Soft-start procedures are theoretically promising but their effect has not been tested to a large degree.
- Ramp-up or soft-start methods may do more harm than good if animals approach the sound source initially when levels are still low, and then become exposed to loud levels before having a chance to retreat (Weilgart 2007). Additionally, as sound fields can be complex, ramp-ups may not give the animal enough information on which direction to swim to minimize its exposure (Weilgart 2007).
- *Acoustic harassment* devices are designed to chase any animals out of the area prior to activity. "These devices have been used, both for seals and harbor porpoises and have been effective in scaring the animals away from the source" (Yurk et al. 2000 and Culik et al. 2001 as reported in Thomsen et al. 2006). Culik et al. (2001 as cited in Thomsen et al. 2006) reported a mean avoidance zone of 500 m around a 'pinger' for porpoises while Cox et al. (2001 as cited in Southall et al. 2007) reported a smaller avoidance response of approximately 208 m. Therefore, this system seems to work at relatively short ranges, but it might be necessary to deploy several 'pingers' at different distances from the construction site" (Thomsen et al. 2006).

While ramp-up and acoustic harassment may significantly decrease the risk of exposing animals to detrimental sound levels by deterring them from the zone of injury, they do not reduce the size of any of the zones of impact. Those mitigation measures that reduce sound pressure levels radiated into the water column have the advantage of reducing the size of all zones of impact (Madsen et al. 2006b, air bubble curtain and mantling, below).

- Air-bubble curtain around the pile has the potential to decrease source levels by 10 to 20 dB, depending on frequency (Wursig et al. 2000 as cited in Thomsen et al. 2006). This method is "very expensive and might be only effective in relatively shallow water" (Krust et al. 2003 reported in Thomsen et al. 2006).

- Mantling of the ramming pile with acoustically isolated material such as plastic may decrease source levels by 5 to 25 dB (in higher frequencies better than lower ones). Mantling "seems very promising but has so far only been tested in a relatively short pile" (Thomsen et al. 2006).

- Pile driving activities could be scheduled at the time of year when the fewest marine mammals are expected in the project area.

Weilgart (2007) also discussed mitigation measures currently suggested for pile driving and their shortcomings. Safety zones of 500 m for sound levels greater than 180 dB re 1 μPa (current regulation), may not be as effective as previously thought. "Not only is the assumed 'safe' noise level difficult to determine, but ascertaining the safety zone distance corresponding to this level is not always straightforward" due to the variable properties of sound propagation (Weilgart 2007).

Decommissioning

Potential noise impacts during removal of turbines and foundations may be decreased by the use of mechanical cutting instead of explosives.

8.1.1.1.3 Electromagnetic Field

Wind facilities and other offshore alternative energy technologies discussed in this report (i.e., wave and current) would all make use of subsea power cables to transmit power from individual turbines to an offshore substation, and from the substation to shore. These cables will produce electromagnetic fields (EMF) that may impact marine mammals. For some of the larger projects, the length of cable needed is substantial.

EMF is defined as electric (E) and magnetic (B) fields. E fields can be contained using shielding within industry standard cables, but B fields are detectable outside the cable, and induce a secondary electric field (iE) outside the cable. Industry standard calls for cable burial to at least 1 m deep to further decrease the likelihood of EMF emissions. However, CMACS (2003) determined that cable burial will provide some but not total mitigation for B field emitted. Some species of cetaceans have been shown to use the Earth's geomagnetic fields for migration and to orient themselves in their environment (CMACS 2003). According to Gill et al. (2005), sperm whales and fin whales are magnetoreceptive (i.e. responsive to B fields). The magnetoreceptivity of other non-listed species is not yet determined. More information is needed regarding identification of current EMF emission levels in the sea floor, behavioral responses and dose levels of EMF for potential projects, and cumulative impacts of multiple cables in an area.

Walker et al. (1992), analyzed fin whale sightings data over the continental shelf off the northeastern United States The results showed a series of associations of fin whale sighting positions with geomagnetic but not bathymetric parameters. Sighting positions were associated with areas of low-intensity geomagnetic field in the winter (p = 0.2) and low-gradient geomagnetic field in the fall (p = 0.008). These associations were correlated with the general pattern of the northward and southward migrations during spring and fall respectively by mysticete whales (Walker et al. 1992). The authors' results are consistent with the hypothesis that fin whales possess a magnetic sense and that they use it to travel in areas of low geomagnetic field gradient and possibly low magnetic intensity during migration. Kirschvink et al. (1986 as cited in Gill et al. 2005) also found that strandings of fin whales were significantly correlated ($p < 0.01$) to magnetic minima in the Earth's magnetic field. This information on fin whales' magnetic sense may be useful for assessing potential impacts from electromagnetic fields produced by power cables for offshore energy projects.

8.1.1.1.4 Other Impacts

Other potential impacts to marine mammals include turbidity from cable and scour protection construction and removal. Increased turbidity may indirectly impact manatees through impacts to their benthic food sources. Accidental spills of fluids used for construction and/or operation (e.g. hydraulic fluid, oil, and gas) may impact any marine mammals that come in direct contact with any such fluids.

8.1.1.2 Wave Energy

Wave energy devices are installed at or near the surface, and would likely be of one of the following four general design types: (1) terminator devices, which consist of a stationary component (fixed to the seafloor or the shore) and a moving component that responds to waves, (2) point absorbers which consist of a floating buoy-like component attached to the seafloor with cables, (3) attenuators, or long multi-segmented floating structures that are attached to each other with hinges and anchored to the seafloor, and (4) overtopping reservoirs, which consist of a wall that collects water from rising waves (USDOI, MMS 2007).

Many of the impacts potentially caused by installation and operation of wave devices are similar to those for wind energy and include increased vessel traffic (producing noise and risk of collision), pile driving for anchoring the devices, physical presence of the devices causing alteration of habitat, and EMF from generators and cables to shore. Potential impacts that are specific to wave energy projects include entanglement in the wave structure, entanglement in the anchoring cables, device operating noise, and physical presence of the structures (USDOI, MMS 2007). The number of devices per area may be relatively substantial (up to 300). Each point absorber wave device would require four concrete anchors with a buoy in the center. If the area is large enough, and spacing between devices is close, the potential for large whales to entangle in cables to the seafloor is increased. Additionally, a large area with close cables may create a "wall effect," which may potentially cause whales to abandon the area as useful habitat (USDOI, MMS 2007).

Sound source levels from wave devices are not known, and research on the effects of cumulative source levels of multiple devices is especially needed (USDOI, MMS 2007). The noise during operation of wave devices would be continuous, and may potentially cause auditory masking, behavioral changes, and abandonment of habitat. If wave facilities were located in important habitat areas used for feeding, breeding, and migration, the resultant effects may be at the population level. Mitigation measures for wave devices include: locating the devices at adequate distances from each other; avoiding important habitat areas and whale migration routes; making lines in the water column taut, so that whales are less likely to be entangled; and using thick lines, which are less likely to cause abrasions and would decrease the likelihood of impacts from entanglement (USDOI, MMS 2007).

8.1.1.3 Current Energy

Potential impacts from current energy activities are similar to those from wind and wave project activities with the following exceptions specific to current projects: risk of collision with underwater turbines, entanglement in anchoring cables, and changes to local currents (USDOI, MMS 2007).

Current energy devices can cover several square miles of ocean habitat per facility, and one facility can include over 100 generating units. According to Elcock (2006 as cited in USDOI, MMS 2007) from the Argonne National Laboratory, the distance between test devices ranged from 12 m (in a linear turbine design, which can span up to one km in length) to 610 m. When units are placed 610 m from each other, the risk of entanglement in cables and collision with turbines is relatively minor. However, in the linear turbine design, the relatively small distance of 12 m creates a wall effect, increasing the risk of turbine collision and entanglement, especially if there are more than 100 units (Elcock 2006 as cited in USDOI, MMS 2007).

Rotor collision is less likely with large species of whales and with adults, who are generally strong swimmers. An increased risk for rotor collision exists for juveniles that are not strong enough to avoid the turbine (Frankel 2006 as cited in USDOI, MMS 2007). Sound source levels from current devices are not known at this time, but may potentially cause the abandonment of a habitat, since turbine noise during operation is continuous and may cause auditory masking, and/or changes in foraging, socializing, or movement. Sound source level data are needed, especially on the cumulative levels from the entire facility (USDOI, MMS 2007). Impact levels will be dependent on those levels and the distance of propagation.

8.1.2 Non-Endangered Species

Potential impacts from offshore alternative energy projects to non-endangered marine mammals in the northeast region are basically the same as for federally listed species. This section will review impact information and provide specific details for non-listed species. Nonetheless, important information for assessing impacts to non-endangered marine mammals that has been previously covered will not be repeated herein.

Twenty-five species of non-endangered marine mammals may occur in the Northeast Shelf region. These include one baleen whale (mysticetes), 20 toothed whales (odontocetes) and four seals (pinnipeds). The minke whale (a mysticete) is the only non-endangered baleen whale that occurs in the northeast region. The natural history of these species, including distribution and likely occurrence throughout the region, is discussed in Section 3.1.

As with the endangered marine mammals, potential impacts of greatest concern include vessel collisions and anthropogenic noise. These and other impacts associated with offshore wind, wave, and current projects will be discussed in this section.

8.1.2.1 Offshore Wind Energy

8.1.2.1.1 Vessel Collision

8.1.2.1.1.1 Mysticetes (minke whale)

In a study of large whales and ship collisions from 1975 to 1996, Laist et al. (2001) determined that 5 percent (5 of 105 stranding deaths) of minke whale records indicated vessel collision as the cause of death. From 2001 to 2005, two minke whale mortalities from ship strikes were recorded, one in Massachusetts and the other in New Jersey, in June and May, respectively (Waring et al. 2007).

8.1.2.1.1.2 Odontocetes

Recorded odontocetes' reactions to vessels can be variable, ranging from curious approach to avoidance from relatively long distances. Dolphins' reactions seem to depend on species and concurrent activity. While resting, animals tend to avoid vessels; while foraging, dolphins will typically ignore vessels; and if socializing, they may approach vessels. For example, *Stenella* spp. started to avoid a survey ship when it was as far as 7 to 3 km away (Au and Perryman 1982 as cited in Southall et al. 2007); during a ship survey, a harbor porpoise drastically changed its swim direction to avoid the ship from 800 m away (Barlow 1988 as cited in Richardson et al. 1995). Yet killer whales rarely show avoidance within 400 m (Richardson et al. 1995). Many odontocetes show considerable tolerance of vessel traffic. However, they sometimes react at long distances if confined by shallow water, or if previously harassed by vessels (Richardson et al. 1995).

In a study on the effects of watercraft noise on the acoustic behavior of bottlenose dolphins in Sarasota Bay, Florida, Buckstaff (2004 as cited in Southall et al. 2007) exposed 140 dolphins to vessel noise passing within 100 m approximately every 6 minutes. The duration and frequency range of dolphins' signature whistles did not change significantly relative to vessel approaches (Buckstaff 2004 as cited in Southall et al. 2007). However, dolphins whistled significantly more often at the onset of vessel approaches than they did during and after vessel approaches (Buckstaff 2004 as cited in Southall et al. 2007). Whistle rate was also significantly greater at the onset of a vessel approach than when no vessels were present (Buckstaff 2004 as cited in Southall et al. 2007). These changes in whistle behavior may be due to heightened arousal, increasing motivation to get closer to each other or it may be a way to continue to communicate in an increasingly noisy environment, thus compensating for signal masking (Buckstaff 2004 as cited in Southall et al. 2007). Buckstaff (2004 as cited in Southall et al. 2007) states that "watercraft may provide the greatest source of anthropogenic noise for bottlenose dolphins living in coastal waters."

Palka and Hammond (2001 as cited in Southall et al. 2007) studied the potential bias (response to vessel) caused by line transect sampling on cetaceans in the North Atlantic: white-sided dolphins, harbor porpoises, minke whales, and white-beaked dolphins. White-sided dolphins, harbor porpoises, and minke whales avoided the survey ship, and white-beaked dolphins were attracted to the ship (Palka and Hammond 2001 as cited in Southall et al. 2007).

8.1.2.1.1.3 Pinnipeds

Seals, vulnerable to noise sources in both air and water, have variable reaction to vessels. Not all seals respond in the same way to a disturbance (Lelli and Harris 2001). Differences between groups and within groups have been observed (Suryan and Harvey 1999 as cited in Southall et al. 2007). However, in a study of sex and age segregation of harbor seal haul-out sites during breeding season in the Passamaquoddy Bay, Maine, region, Kovacs et al. (1990) states that "disturbances greatly influence counts and can override other factors that influence the number of animals using a site." In Holland, harbor seals that give birth on tidal flats often react to boats by moving into the water (Richardson et al. 1995), which may reduce pup survival.

In a study on the effects of human disturbances on harbor seal haul-out behavior in Gun Point Cove, Casco Bay, Gulf of Maine, Lelli and Harris (2001) found that "the level of boat traffic in the Cove was, by far, the single strongest predictor of harbor seal haul-out number, accounting for 27 percent of its variability." In 122 days of observation, 85 incidents in which the harbor seals were flushed off their haul-out ledges were observed. Of these, 93 percent were caused by boats (Lelli and Harris 2001).

8.1.2.1.2 Anthropogenic Sound

The potential impacts to cetaceans from anthropogenic noise produced by offshore wind projects were discussed regarding federally listed species. Hence, sound impacts to non-endangered mysticetes and odontocetes will be discussed only briefly with additional information provided for non-endangered species in the northeast region.

Noise levels above 143 dB re 20 μPa in air and above 212 dB re 1 μPa in water can cause a temporary threshold shift. Factors influencing the amount of threshold shift include the amplitude, duration, frequency context, temporal pattern, and energy distribution of noise exposure (Southall et al. 2007). Exposure to noise levels of 149 dB re 20 μPa in air and 218 dB re 1 μPa in water can cause PTS for pinnipeds. PTS can occur from a variety of causes, but it is most often the result of intense and repeated noise exposures. Alternative energy project activities that are likely to reach these sound pressure levels include seismic site surveys and pile driving.

8.1.2.1.2.1 Mysticetes (minke whales)

Vessel Noise

Vessel noise may result in effects on marine mammal communication including masking, signal degradation, reduction of acoustically useful ranges (specific to foraging and reproduction) and physiological effects (stress and hearing impairment) (Southall and Scholik-Schlomer 2008). In a study analyzing whales' responses to line transect survey vessels, 272 minke whales in the Gulf of Maine avoided vessels with estimated received levels of 110 to 120 dB re 1 μPa from 717 m away (Palka and Hammond 2001 as cited in Southall et al. 2007). Minke whales' behavioral responses in this study included:

- Prolonged orientation behavior,
- Individual alert behavior,
- Minor changes in locomotion speed, and/or dive profile but no avoidance of sound source,
- Moderate change in respiration rate,
- Minor cessation or modification of vocal behavior (Southall et al. 2007).

Seismic Site Survey

Behavioral responses from seismic site surveys are not available for minke whales (a mysticete). See Section 8.1.1.1.2.1 above for details of responses for endangered species of mysticetes.

Construction/Pile Driving

Behavioral studies of pile driving on minke whales are not available. However, pile-driving sound pressure levels may overlap with minke whales' calls (151 to 175 dB re 1 µPa at 1 m) at long distances from the activity. See Section 8.1.1.1.2.1 above for details of pile driving on mysticetes.

Operation Noise

Behavioral studies of potential impacts of turbine noise on minke whales are not available. See Section 8.1.1.1.2.1 above for potential impacts of operation noise on endangered mysticete species.

8.1.2.1.2.2 Odontocetes

Vessel Noise

Some odontocetes exhibit tolerance to watercraft, but apparent disturbance reactions have also been documented (Nowacek et al. 2001 as cited in Southall et al. 2007). Previous research has shown that boats can affect bottlenose dolphin behavior. Specific responses include changes in dive length, surfacing patterns, and foraging habitat selection (Allen and Read 2000 as cited in Nowacek et al. 2001). In Sarasota Bay, Florida, short-term shifts in local habitat use have been observed during periods of heavy boat traffic (Wells 1993 as cited in Nowacek et al. 2001).

Energy of boat noise ranges between 0.1 and 10 kHz. This range overlaps that of dolphin whistles (4 to 20 kHz), an important mode of communication between individuals (Buckstaff 2004 as cited in Southall et al. 2007). In a study of the effects of watercraft noise on the acoustic behavior of bottlenose dolphins in Sarasota Bay, bottlenose dolphins' rate of whistle production increased at the onset of a vessel approach, and then decreased during and after vessel passage. These results indicate that vessel approaches affect the acoustic behavior of dolphins. Whistles were produced within a frequency range of 3 to 23 kHz, and watercraft noise was recorded at 0.5 to 12 kHz. The average signal-to-noise ratio (SNR) for boat approaches ranged between 4 dB (idling) and 13 dB (planing) with some SNR as much as 26 dB above ambient noise for this study (Buckstaff 2004 as cited in Southall et al. 2007). "Therefore, because they [dolphins and boats] share some frequency bands and generate above-ambient received levels, boat noise can play a role in signal masking, and is most likely to occur for close-approaching boats" (Buckstaff 2004 as cited in Southall et al. 2007).

Studies of odontocetes' responses to non-pulse (vessel) sound have been done in the laboratory and field. With studies done in the field using noise levels emitted from vessels themselves (as opposed to using prerecorded playback sound of vessels), isolating the effects of vessel noise from vessel presence remains a challenge. The following studies used actual vessels for sound levels produced, and therefore the behavioral responses cited here may be from vessel presence and/or vessel noise.

White-beaked dolphins in the North Sea and Atlantic white-sided dolphins in the Gulf of Maine were exposed to research vessels with received levels ranging between 110 and 120 dB (Palka and Hammond 2001 as cited in Southall et al. 2007). The white-sided dolphins exhibited avoidance behavior out to approximately 592 m, while the white-beaked dolphins approached vessels between 150 and 300 m away, but avoided vessels at 300 to 700 m away (Palka and Hammond 2001 as cited in Southall et al. 2007). Harbor porpoises are relatively sensitive to a wide range of anthropogenic sound at very low exposures (90 to 120 dB re 1 µPa), at least for initial exposures (Southall et al. 2007). All recorded non-pulse exposures exceeding 140 dB re 1 µPa induced profound and sustained avoidance behavior (Southall et al. 2007). Impact level for odontocetes from vessel noise is minor to moderate depending on the animals' activity during vessel passage and on the animals' distance from the vessel.

Seismic Site Survey

Behavioral responses from seismic site surveys for non-threatened odontocete species are not available. However, the bulk of energy at frequencies ranging from 0.3 to 3 kHz increases the concern of the potential impacts for odontocetes, including dolphins and beaked whales (Madsen et al. 2006a). See Section 8.1.1.1.2.2 above for details of responses for endangered species of mysticetes.

Construction/Pile Driving

The responses of toothed whales to pile-driving sounds have been documented from construction of two offshore wind parks in Denmark. These studies showed a significant decrease in detection of porpoise clicks during pile driving relative to the pre-exposure baseline. Median waiting time (the period between two consecutive echolocation encounters) increased from a range of 6 to 23 hours to 1 to 8 days, for positions both inside the construction area and 10 km away (Henriksen et al. 2003 and Tougaard et al. 2005 as reported in Madsen et al. 2006b). It is not known whether the absence of recorded clicks was due to the porpoises leaving the area or to a change in vocal behavior. Despite uncertainty regarding the exact nature and magnitude of impacts, it is clear from these studies that porpoises were affected by the sounds at least 10 km away (Madsen et al. 2006b).

Operation Noise

Koschinski et al. (2003) studied the reactions of free-ranging harbor porpoises to playbacks of prerecorded (550 kW) and later simulated (2 MW) turbine noise. The sound (between 30 and

800 Hz with peak source levels of 128 dB (re 1 μ Pa^2/Hz at 1 m) at 80 and 160 Hz (1/3-octave center frequencies) was replayed from an underwater transducer. Harbor porpoise showed a distinct reaction to wind-turbine noise. The closest observed approaches to the transducer were significantly nearer in the control sessions (median distance away 120 m) than those recorded during the turbine sound sessions (median distance away 180 m, $p < 0.001$).

8.1.2.1.2.3 Pinnipeds

Vessel Noise

The effects of non-pulse exposures (vessel noise) on pinnipeds in water are poorly understood (Southall et al. 2007). Underwater vocalization frequencies of hooded and harbor seals range from less than 1 to 10 kHz with source levels ranging from approximately 95 to 193 dB re 1 μPa; those of gray and harp seals range from less than 1 to 4 kHz (Richardson et al. 1995).

Small boats with quiet engines, little human motion on board, and slow constant speeds elicit the least reaction (Richardson et al. 1995). Exposures to non-pulsed sound in water between 90 and 140 dB re 1 μPa generally do not appear to elicit strong behavioral responses in pinnipeds (Southall et al. 2007). In a study of harbor seals in captivity, no response was indicated from 80 to 100 dB re 1 μPa exposure, and a single avoidance behavior was recorded for 100 to 110 dB re 1 μPa sound exposure (Kastelein et al. 2006 as cited in Southall et al. 2007). No data exists for exposures at higher levels (Southall et al. 2007).

Noise frequency ranges of construction vessels overlap with underwater vocalization frequencies of all four seal species in the North and Central Atlantic. This overlap may result in masking or signal degradation, which could lead to behavioral changes.

Seismic Site Survey

Quantitative data on reactions of pinnipeds in water to seismic air gun sound pressure are very limited (Southall et al. 2007). Generally, pinnipeds exposed to sound pressure levels ranging from 150 to 180 dB re 1 μPa appear showed limited avoidance behavior (Southall et al. 2007). Received sound levels exceeding 190 dB re 1 μPa are likely to elicit avoidance responses in some ringed seals (Southall et al. 2007).

Construction/Pile Driving

Seals can detect very high frequencies of underwater sound, up to 180 kHz for the harbor seal. The upper limit of effective hearing is approximately 60 kHz. Seals' reactions to sound levels appear to vary between species. For example, a study on the effects of pile driving on ringed seals (*Phoca hispida*) did not show dramatic reactions to underwater impulses with received levels of at least 150 dB re 1 Pa (RMS; Blackwell et al. 2004 as cited in Southall et al. 2007). In a different study, pile-driving activities (no sound levels were measured) did have a significant effect on the haul-out behavior of harbor seals, with a 10 to 60 percent reduction in the number of seals hauled out approximately 10 km from the pile-driving compared to periods with no pile-driving (Madsen et al. 2006b).

Operation Noise

Koschinski et al. (2003) studied the reactions of harbor seals to playbacks of prerecorded (550 kW) and later simulated (2 MW) turbine noise. The sound (between 30 and 800 Hz with peak source levels of 128 dB (re 1μ Pa^2/Hz at 1 m) at 80 and 160 Hz (1/3-octave center frequencies) was replayed from an underwater transducer. Harbor seals showed the following reactions to wind-turbine noise: (1) Their surfacings were recorded at increased distances, with a median distance of 284 m with operation noise, compared to 239 m without operation noise ($p = 0.008$); and (2) The closest observed approaches to the transducer were significantly nearer in the control situations (median distance of 120 m) without operation noise than in wind-turbine sound sessions (182 m, $p<0.001$; Koschinski et al. 2003).

Henriksen and Teilmann (2008) concluded that for seals, turbine noise levels reached 30 dB above the hearing threshold within 1,000 m from the turbines. The authors conclude that this size range for noise detection is significant although the effects on the species are not yet known.

8.1.2.1.2.4 Mitigation

Mitigation measures for potential noise impacts to non-endangered marine mammals are the same as for threatened or endangered species (see Section 8.1.1.1.2.4).

8.1.2.1.3 Electromagnetic Field

According to Gill et al. (2005), the following species are magnetoreceptive (i.e. they respond to B fields): harbor porpoise, bottlenose dolphin, Atlantic white-sided dolphin, Risso's dolphin, striped dolphin, long-finned pilot whale, and pygmy sperm whale.

Kirschvink et al. (1986 as cited in Gill et al. 2005) also found that strandings of Atlantic white-sided dolphins and long-finned pilot whales were significantly correlated ($p < 0.01$) to magnetic minima in the Earth's magnetic field. Strandings of common dolphins, Risso's dolphins, and beaked whales in the family Ziphiidae were also significantly correlated ($p < 0.05$) to magnetic minima (Kirschvink et al. 1986 as cited in Gill et al. 2005). More data are needed for behavioral and dosage response to EMF for cetaceans.

There is no evidence that pinnipeds are magnetoreceptive (CMACS 2003).

8.1.2.1.4 Other Impacts

Other potential impacts to non-threatened or non-endangered species include physical disturbance of benthic habitat and increased turbidity during cable burial, which may impact the food resources of various species (especially the benthic prey items of seals). Additionally, the presence of wind turbines may attract curious dolphins and/or seals. Accidental spills of hydraulic fluid, oil, or gas also pose a threat to any animals in direct contact with such fluids.

8.1.2.2 Wave Energy

Potential impacts to non-listed cetaceans and seals from wave energy project activities are similar to those to threatened and endangered species (see Section 8.1.1.2 above).

8.1.2.3 Current Energy

Potential impacts to non-listed cetaceans and seals from ocean current energy project activities are similar to those for threatened and endangered species (see Section 8.1.1.3 above).

8.2 MARINE BIRDS, COASTAL BIRDS, AND BATS

Marine birds, coastal birds, and bats could all be impacted by offshore alternative energy projects in the Northeast Shelf region. Potential impacts of greatest concern include collisions with above-water structures by animals in flight and alteration of habitat use related to changes in prey availability or temporary disturbance. These and other impacts will be discussed both for federally listed threatened or endangered species and for non-listed species.

8.2.1 Threatened or Endangered Bird Species

Two species of federally listed birds, the roseate tern and piping plover, occur in the Northeast Shelf region. The natural history of these species, including distribution and likely occurrence throughout the region, are discussed in Section 3.2.

The types of impacts that would affect roseate tern and piping plover are the same as for other coastal or marine birds and are discussed in the following sections. Key considerations for these species include temporary or permanent loss or modification of foraging habitat and potential impacts from collisions with turbines or other above-water structures such as meteorological towers. Impacts to the populations of roseate tern and piping plover nesting in the northwest Atlantic were specifically examined at length for the Cape Wind Energy Project (USDOI, MMS 2009; ESS Group 2004a; 2004b; Arnold 2007; USDOD, ACE 2004). A population viability analysis for roseate tern was proposed based on population data and vital rate information (Arnold 2007). Potential impacts and mortalities were analyzed, and minimization and mitigation efforts were presented (Hatch and Brault 2007).

The level of impact to roseate tern and piping plover would be dependent upon project-specific considerations. Due to the rarity of these species, the significance of any impacts could be higher than for non-listed species.

8.2.2 Non-Endangered Bird Species

The natural history of non-endangered bird species that occur in the Northeast Shelf region is reviewed in Section 3.2. Potential impacts from offshore wind, wave, and current energy projects are discussed in the following sections.

8.2.2.1 Offshore Wind Energy

Based on its likelihood of commercial development in the near future, offshore wind is the primary technology type considered in this synthesis. Many potential impacts from wave or current energy projects would be similar to those described in this section for wind. Several key documents review potential impacts to birds from offshore wind facilities. These include the MMS Worldwide Synthesis (Michel et al. 2007), the MMS Programmatic EIS (USDOI, MMS 2007), and the Cape Wind FEIS (USDOI, MMS 2009).

Additional, specific information to assess potential bird impacts in the study area is also available from other sources. Tingley (2003) summarized and reviewed existing literature on offshore wind facilities with a focus on the proposed Cape Wind Energy Project. Plumpton et al. (2007) discuss potential impacts to waterfowl and migrating avian species in Virginia and northeast North Carolina for the U.S. Navy; the U.S. Navy has a website linking the EIS for this project, the Navy Outlying Landing Field, and associated appendices and attachments (U.S. Navy 2008). Kingsley and Whittam (2001) examined and summarized potential avian impacts for a proposed wind facility on North Cape, Prince Edward Island, including a literature review and list of migrating and breeding bird species found in the Atlantic Canadian Maritime provinces. Although Kingsley and Whittam's data was recorded outside the boundaries of this synthesis, theirs is one of the few studies available that discuss the potential offshore impacts to birds of the North Atlantic, and considerable species overlap exists between the Canadian Maritimes and the U.S. northeast region, making their study relevant to this review.

8.2.2.1.1 Collisions with Above-Water Structures

Collisions with above-water structures could impact marine, coastal, or migratory birds, but the extent of this impact is difficult to assess from the currently available literature, which it does not specifically address offshore structures within the northeast region. Thus, although the potential for collisions with wind turbines or other human structures is a key issue for birds, discussion of potential impacts for the scope of this synthesis must be based on information sources that address avian impacts with either onshore structures or offshore structures in other regions.

Annual rates of collision with existing oil and gas platforms such as those in Europe or the Gulf Coast range in the hundreds of thousands (Russell 2005). In the northern Gulf of Mexico, Russell (2005) estimated annual rates of bird mortality from collisions with oil and gas platforms at 200,000. One of the more complete sources of information on avian mortality (Erickson et al. 2005) provides a summary and review of literature on avian mortality in which it was estimated that approximately 500 million to over 1 billion birds are killed in the United States annually by anthropogenic sources, including collisions with structures such as buildings, towers, telephone poles, and onshore wind turbines; however, as noted by these authors, avian mortality is difficult both to sample and to estimate due to the difficulties of observer bias and questionable carcass disappearance or scavenging rates.

The U.S. Fish and Wildlife Service (USFWS) Office of Migratory Bird Management issued an annotated bibliography of bird mortality reports from human structures, including towers (Trapp 1998). The USDOI, FWS (2002) also developed a fact sheet that lists sources of human-caused mortality to bird populations and gives estimates for each source. Its estimates for collisions with communication towers (not wind structures) range from 4 to 50 million cumulatively, and a nationwide study is recommended to address the issue (USDOI, FWS 2002). The U.S. Department of Energy (USDOE), National Renewable Energy Laboratory (NREL), has researched the effects of wind energy on birds and bats since 1994, and has many ongoing research projects (Sinclair 2001).

For wind energy facilities, turbine collision during operation could cause impacts for some species, and for threatened or endangered species the impacts could be major due to their reduced population levels. Although it was recognized anecdotally in the early 1980s that wind structures could have impacts on birds, most concerns over avian mortality from wind turbines stemmed from a study conducted at one of the first large-scale wind energy developments in the United States in Altamont, California, where data collected over a four-year period (1984-1988) documented bird fatalities (Erickson et al. 2005). Avian impact and mortality studies conducted at this facility, and then several subsequent studies conducted in California and then across the United States, confirmed and supported the concept and scale of avian impacts from onshore wind facilities. Projected annual bird fatalities from wind projects nationwide ranged from 20,000 to 37,000 for 2003, and the average numbers of avian collision mortalities were 2.11 birds per turbine and 3.04 birds per megawatt (MW) (Erickson et al. 2005).

Continual research into wind turbine development has reduced mortality rates in two ways. First, because older turbines produce less power per turbine, it took more turbines to produce the energy that newer facilities can produce with fewer turbines (GAO 2005). Experts suggest that the sheer numbers of turbines in large wind parks such as the one at Altamont, California, were the reason for the high avian mortalities, since there is little chance for birds to avoid such a large area (GAO 2005). Second, some scientists believe that turbines of the older design were particularly fatal to raptors since the old turbines were mounted between 60 to 80 feet in the air; currently designed towers are mounted 200 to 300 feet in the air (GAO 2005).

The National Research Council published a thorough examination of the effects and potential impacts of wind energy facilities in *Environmental Impacts of Wind-Energy Projects*; this book includes a lengthy discussion of birds and bats and a detailed literature review of studies (NRC 2007). The National Wind Coordinating Committee issued a paper summarizing and reviewing sources of avian mortality at wind facilities (Erickson et al. 2001) as well as a guidance document outlining steps for studying bird-tower interactions (Anderson et al. 1999). Kunz et al. (2007) also created a guidance document providing metrics and methods for investigating birds and bats in relation to wind energy development. In 2008 a methodology for determination of migratory bird mortality risk at wind energy facilities was presented using modern avian radar and meteorological systems (Merritt et al. 2008). The U.S. Geological Survey Patuxent Wildlife Research Center has an updated database of marine bird distribution that they use for assessing potential wind development impacts in the northeast region (Johnston and Parsons 2008).

There is a shortage of information on migratory bird routes and the ways in which topography, weather, and turbine type may affect mortality; experts suggest that only one-third of the 800 species of migratory birds in the United States have habitats or pathways that are clearly understood (GAO 2005). As noted in the Cape Wind FEIS (USDOI, MMS 2009), although coastal areas concentrate migrant songbirds during migratory flight and stopover events, little data exists that can quantify numbers of migratory birds along the Atlantic Coast, and relatively few migratory species actively use the marine habitat. Potential impacts to migrating shorebirds and waterfowl are discussed by Burger et al. (2004). Berthold et al. (2001) wrote *Bird Migration*, providing a comprehensive and scholarly approach to bird migration that discussed significant threats to these species and measures of conservation. Certain species of migratory birds, such as red knot and purple sandpiper, are more susceptible to impacts due to their narrow routes of travel, which limit them to coastal areas (Watson and Malloy 2006). Blaydes and Firestone (2008) provide a comprehensive discussion on the impacts of wind energy on migrating birds and how the Migratory Bird Treaty Act should be applied to these facilities and on the issues of “take” or bird mortality. Bird collisions with slow-moving turbines due to motion smear, or an inability to see the individual turbines, is being studied to identify mortality reduction strategies (Hodos 2003).

8.2.2.1.2 Other Impacts

In addition to the direct collision impacts discussed above, other potential impacts to birds include habitat loss or modification and changes to foraging or flight behavior. These impacts could result in increased energy expenditure, decreased breeding success, or increased mortality (USDOI, MMS 2009).

The increased boat traffic associated with all project phases for offshore wind facilities is not anticipated to significantly impact most bird species, given their overall ability to avoid the ships and the relatively minimal vessel traffic in comparison to that of typical ship traffic lanes. However, some species, including red knot (*Calidris canutus rufa)* and piping plover (C*haradrius melodus*), are highly sensitive to human disturbance, particularly during nesting and pre-migratory staging activities (USDOI, MMS 2009). The additional noise and human presence associated with increased boat traffic could have a positive impact on some species, notably gulls and some terns, which would be attracted to them (USDOI, MMS 2009). However it is well-documented that birds collide with large structures, including boats (Erickson et al. 2005); thus some collision impacts from increased boat traffic would be expected.

Oceangoing ships churn water and can create temporary, localized upwelling situations that could increase the presence of surficial prey and serve as an attractant to birds. Also, construction vessels could provide a continuously lighted environment, which can attract flying insects. Because of this, some contact can be expected to occur between project vessels and foraging/feeding seabirds. Mortality in these situations is thought to be negligible and should not have an overall impact on non-endangered species. Due to the large area in which these birds can choose to feed and the typical avoidance behavior of these species toward any disturbance source, such as large ships or structures, any adverse impact to feeding could be short-term or transitory (Erickson et al. 2005).

Boats, buoys and other above-water structures have the potential to provide a resting place for migrating birds that have been affected by weather (i.e., blown offshore or lost in the fog) or exhaustion (Watson and Malloy 2006). Marine birds may also be attracted to above-water structures. In some circumstances these structures may be used for roosting or nesting but this would likely be minimal (USDOI, MMS 2009).

Spills of oil or other hazardous materials or fluids from construction or transport vessels could also impact marine and coastal birds. Mortality or toxicity could occur directly due to contact with spilled materials, or indirectly due to contamination of habitat and prey items. The occurrence and effects of oil spills are difficult to predict or observe with the exception of large exceptional incidents, such as the 1989 Exxon Valdez oil spill in Prince William Sound Alaska, after which approximately 30,000 bird carcasses were recovered, including 250 bald eagles, but overall mortality estimates ranged from 100,000 to 300,000 birds of all species (Erickson et al. 2005). Certain offshore wind facilities may pose a risk of vessel collisions that could result in spills. Small spills and chronic oiling are much less publicized yet still significant sources of seabird mortality; estimates of avian mortality from oiled corpses found on beaches in the United States range from 0.01 to 3.68 per km of shoreline (Erickson et al. 2005). Indirect impacts include a reduction in the availability of forage due to contamination, i.e. fish kills, and exposure to contaminants in prey items. Any spills during routine conditions would likely be small in volume due to the types of vessels involved; liquids transported would be limited to those necessary for the ship to operate or for work performed on the turbines, which is limited in quantity and would result in no more than minor impacts.

Physical disturbance, operational noise, and nighttime lighting resulting from construction activities would temporarily alter foraging behavior or prey availability for some coastal or marine bird species (USDOI, MMS 2009). Some species may be able to tolerate high levels of human disturbance without exhibiting avoidance behavior, while others will actively avoid the area during construction and operation. These activities are not anticipated to alter the migration patterns of avian species within the area. However lighting of wind structures could result in increased impacts, particularly for night-migrating species, raptors, or bats within the area (USDOI, MMS 2009).

Installation of offshore structures such as turbine monopiles, tower bases, and transmission cables has the potential to disturb, temporarily or permanently, the benthic environment. This will indirectly affect marine bird species that feed on the benthic predators (i.e. fish, invertebrates). While this type of impact is expected to be small, and most bird species should be able to move to locations where food is available, it may have an increased impact on sensitive species (piping plover, roseate tern, and red knot). In addition these structures will over time create microhabitats that will increase area for benthic epifauna (i.e., mussels) and may function as fish-attracting devices (FADs), which aggregate and concentrate fish prey near the artificial structures and attract marine birds, particularly diving birds, gulls, and terns (USDOI, MMS 2007; USDOE 2008); this has positive and negative impacts since increased prey availability and attraction would also increase the risk of collision.

8.2.2.2 Wave and Ocean Current Energy

Many of the types of potential impacts to birds from wave and current energy facilities are essentially the same as those from offshore wind facilities. Examples of similar impacts include collisions with above-water structures (i.e., ships), alteration in habitat use related to changes in prey availability, temporary disturbances during the construction and decommissioning phases of a project, and accidental spills or leaching of toxic chemicals (Michel et al. 2007; USDOI, MMS 2007; USDOE 2008).

Wave or current energy devices require the installation of structures or devices in the water column that may function as FADs, similar to the structures from wind technology. However, unlike the wind energy structures, wave or current energy devices have moving parts within the water or at the surface. This potential for attracting fish could result in either positive or negative impacts to birds, depending on the bird species, foraging style (diving versus dabbling), and the specific technology shape and function. A surface or underwater structure with slow-moving parts that attracts fish, providing increased prey for diving birds, could be a positive impact. In opposition, many of the underwater technologies include moving parts such as turbine rotors that pose a potential for collision for diving birds (USDOE 2008). Studies have reviewed ways to reduce this risk, including reducing the encounter risk using antifoulant paints (which would minimize the development of the structure into an FAD); making the blades, structures and in particular, rotors, highly visible to avoid collision; shielding blades or other moving parts where possible; and softening the collisions by reducing the blade edge (USDOE 2008).

Seawater presents a harsh environment for mechanical devices with moving parts. Wave and current turbines will require hydraulic fluid and lubricants that may be toxic to birds should they be released into the environment. Spills or leaks of such fluid should be avoidable by most bird species, but has the potential to affect larger numbers of individuals as the size of the leak or spill increases (USDOE 2008). Typically permit conditions will contain requirements for spill prevention and response plans to minimize this risk.

8.2.3 Bats

Bats that fly over waters of the Northeast Shelf may be impacted by collisions with above-water structures associated with offshore alternative energy projects. The natural history of bat species that may be impacted is reviewed in Section 3.2.

The magnitude of potential impacts to bats from offshore alternative energy is not well understood. The literature contains very few studies on impacts to bats from offshore structures such as boats and wind facilities, with the exception of those in Europe, and almost no studies directly from the northeast region (USDOI, MMS 2009; Johnson and Arnet 2004; Kunz et al. 2007). Therefore, the information below is from onshore projects or from projects outside the northeast region.

Johnson and Arnet (2004) wrote an important annotated bibliography of bat interactions with wind turbines. The American Wind Energy Association and The American Bird Conservancy issued several reports reviewing bat impacts at wind parks (Johnson 2004; Kunz 2004) including site data from several wind parks, bat fatality rates, reasons why bats collide with turbines, and discussion of collision versus attraction. Kunz et al. (2007) summarized evidence of bat fatalities at wind energy facilities in the United States onshore. Bat Conservation International reviewed surveys from an onshore wind project in West Virginia and gave estimates of 2,092 bats of seven species killed during a several-week survey period, estimating that as many as 4,000 bats could have been killed during bat migration (Tuttle 2004). Pre-construction studies have been undertaken in several states for onshore facilities. These studies typically use mist netting, recordings of echolocation, or a combination of both (Arnett et al. 2007).

Estimates of bat mortality from studies conducted in the Appalachian Highlands have found thousands of bats killed in relatively short time periods; in one study 2,000 bats were killed during a 6-week period. Bat Conservation International suggested that bat mortality rates in the Appalachians from ridgetop turbines could be as high as tens of thousands of bats in a season

(GAO 2005). As of the 2005 GAO report, none of the bats killed by wind power was listed as an endangered species; however, it is noted that few studies identify bats killed by species.

Post-construction mortality surveys at onshore wind projects have revealed a consistent pattern of bat mortality despite diverse methodologies and sampling periods. The species composition of bats killed at onshore wind facilities from across the country continuously suggests that migratory tree bats (such as the hoary bat, silver-haired bat, eastern red bat, eastern pipistrelle bat, and Brazilian free-tailed bat) are being killed at higher rates than other species. Although the causes of this mortality are unknown, wind turbines clearly represent an additional mortality risk for these species. Evidence indicates that tree bats may sometimes migrate with birds and that bat migrations may be similar to bird migrations; therefore bats may be susceptible to similar mortality factors. There are numerous reports of tree bats found among dead birds that collided with human-made structures. Most of these incidents occurred during autumn and involved multiple species. Many reported collision events involved tens to hundreds of birds but only a few bats. Unlike the mortality data from buildings, wind turbines appear to impact migratory tree bats at high rates (Johnson and Arnet 2004).

It is not clearly understood why bats collide with wind turbines. Bats have the ability to echolocate and thus avoid collision with meteorological towers and structures shaped like them (GAO 2005). Studies attempting to find definitive reasons or provide a clear understanding of bat-turbine interactions are numerous and varied in scope, and focus on several different features, including bat attraction, especially to ultrasound emissions (Szewczak and Arnett 2006), and barotrauma, due to the effect of rapid air-pressure reduction near moving wind turbines (Baerwald et al. 2008). Other hypotheses include bat attraction due to foraging on insects attracted by lighting, bats killed while investigating the structures as roost sites, and bats not echolocating while flying and thus being unable to avoid the collisions (GAO 2005).

Despite the uncertainty surrounding why bats collide with onshore wind turbines, researchers have suggested several possible mitigation strategies. Since most bats are killed during the fall migration when wind levels are low, researchers have suggested that turning off some turbines during this time period could reduce kills with modest reduction in power production (GAO 2005). The importance of preconstruction studies to identify habitat usage by bats relative to project siting has also been emphasized, and ultrasonic devices to deter bats from wind turbines have been proposed (GAO 2005). Nonetheless, comprehensive studies are needed to test the effectiveness of possible mitigation strategies to reduce bat kills from wind turbines (GAO 2005).

Potential impacts to bats are difficult to estimate; no studies have been conducted with the goal of obtaining a visual, auditory, or physical observation of bats in offshore waters, and no studies have occurred to track migrating patterns of bats along the east coast (USDOI, MMS 2009). Studies from land-based wind facilities show that bats are killed at higher numbers during migratory periods (July-September), suggesting that migrating bats are highly susceptible (GAO 2005). Little is known about bat migration in general. Although relative risk cannot be clearly determined in the absence of site-specific population density data for each species, five species of bats (the hoary bat, silver-haired bat, eastern red bat, eastern pipistrelle bat, and Brazilian free-tailed bat) appear to be killed during onshore collisions at a higher rate than would be predicted based on the abundance of these species from capture surveys. The reason for these species being at higher risk of collision mortality is uncertain. The first two species (the hoary bat and silver-haired bat) are found across North America and are therefore potentially found at any wind development site in North America. The other three species (the eastern red bat, eastern pipistrelle bat, and Brazilian free-tailed bat) are more regional in distribution than these pan-continental species but still have geographic ranges that extend over thousands of miles; all of these bats have known ranges that include the northeast region with the exception of the Brazilian free-tailed bat. It is likely that these large geographic ranges and the long-distance migratory behavior of these species have exposed them to a higher risk of turbine-related collision mortality at onshore wind facilities. Any of these migrating bats have the potential to be found in offshore or coastal areas as they migrate for the following reasons: (1) It is known that some species migrate over water and have been found on coastal islands even though the lack of food availability and roosting locations decreases the chances of bats spending a significant amount of time offshore (USDOI, MMS 2009); (2) Their migratory pathways are unclear but they could fly offshore either in an effort to fly in a straight-line path that crosses water, or in an effort to forage and follow prey items over water as they migrate (Cryan 2003); (3) Bats have been found to use boats as stopover or rest areas during migration (Constantine 2003); and (4) Weather events may blow them off-course and offshore (USDOI, MMS 2009; USDOI, MMS 2007).

8.3 SEA TURTLES

Five species of sea turtles may occur in the Northeast Shelf region: the loggerhead, leatherback, green, Kemp's ridley, and hawksbill. All five of these species are federally listed as threatened or endangered. The natural history of each species, including distribution and likely occurrence throughout the region, is discussed in Section 3.3.

Sea turtles of the northeast region could be impacted by offshore alternative energy projects in a number of ways. Potential impacts of greatest concern include vessel collisions and anthropogenic noise. These and other impacts will be discussed for wind, wave, and current energy projects in the following sections.

8.3.1 Wind Energy

8.3.1.1 Vessel Collision

All phases in the development of wind facilities or other offshore alternative energy projects would result in increased vessel traffic in the project area. Vessel strikes are therefore a key concern for sea turtles.

Sea turtle stranding data for the U.S. Gulf of Mexico and Atlantic coasts, Puerto Rico, and the U.S. Virgin Islands show that between 1986 and 1993, about 9 percent of the 16,102 living and dead sea turtles found stranded had propeller or other boat strike injuries (Lutcavage et al. 1997). Sea turtles sometimes spend as much as 26 percent of their time at the surface, engaged in surface basking, feeding, orientation, and mating (Lutcavage and Lutz 1997). Injuries from boat strikes are recorded at higher frequencies in areas where recreational boating and vessel traffic are intense (USDOC, NMFS and USDOI, FWS 2007). In the U.S. Atlantic from 1997 to 2005, 14.9 percent of all stranded loggerheads were documented as having sustained some type of propeller or collision injuries (USDOC, NMFS and USDOI, FWS 2007). The incidence of propeller wounds has risen from approximately 10 percent in the late 1980s to a record high of 20.5 percent in 2004 (USDOC, NMFS unpublished data as cited in USDOC, NMFS and USDOI, FWS 2007).

8.3.1.2 Noise

The noise generated by various activities during the development of offshore wind facilities could potentially impact sea turtles. The magnitude of any impact would depend on the level, frequency, and duration of sounds generated by project activities, as well as the sensitivity of each species to anthropogenic noise.

Differences in functional morphology and behavioral hearing capabilities among species and life history stages of sea turtles have not been documented. Only juvenile loggerhead and green sea turtles have undergone any auditory investigations (Bartol and Musick 2003). Green turtles can detect limited frequencies ranging from 200 to 700 Hz, with the greatest sensitivity at the low-tone region of about 400 Hz, and loggerhead turtles have their greatest sensitivity in the low-frequency region from 250 to 1,000 Hz (Bartol and Musick 2003).

Vessel Noise

Published acoustic data on sea turtles and behavioral responses to vessel noise are lacking. The hearing range of green sea turtles, 200 to 700 Hz, with peak sensitivity at 400 Hz, overlaps the frequency range of construction vessels (Ridgway et al. 1969). This suggests that sea turtles may be impacted by vessel noise.

Seismic Site Survey

In a study using air guns as acoustic repelling devices, juvenile loggerheads avoided air gun sound frequencies ranging from 100 to 1,000 Hz at three decibel levels (175, 177, and 179 dB re 1µPa at 1 m) upon first exposure. However, turtles appeared to habituate to sound stimuli, and after three separate exposures, turtles no longer avoided the stimuli (Bartol and Musick 2003).

Construction/Pile Driving

Studies of impacts from pile driving on sea turtles are lacking. Broadband frequencies typical for pile driving (20 Hz to > 20 kHz; Madsen et al. 2006b) and sound pressure levels at or above 180 dB "could disturb normal behaviors (e.g. feeding) and cause affected individuals to move away from the construction area" (USDOI, MMS 2007). However, any hatchlings that were living on sargassum rafts, or passively carried by currents into the vicinity of pile driving would not be able to swim away and could be exposed to potentially damaging sound pressure levels.

Operation Noise

It is not known how sea turtles may respond to or be affected by turbine noise (USDOI, MMS 2007). Underwater turbine noise may reach levels of 90 to 115 dB at a distance of 110 m, with frequencies ranging from 20 to 1,200 Hz with the most energy (sound pressure) at 50, 160, and 200 Hz (Thomsen et al. 2006). USDOI, MMS (2007) suggests that sea turtles may be affected by turbine noise at these levels. Potential responses to turbine noises generated during normal operations may be expected to be behavioral and include avoidance, disorientation, and disturbance of feeding behavior (USDOI, MMS 2007). Turbine noise is continuous, and may result in long-term avoidance. If hatchlings are passively transported via currents to the wind facility area, they would not be able to actively swim away, and could experience long-term exposure to the turbine noise (USDOI, MMS 2007). “Few studies are available on sea turtle hearing sensitivity or noise-induced stress” (USDOI, MMS 2007).

Decommissioning

If explosives are used to dismantle wind turbine platforms, the sound pressure levels may cause injury to any sea turtles in the vicinity. Klima et al. (1988) recorded the results of various sound pressure levels on Kemp’s and loggerhead sea turtles in cages at various distances (229, 366, 549, and 915 m) from explosions measuring 221, 217, 213, and 209 dB. Two Kemp’s and two loggerheads were found unconscious at 366 m from the sound source, and one loggerhead was found unconscious at 915 m. Both Kemp’s and loggerheads at 229, 549, and 915 m had dilated blood vessels at the base of their throats and flippers, which persisted for weeks after the explosions. Decommissioning options that would emit less sound than would explosives include acetylene torches, mechanical cutting, and high-pressure water jets (USDOI, MMS 2007).

8.3.1.3 Electromagnetic Field

Wind facilities use subsea power cables to transmit power from individual turbines to an offshore substation, and from the substation to shore. These cables will produce electromagnetic fields (EMF) that may impact sea turtles.

In a study to determine whether sea turtles possessed a magnetic compass sense, Cain et al. (2005) concluded that for young loggerheads, regional magnetic fields function as navigational markers and elicit changes in swimming directions at crucial geographic boundaries. In another study, juvenile green and loggerhead turtles from North Carolina, Virginia, and New York were experimentally displaced during migration and non-migration seasons. Those tested in the summer oriented in directions coinciding with routes toward where they were captured (non-migration), while turtles tested during autumn migration oriented southward, consistent with seasonal movements of North Carolina turtles at that time of year. Lohmann and Lohmann (1996 as cited in Gill et al. 2005) concluded that sea turtles’ magnetic sense allows them to use combinations of magnetic field intensity and field line inclination in the ocean to determine direction and position during long-distance migrations.

Magnetic fields generated by subsea power cables may be of sufficient intensity to affect species that are magnetoreceptive and use geomagnetic fields for orientation and migration (CMACS 2003). According to Irwin and Lohmann (2003 as cited in Gill et al. 2005), magnetic orientation in loggerhead turtles can be disrupted by strong magnetic pulses (five brief pulses of 40,000 µT). Data are needed for a more comprehensive list of those species that have magnetic sense, on levels of EMF that can be sensed, and on the cumulative effects of multiple subsea cables.

8.3.1.4 Other Potential Impacts

During wind facility construction, operation, and decommissioning, sea turtles may also be affected by increased turbidity from cable trenching, discharge of liquid waste (e.g. hydraulic fluid), and accidental fuel spills. Oil spills can significantly affect sea turtles' respiration, skin, some aspects of blood chemistry and composition, and salt gland function (USDOC, NMFS and USDOI, FWS 1991). Additionally, artificial lighting can cause disorientation (loss of bearing) and misorientation (incorrect bearing) in hatchling green turtles, and can cause adult females to avoid brightly lit areas on nesting beaches (USDOC, NMFS and USDOI, FWS 1991).

8.3.2 Wave Energy

The potential impacts on sea turtles from seismic site surveys, construction activities (e.g. anchoring wave devices), and decommissioning activities (e.g. removal of pilings) conducted for wave energy are similar to those for wind energy (Section 8.3.1 above). Anchoring of wave devices may include pile driving, and the noise generated may affect sea turtles in the vicinity of such activities. Similarly, if explosives are used during the removal of the pilings, the noise generated may impact sea turtles in the area.

The various types of wave energy devices that would likely be deployed are reviewed in Section 8.1.1.2. Overtopping wave devices are likely to pose the most significant risk to sea turtles, specifically hatchling sea turtles, especially if located off nesting beaches with seasonally high concentrations of hatchlings. Hatchling and juvenile sea turtles are not strong swimmers and may not be able to avoid getting transported (with the waves) into the overtopping reservoir; this could result in injury or death (USDOI, MMS 2007). Juvenile loggerhead sea turtles appear to spend a majority of time in the top 15 feet of the water column (USDOC, NMFS 2009b), which may increase the risk of entrapment in overtop wave devices.

Sound source levels from wave devices are not known, and information about the effects of cumulative source levels of multiple devices are especially needed. The noise during operation of wave devices would be continuous and may potentially cause auditory masking (overlap in frequency between turbine noise and sea turtles' hearing range, making it difficult for turtles to hear in the presence of turbine noise), behavioral changes, and abandonment of habitat. If wave facilities were located in important habitat areas used for feeding and migration, the resultant impact levels would be greater. Additionally, lights on the devices may disorient hatchling sea turtles, causing them to be misdirected away from the currents and sargassum rafts where they live.

Mitigation measures for wave devices include locating the devices at adequate distances from each other and avoiding important habitat areas and sea turtle migration routes. For example, habitats to be avoided include the coast off North Carolina, due to loggerhead hatchlings swimming offshore (from mid-May to mid-August) and the potential migratory pathway for loggerheads in the continental shelf waters between nesting and foraging areas (from Georgia to Cape Hatteras).

8.3.3 Current Energy

The potential impacts on sea turtles from seismic site surveys, construction activities (e.g. anchoring wave devices), and decommissioning activities (e.g. removal of pilings) conducted for current energy are similar to those for wind energy (Section 8.3.1 above). Anchoring of underwater turbines and the associated infrastructure to the ocean floor may include pile driving, and the noise generated may affect sea turtles in the vicinity. Similarly, if explosives are used during the removal of the pilings, the noise generated may impact sea turtles in the area.

The various types of current energy devices that would likely be deployed are reviewed in Section 8.1.1.3. Potential impacts from current energy activities are similar to those from wind and wave project activities. The following two exceptions are unique to current projects: (1) the risk of collision with underwater turbines (for turtles moving horizontally) and (2) changes to local currents.

Collisions with rotor blades pose the most significant threat to sea turtles. Risks may be greatest for newly hatched and juvenile sea turtles, which are not strong swimmers and may not be able to avoid the rotor blades.

Another potential impact of operating a current energy facility is a reduction in current energy and velocity during operation due to structural drag. Hatchlings and juveniles rely on currents to carry them offshore, where they can live among sargassum rafts. Changes in the currents needed to transport hatchlings out to these rafts could affect the turtles' viability. The magnitude of current energy loss and reduction in velocity depends on the technology used, specific design, and spacing of the devices. Additionally, light pollution from lights on current devices may attract turtles.

Sound source levels from current devices are not known at this time, but may potentially cause the abandonment of a habitat since turbine noise during operation is continuous and may cause auditory masking, and/or changes in foraging, or migration movements. Sound source level data are needed, especially the cumulative levels from the entire facility.

8.4 FISH RESOURCES AND ESSENTIAL FISH HABITAT

Fish resources in the Northeast Shelf region could be subject to direct and indirect impacts from the development of offshore alternative energy projects. Both adverse and beneficial impacts could result. The nature and magnitude of effects depend upon project actions and site-specific conditions, and likely impacts vary among species or species groups affected. Potential impacts of greatest consequence to fish include habitat alteration, noise, and electromagnetic fields. Information available for these and other impacts will be reviewed in this section for offshore wind, wave, and current energy facilities.

Potential impacts must be considered for project-specific actions and consequences, but also in the larger context of overall cumulative impacts and stressors to fish resources. Fish in the Northeast region are subject to anthropogenic impacts from overfishing, habitat degradation, and pollution (Buchsbaum et al. 2005). Climate change may also impact the composition of fish communities in the region (Collie et al. 2008). Nonetheless, major declines in fishery stocks over the past 30 years have largely been attributed to overfishing (e.g., Buchsbaum et al. 2005; Aquarone and Adams 2009; Gabriel 1992; NEFSC 2008). Heavy fishing pressure by foreign fleets beginning in the mid-1960s resulted in a collapse of the groundfish fishery by the early 1970s (Buchsbaum et al. 2005). Implementation of the Magnuson Fishery Conservation and Management Act of 1976 coincided with a partial recovery of groundfish stocks during the late 1970s (Buchsbaum et al. 2005). Fishing effort by domestic fleets increased throughout the 1980s and the overall decline in groundfish stocks resumed (Gabriel 1992; Buchsbaum et al. 2005). Overfishing and population declines for many fish stocks continue to this day (Buchsbaum et al. 2005; NEFSC 2008), and system-level changes (e.g., changes in numerically dominant demersal species) associated with overfishing have been reported in the Northeast Shelf region (Link 2007; Steneck et al. 2004).

8.4.1 Threatened or Endangered Fish Species

Two fish species in the Northeast Shelf region are currently federally listed as threatened or endangered species. Shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic salmon (*Salmo salar*) are both federally listed as endangered species. Similar to other fish species, potential impacts to shortnose sturgeon and Atlantic salmon include habitat alteration, noise, and electromagnetic fields. These and other potential impacts will be discussed in sections below for other fish species. Shortnose sturgeon do not use offshore habitat. Adult Atlantic salmon migrate through offshore waters of the GOM en route to foraging grounds off Newfoundland, Labrador, and Greenland. Impacts to salmon passing through GOM waters during feeding migrations could be similar to impacts described for pelagic species below. Both shortnose sturgeon and Atlantic salmon rely primarily on riverine and estuarine habitat, which would not be impacted by offshore alternative energy projects, except potentially by transmission cables. Therefore, activities related to cable placement and the potential consequences associated with electromagnetic fields from subsea power cables are among the key concerns to be considered in areas where populations of shortnose sturgeon or Atlantic salmon exist. Information to characterize these impacts is reviewed below for other fish species.

The level of impact to shortnose sturgeon and Atlantic salmon would be dependent upon project-specific considerations. Due to the population levels of these species, the magnitude of any impacts could be higher than for non-listed species. Nonetheless, compliance with Endangered Species Act regulations should minimize impacts to these species and their habitats.

8.4.2 Other Fish Species

8.4.2.1 Offshore Wind Energy

Based on the likelihood of commercial development in the near future, offshore wind is the primary technology type considered in this synthesis. Many potential impacts from wave or current energy projects would be similar to those described in this section for wind. Several key documents review potential impacts to fish from offshore wind facilities. These include the MMS Worldwide Synthesis (Michel et al. 2007), the MMS Programmatic EIS (USDOI, MMS 2007), and the Cape Wind FEIS (USDOI, MMS 2009).

8.4.2.1.1 Physical Disturbance and Habitat Alteration

Various activities during the pre-construction, construction, operational, and decommissioning phases of an offshore wind energy project would result in physical disturbance and alteration of fish habitat. Installation of meteorological (met) towers during site evaluations; installation of monopiles, foundations, and transmission cables during construction; maintenance activities during operation; removal of project structures during decommissioning; and anchoring and positioning of vessels during all project phases are examples of activities that would disrupt benthic habitat. In addition to the reports cited above, impacts related to physical disturbance and habitat alteration from the development of offshore alternative energy facilities are reviewed and discussed by Gill (2005) and Petersen and Malm (2006).

Disruption of the seafloor could directly impact certain fish species and displace or alter their habitat. For example, tilefish inhabit burrows in soft-bottom habitat, and other species such as sand lance bury themselves within the sediments. Indirect impacts to fish are also plausible. Seafloor habitat disruption and alteration would directly impact benthic invertebrates. (Impacts to the benthos are discussed in Section 8.5.) Benthic habitat in the footprint of project structures would be permanently displaced, and areas disrupted during cable placement could be temporarily defaunated. Hence, indirect impacts to fish could result from changes in the availability of invertebrate prey items.

Physical disruption of soft sediments would also result in turbidity and siltation. Wilber and Clarke (2001) reviewed impacts to fish and shellfish from increased suspended sediment concentrations associated with dredging activities. Based on the mobility of fishes, the exposure duration, and the available refuges in the open-ocean environment, any impacts from turbidity to adult fish are likely to be negligible (Wilber and Clarke 2001). Although most adult fish would avoid this temporary disturbance, life stages of certain species could be impacted. Winter flounder, Atlantic herring, and ocean pout all have demersal eggs, attached to bottom substrates, which are vulnerable to impacts from siltation (USDOC, NMFS 2009c). Resuspension of contaminants within the sediments could increase the magnitude of any impacts from turbidity or siltation.

During the operational project phase, the presence of hard substrates from wind turbine and electrical substation monopiles and foundation structures would represent a long-term displacement of existing habitat with new hard-bottom habitat. Although typically occupying a relatively small footprint, these structures would alter currents and water movement, causing changes to sediment transport and deposition that could further affect nearby soft-bottom benthic communities (Michel et al. 2007).

Perhaps the most significant habitat alteration would be the introduction of artificial reef (Wilhelmsson et al. 2006). Project structures would introduce vertical and horizontal hard surfaces that would likely be colonized over time by fouling communities. Various species of fish that associate with reefs would be attracted to project structures as artificial reefs. This outcome has been observed at offshore wind facilities in Europe, where significantly higher densities of fish have been reported near wind turbine monopiles than near reference sites (Wilhelmsson et al. 2006; Michel et al. 2007). The influence on local fish communities would depend on site-specific conditions such as previous availability of hard-bottom habitat in the project area. Steimle and Zetlin (2000) reviewed biotic communities associated with artificial reef habitats in the MAB, and listed fish species commonly associated with structure. (See Section 8.4.) Such species would likely be attracted to structure from offshore alternative energy facilities.

8.4.2.1.2 Noise and Vibration

The activities listed above that would cause physical disturbance during various project phases would also produce sound that may impact fish. Potential impacts to fish from noise associated with offshore alternative energy projects are considered in the key impact reports listed above (Michel et al. 2007; USDOI, MMS 2007; USDOI, MMS 2009) and reviewed by Wahlberg and Westerberg (2005) and by Vella et al. (2001). Hastings and Popper (2005) and Popper et al. (2004) reviewed the available literature on effects of anthropogenic sound on fish behavior and physiology.

Hearing capabilities in fish range widely among species, although most fish can hear within the frequency range of 60 to 3,000 Hz, with sensitivity to sound levels as low as 50 to 110 dB (Vella et al. 2001). The hearing capabilities and sensitivity of a fish species to noise are dependent upon factors including audible threshold, presence of a swim bladder (fish with swim bladders are more sensitive), size of the swim bladder (larger swim bladders mean higher sensitivity) and coupling of the swim bladder to the ear, and attributes of the otolith system (Vella et al. 2001).

Impacts to fish from anthropogenic sound range from behavioral responses and auditory masking to physiological damage including temporary or permanent hearing loss, or even mortality (Hastings and Popper 2005; Popper et al. 2004; McCauley et al. 2003). The nature of any impacts is dependent upon the level and duration of sound exposures experienced by fishes in the project area. Noise generated by pile-driving activities for installation of met towers or monopiles could result in physiological damage to fish (USDOI, MMS 2007). Hastings and Popper (2005) reviewed the known effects of pile-driving noise to fish. The authors noted the lack of peer-reviewed literature and the general lack of data needed to provide a clear understanding of the issues. Nonetheless, they reported that it was evident that pile -driving noise can kill fish near the source. McCauley et al. (2003) investigated impacts to fish from high-intensity anthropogenic sound produced by air guns used in seismic surveys. They reported extensive damage to ears of pink snapper (*Pagrus auratus*) exposed to operating air guns in a caged experiment, but noted that noise avoidance behavior, typical of fish, may reduce physical damage from high-intensity sound under real-world conditions. The use of explosives for removal of met towers or project structures during decommissioning would also have physiological impacts to fish that, depending on distance from the source, could include mortality (Hastings and Popper 2005).

Offshore wind facilities would also produce low-level noise. Increased vessel noise would occur during all phases throughout the lifetime of a project, and during the operational phase, wind turbines would generate noise. The low-level, constant background noise that may be generated by vessel operation or wind turbine operation could cause *auditory masking*: Biologically relevant sounds (e.g., for predator avoidance, prey location, or communication) could be interfered with by noise generated from project activities (Popper et al. 2004). Behavioral responses (such as avoidance or attraction) to low-level noise may also occur and could interrupt normal feeding, migration, or other activities (Popper et al. 2004). The distance at which fish may hear operating wind turbines is difficult to determine and varies among species (Wahlberg and Westerberg 2005).

8.4.2.1.3 Electromagnetic Field

Offshore wind facilities use subsea power cables to transmit power from individual turbines to an offshore substation, and from the substation to shore. These cables will produce an electromagnetic field (EMF) which may impact fish. An overview of EMFs generated by offshore wind facility cables and mitigation strategies for reducing EMFs is provided in CMACS (2003). Potential impacts to fish from EMFs are reviewed or considered in a number of sources including Gill et al. (2005), Ohman et al. (2007), Michel et al. (2007), USDOI, MMS (2007), and USDOI, MMS (2009).

Electromagnetic fields are composed of E (electric) and B (magnetic fields). E fields are retained within industry standard cables, while B fields are detectable outside the cable. In addition, a B field induces a second electric field, the iE (induced electric) field, which is detected outside of industry standard cables. The intensity of EMF emissions is operation-specific and also varies depending on the cable and on mitigation measures used such as shielding or cable burial (Gill et al. 2005; CMACS 2003).

Electromagnetic (EM) sensitivity has been identified in a number of fish species. Elasmobranchs (sharks and rays) are well known to be electroreceptive, using specialized receptors (ampullae of Lorenzini) to detect electrical fields (Gill et al. 2005). Other electrosensitive species identified by Gill et al. (2005) that occur in the study area included Atlantic salmon and Atlantic cod. Evidence for magnetosensitivity has been reported for a larger number of fishes including the elasmobranchs, several teleost fishes, and fish in the family Scombridae (tunas and mackerels; Gill et al. 2005). The consequences to EM-sensitive species of the presence of EMFs generated by subsea power cables are not well understood (Gill et al. 2005). Many electrosensitive species use electroreception to identify prey, and EMFs may elicit behavioral responses such as attraction or repulsion depending on the species affected and the intensity of the field (Gill et al. 2005). Orientation and navigation capabilities in certain species may also be compromised by EMFs (USDOI, MMS 2009). Monitoring at an offshore wind facility in Denmark has indicated that the migration behavior in some fishes (herring, eel, cod, and flounder) was affected by EMFs (USDOI, MMS 2007). Minor effects have also been demonstrated in studies of the European eel in the Baltic Sea (Ohman et al. 2007). Nevertheless, there is little existing evidence to suggest that fish are affected by EMFs from subsea power cables, and research is needed to address this question (Gill et al. 2005; Ohman et al. 2007; USDOI, MMS 2007).

8.4.2.1.4 Other Potential Impacts

Other impact-producing factors from offshore wind facilities could affect fishes. The introduction of artificial light sources on wind facility structures could result in behavioral responses or changes in prey availability for certain species. Keenan et al. (2007) examined the effects of the artificial light fields on the fish community near two oil platforms in the Gulf of

Mexico. They concluded that fish communities surrounding petroleum platforms likely benefit from artificial light, which allows them to locate and capture prey items, and attracts positively phototaxic prey species. Contaminant discharges from accidental spills of varying magnitude could also represent an impact to fishes (USDOI, MMS 2007). Small amounts of contaminants released in minor spills under normal conditions would not likely represent significant impacts to fish. However, in the unlikely event of a major spill related to a large vessel collision with facility structures, impacts to fish from contaminants could be more consequential (USDOI, MMS 2007).

8.4.2.2 Wave and Current Energy

Many of the impact-producing factors identified for wind power would also be factors for wave and current energy. As with wind projects, key impacts to fish could include habitat alteration, noise, and electromagnetic fields. Artificial light and contaminants from accidental spills would also be potential impacts to fish from wave or current energy facilities. The information to characterize these impacts is reviewed and discussed in the sections above for wind. Hence, only impacts that have not been reviewed in the section above on wind will be discussed below. Key documents that have reviewed impacts to fish from current energy or wave energy facilities include USDOE (2008), Nelson et al. (2008), Michel et al. (2007), and USDOI, MMS (2007).

Reduced water velocities will result from the extraction of kinetic energy by current energy devices (USDOE 2008). Likewise, wave energy will be reduced in the shadow of wave energy facilities (Nelson et al. 2008). These changes to waves and currents could affect fish through changes in the distribution of planktonic eggs and larvae, or through altered sediment transport processes that impact benthic habitat (USDOE 2008, Nelson et al. 2008). In addition, fish could be impacted by contact with moving parts on these devices. USDOE (2008) discusses the possibility that fish could be injured by strike or impingement from rotor blades on current energy devices. USDOI, MMS (2007) notes that certain designs for wave energy devices could result in entrainment, impingement, or entrapment of fish. Certain beneficial impacts may also result. Reduced commercial fishing pressure within the boundaries of an offshore wave or ocean current facility could create a de facto marine reserve that benefits some fish species (Nelson et al. 2008).

Objects floating or suspended in the water column serve as fish aggregation devices (FADs) that attract certain species (Rountree 1989). FADs have long been used by commercial fishers as a highly effective way to attract fish (Rountree 1989). Mechanisms behind the association of fish with floating objects are not thoroughly understood. Many researchers have suggested that certain species use floating objects in some manner that provides protection from predators, but others are skeptical of this hypothesis (Rountree 1989). Regardless of the underlying causal mechanisms, both wave and current energy devices are likely to function as FADs (Nelson et al. 2008; USDOE 2008). Species that may be attracted to project structures would vary depending on location. Rountree (1989) compared fish assemblages associated with various FAD designs in the coastal waters off South Carolina. Several jacks in the genera *Decapterus* and *Caranx* were among the most abundant species recorded; these taxa have also been associated with floating *Sargassum* spp. in the region (Rountree 1989). Jacks are uncommon within the Gulf of Maine

(Collette and Klein-MacPhee 2002) but would likely be among the abundant species attracted to wave and current energy devices deployed in certain areas within the MAB.

8.4.3 Essential Fish Habitat

Essential fish habitat (EFH) has been designated throughout the Northeast Shelf region for a number of demersal and pelagic species (see Section 3.4.3). Potential impacts to EFH from offshore alternative energy facilities would be as described above for habitat alterations that could impact benthic habitat (see Section 8.4.2.1.1) or contaminant releases (see Section 8.4.2.1.4) that could affect EFH for both pelagic and demersal fishes. EFH could also be impacted by other factors reviewed above including the introduction of EMFs from subsea power cables (see Section 8.4.2.1.3).

EFH for demersal fish with a close association to the benthos (where impacts would generally be of a higher magnitude and duration) is more likely to be adversely impacted than EFH for pelagic species (see species profiles and habitat descriptions in Section 3.4.3). Any adverse impacts to EFH would be minimized or mitigated, in part, through additional safeguards resulting from the required consultation with NMFS.

8.5 BENTHIC RESOURCES AND SEAFLOOR HABITATS

The development of offshore alternative energy facilities could directly impact benthic resources in the Northeast Shelf region in both adverse and beneficial ways. The nature and magnitude of effects would depend upon project-specific actions and site-specific conditions. Potential impacts of greatest consequence to both soft-bottom and hard-bottom benthic communities would likely be those related to physical disturbance and habitat alteration. Information available for these and other impacts will be reviewed in this section for offshore wind, wave, and current energy facilities.

Potential impacts to the benthos from offshore alternative energy must also be considered in the larger context of overall cumulative impacts and stressors to benthic resources. Benthic communities in the Northeast region have been subject to anthropogenic impacts from commercial fishing activities, habitat degradation, and pollution (Langton et al. 1994; Buchsbaum et al. 2005).

Impacts related to overfishing and to various fishing methods have been investigated by a number of researchers. Collie et al. (1997) and Hermsen et al. (2003) reviewed impacts from mobile fishing gear to benthic communities in the Northeast region and found significant differences between benthic communities at sites disturbed by bottom fishing and those at undisturbed sites. Steneck et al. (2004) attributed temporal changes in the trophic structure of kelp forests in the Gulf of Maine to overfishing by humans. Using archaeological, historical, ecological, and fisheries data the authors identified distinct, sequential phases during which the species that functioned as apex predators were influenced by human fishing practices.

Sand and gravel mining for beach replenishment is another example of a human activity that directly impacts the benthos. Hobbs (2002) reviewed the environmental consequences and impacts to benthic communities from sand mining for beach nourishment. Additional references that discuss offshore aggregate mining activities in the Northeast region and related impacts to the benthos are listed in Section 3.5.

Impacts to the benthos from pollution and waste disposal have also been reported on. For example, Vitaliano et al. (2007) examined recovery of benthic macrofaunal assemblages following cessation of sewage sludge disposal in the New York Bight.

Invasive species that are introduced through human-mediated transport also have the potential to alter benthic community structure and function (Carlton 2003). Bullard et al. (2007) reviewed the biology, current distribution, and potential threat to marine communities of the nonindigenous colonial ascidian, Didemnum sp. A. The origin of this ascidian is unknown, and it has been undergoing a massive population explosion on both the east and west coasts of the United States. Didemnum sp. A has been widely reported from docks, floats, and piers from Maine to Virginia. Off New England, colonies have been reported from subtidal sites, up to 81 meters bottom depth, including Georges, Stellwagen, and Tillies Banks. Large colonies have been reported from Georges Bank (see also Valentine et al. 2007), and Bullard et al. (2007) cautioned that Didemnum sp. A has the potential to alter marine communities and negatively impact the fishing and aquaculture industries.

8.5.1 Soft-Bottom Benthic Communities

8.5.1.1 Offshore Wind Energy

Based on the likelihood of commercial development in the near future, offshore wind is the primary technology type considered in this synthesis. Many potential impacts from wave or current energy projects would be similar to those described in this section for wind. Several key documents review potential impacts to benthic resources from offshore wind facilities. These include the MMS Worldwide Synthesis (Michel et al. 2007), the MMS Programmatic EIS (USDOI, MMS 2007), and the Cape Wind FEIS (USDOI, MMS 2009).

8.5.1.1.1 Physical Disturbance and Habitat Alteration

Various activities during the pre-construction, construction, operational, and decommissioning phases of an offshore wind energy project would result in physical disturbance and alteration of benthic habitat. Direct impacts to benthos during the various project phases are analyzed in the MMS reports cited above. In addition, impacts related to physical disturbance and habitat alteration from the development of offshore alternative energy facilities are reviewed and discussed by Gill (2005) and Petersen and Malm (2006). These impacts are briefly reviewed below.

In directly affected soft-sediment habitats, physical disturbance would result in partial or complete defaunation due to direct mortality, physical damage, or displacement of organisms. Organisms may be temporarily more vulnerable to predation when they are displaced (Dernie et al. 2003). The magnitude of these impacts and area affected would depend on project activities. During the pre-construction phase, the installation of meteorological (met) towers and the surveys associated with site evaluations could disturb and alter the benthos. Any impacts from these activities would be local and transient. During the construction phase, physical disturbance and habitat alteration would be caused by the installation of monopiles for wind turbine generators and electrical substation platforms and by the installation of subsea power transmission cables. Within the footprint of project structures there would be complete defaunation of the soft-sediment community and long-term habitat alteration. Nearby benthic habitat would be disturbed, and siltation from suspended sediments could produce additional impacts on local surrounding benthos. Vessel operations related to cable placement and monopile installations would also disturb the sediments due to anchoring, anchor cable sweep, or other vessel positioning and stabilization activities (e.g., if jack-up barges are used). During the operational project phase, the presence of project structures would alter currents and water movement, potentially causing changes to sediment transport and deposition that could further affect nearby soft-bottom benthic communities (Michel et al. 2007). Finally, during the decommissioning phase, the removal of transmission cables and monopiles or the conversion of project structures into artificial reef could result in physical disturbance of the benthos, including the damage and destruction of invertebrate organisms.

Turbidity and Siltation

Physical disruption during various project phases would also result in turbidity and siltation, which could further impact nearby benthos. Finer sediments would disperse and cover a larger area of seafloor than would coarser sediments. Larger, motile organisms are less vulnerable to impacts from siltation than are smaller, sessile animals, which may be smothered when buried under sediments, and filter feeders are more vulnerable to turbidity and siltation than are deposit feeders. Wilber and Clarke (2001) reviewed impacts to fish and shellfish from increased suspended sediment concentrations associated with dredging activities. The authors reported that increased concentrations of suspended sediments can have detrimental consequences for benthic fauna including reduced bivalve pumping rates and direct mortality, but these adverse impacts are often associated with long-term exposures. Turbidity associated with offshore wind project activities would be local and transient, and adverse effects may not be detectable depending on the existing environmental conditions. Macroalgae or submerged aquatic vegetation (SAV) could also be impacted by turbidity or siltation (USDOI, MMS 2009). Plants are dependent on sunlight and increased turbidity from suspended sediments could temporarily reduce light levels. The deposition of suspended sediments onto its blades could further reduce a plant's ability to photosynthesize. Thus, turbidity and siltation could reduce productivity and at high levels, over time, could kill plants such as eelgrass (Thayer et al. 1984). Resuspension of contaminants within the sediments could increase the magnitude of any impacts to the benthos from turbidity or siltation.

Benthic Recovery

Impacts to benthic communities from physical disturbance and habitat alteration would likely be relatively local and for the most part transient. Except for areas within the footprint of project structures, repopulation of disturbed substrates would be expected.

Following a physical disturbance, biological recovery is dependent, in part, on the physical recovery of the sediments. For example, conversion of benthic habitat could occur from uneven settling of grains of varied sizes in the sediments covering the buried transmission cables (Dernie et al. 2003). This type of habitat conversion would have greater impacts where sediment particle sizes are mixed that where sediments are homogeneous. The restoration of marine soft-sediment habitats occurs through a range of physical (e.g. currents, wave action) and biological (e.g., bioturbation, tube building) processes (Dernie et al. 2003). In general, physical processes are more important in high-energy environments, while biological processes dominate in low-energy ones.

Rates of recolonization and succession can vary considerably among benthic communities, and are also influenced by hydrodynamic conditions. Hydrodynamic forces largely control overall sediment composition such that coarse, sandy sediments predominate in high-energy environments and silty, muddy sediments accumulate in low-energy environments (Snelgrove and Butman 1994). In high-energy environments repopulation can often be largely attributed to bedload transport of adult and juvenile organisms (Zajac and Whitlatch 2003). Restoration of invertebrate communities in low-energy environments is more dependent upon larval settlement and recruitment and upon adult migration (Zajac and Whitlatch 2003). The nature of these biological processes varies by species and time of year. Therefore, recovery rates are linked to a complex and variable mixture of factors related to environmental conditions, life history and population characteristics, and biotic interactions (Wilber and Clarke 2007; Zajac and Whitlatch 2003).

Full recovery of the benthos could require anywhere from several months to several years, or even longer (Wilber and Clarke 2007; Dernie et al. 2003). Dernie et al. (2003) reported that the fastest biological recovery rates are associated with sandy sediments. The authors argued that the resident fauna in such habitats are adapted to physical disturbance. Many species that are characteristic of sandy sediments are relatively mobile, and bedload transport is an important dispersal mechanism in such dynamic, high-energy environments (Dernie et al. 2003, Zajac and Whitlatch 2003). Nonetheless, Newell et al. (1998, as cited in Wilber and Clarke 2007) reported faster recovery rates for mud habitat (6-8 months) than for sand and gravel (2-3 years). Impacts and recovery times could vary depending on a long list of variables. Wilber and Clarke (2007) reviewed the existing literature on benthic recovery rates following dredging and dredged material disposal. The authors reported that generalizations regarding typical recovery rates for benthic communities are limited by factors including the spatial scale of the disturbance, the timing and frequency of disturbance, and variability in many site-specific physical and biological factors. Identification of "typical" recovery rates is also limited by the variability in sampling methods used to measure recovery and the lack of a standardized definition for "recovery" (Wilber and Clarke 2007).

8.5.1.1.2 Noise and Vibration

The activities listed above that would cause physical disturbance during various project phases would also produce noise and vibration, which may impact certain benthic invertebrates. Although the majority of research into noise impacts to marine animals has focused on mammals, Hastings and Popper (2005) suggest that certain invertebrates (e.g., crabs, lobsters) could also be impacted by noise. Potential impacts to invertebrates from noise are reviewed by Vella et al. (2001) and discussed in Hastings and Popper (2005) and Popper et al. (2004).

Few studies have attempted to measure the potential impacts of noise and vibration on marine invertebrates, and results have suggested little response except when in immediate proximity to a powerful noise source (Vella et al. 2001). Nonetheless, Wardle et al. (2001, as cited in Hastings and Popper 2005), who investigated the behavior of coral reef fish and invertebrates exposed to noise from seismic air guns, found no permanent changes in the behavior of invertebrates on the reef and no indication of any damage to invertebrate organisms. By contrast, Legardère (1982, as cited in Hastings and Popper 2005) reported that long-term exposure (3 months) to noise (30 dB above ambient) resulted in decreases to both growth rate and reproductive rate in the sand shrimp (*Crangon crangon*). However, there is little evidence to suggest that the low-level operational noise from wind turbines or vessel noise would have measurable impacts on invertebrates (Vella et al. 2001). And no adverse impacts to invertebrates are expected from the noise and vibration generated by operating turbines (Vella et al. 2001).

8.5.1.1.3 Electromagnetic Field

Offshore wind facilities use subsea power cables to transmit power from individual turbines to offshore substations, and from substation to shore. These cables will produce an electromagnetic field (EMF) that may impact benthic invertebrates. An overview of EMFs generated by offshore wind facility cables and of mitigation strategies for reducing EMFs is provided in CMACS (2003). Electromagnetic fields are composed of E (electric) and B (magnetic fields). E fields are retained within industry standard cables, while B fields are detectable outside the cable. In addition, B fields induce a second electric field, the iE (induced electric) field, which is detected outside of industry standard cables. The intensity of EMF emissions is operation-specific and it varies depending on the cable and on mitigation measures used such as shielding or cable burial (Gill et al. 2005; CMACS 2003).

Potential impacts to benthic invertebrates from EMFs are discussed in Gill et al. (2005), Michel et al. (2007), and USDOI, MMS (2007). Little is known about EM sensitivity in marine invertebrates. However, the scientific literature provides some evidence of faunal responses to EMFs, and Gill et al. (2005) list crustaceans and mollusks as organisms with potential sensitivity to magnetic fields. The consequences of apparent detection of these fields have not been well-studied in invertebrates. Based on mitigation measures likely to be employed (e.g., shielding and burial of the cables) population level impacts from EMFs are not expected; however, potential impacts to invertebrates from EMFs are largely unknown (USDOI, MMS 2007).

8.5.1.1.4 Other Potential Impacts

Other impact producing factors from offshore wind facilities could affect benthic resources. Operational wastes, discharges, and accidental spills could reduce water quality through the introduction of nutrients or contaminants, potentially resulting in direct impacts to invertebrates (USDOI, MMS 2007). Most impacts related to intentional or accidental discharges would be avoided or mitigated through adherence to procedures that would be required by various statutes and regulations. Also, the small amounts of contaminants released in minor spills under normal conditions would not likely represent significant impacts. Nevertheless, in the unlikely event of a major spill related to a large vessel collision with facility structures, impacts to invertebrate communities from contaminants could be more consequential (USDOI, MMS 2007). Offshore wind facility structures would also interfere with natural lighting. Project structures would block sunlight, creating shade. Due to changes in the Sun's angle with seasons and with the time of day, the location of these shaded areas would constantly shift and little impact on invertebrates would be expected (USDOI, MMS 2009). Wind park structures would also introduce artificial light from navigation lights or other lighting. Artificial light would likely attenuate with depth, limiting penetration to upper surface waters. Little information is available in the published literature to assess the potential impacts of artificial light on marine invertebrates. Keenan et al. (2007) examined the effects from the artificial light fields to the fish community near two oil platforms in the Gulf of Mexico. They reported that the artificial light attracted positively phototaxic invertebrate species, which were subsequently preyed upon by fishes. This could represent an adverse impact for some invertebrates. Nevertheless, given the light intensities and the areas affected, measurable impacts are not expected.

8.5.1.2 Wave and Current Energy

Many of the impact-producing factors identified for wind power would also be factors for wave and current energy. As with wind, the most consequential impact to benthic resources would likely be from physical disturbance and habitat alteration. Noise, electromagnetic fields, artificial light, and contaminants from accidental spills would also be potential impacts to invertebrates from wave or current energy facilities. The information to characterize these impacts is reviewed and discussed in the sections above for wind. Hence, only impacts that have not been reviewed above will be discussed in the section below. Key documents that have reviewed impacts to benthic resources from current energy or wave energy facilities include USDOE (2008), Nelson et al. (2008), Michel et al. (2007), and USDOI, MMS (2007).

Reduced water velocities would result from the extraction of kinetic energy by current energy devices (USDOE 2008). Likewise, wave energy would be reduced in the shadow of wave energy facilities (Nelson et al. 2008). These changes to waves and currents could affect invertebrates through changes in the distribution of macrozooplankton including the planktonic eggs and larvae of benthic invertebrates (Nelson et al. 2008). Changes to hydrodynamic conditions could also result in altered sediment transport processes, which could impact benthic habitat (USDOE 2008; Nelson et al. 2008). In addition, invertebrates could be impacted by contact with moving parts on wave or current energy devices. USDOE (2008) discusses the possibility that marine organisms could be injured by striking or being impinged upon rotor blades of current energy devices. USDOI, MMS (2007) notes that certain designs for wave energy devices could result in entrainment, impingement, or entrapment of invertebrate species.

Nelson et al. (2008) also discusses potential impacts related to shell mounds. Shell mounds could accumulate on the seafloor beneath project structures over time as fouling organisms (often mussels in the genus Mytilus) are removed from wave or current energy devices during regular maintenance. These mounds of shell material, sediments, and debris could cover and alter the benthic habitat in the immediate vicinity of project structures.

8.5.2 Hard-Bottom Benthic Communities

Hard-bottom benthic communities could be impacted by many of the same potential impact-producing factors from offshore alternative energy that are described above for soft-bottom communities. During various project phases, impacts including physical disturbance, habitat alteration, noise, electromagnetic fields, artificial light, altered currents and sediment transport, and contaminants from accidental spills could also impact hard-bottom benthos in the direct vicinity of project activities. Information available to characterize these impacts is reviewed in the sections above. The following section will review considerations unique to hard-bottom communities.

Natural hard substrate, which is less common than soft sediments in the offshore areas throughout much of the Northeast Shelf region, presents certain difficulties in construction. Therefore any unique hard-bottom communities on natural substrates would likely be avoided most of the time when offshore alternative energy projects are sited. During the operational project phase, the presence of hard substrates from structures such as foundations, anchors, and monopiles would often represent a long-term displacement of existing habitat with new hard-bottom habitat. These structures would in many cases provide substrate for hard-bottom benthic communities where little such habitat exists. Hence, one of the most important consequences to benthic communities from an offshore alternative energy facility could be the introduction of an artificial reef-like substrate (Wilhelmsson et al. 2006). This could represent a beneficial impact to certain benthic invertebrates. Project structures would introduce vertical and horizontal hard surfaces that would likely be colonized over time by fouling communities. This outcome has been observed at offshore wind facilities in Europe, where fouling communities have colonized wind turbine monopiles (Wilhelmsson et al. 2006; Michel et al. 2007).

Biofouling would occur as sessile benthic organisms that require a hard substrate attached themselves to the underwater surfaces of project structures. The presence of structure- forming benthos such as algae or mussels would then attract motile organisms seeking refuge or feeding opportunities. Fouling communities over time could include sessile organisms such as barnacles, mussels, bryozoans, and tunicates; and motile forms such as sea stars, gastropods, amphipod, isopod, and decapod crustaceans. Greene and Grizzle (2007) investigated the ecological succession of fouling communities on open ocean fish cages in the western Gulf of Maine. The authors noted significant seasonal differences in community parameters (density and biomass), but the blue mussel, *Mytilus edulis*, was the dominant organism in most deployments. Steimle and Zetlin (2000) reviewed biotic communities associated with artificial reef habitats in the MAB, and listed invertebrate species commonly associated with structure (see Section 3.5). Such species would likely colonize structure from offshore alternative energy facilities. Nelson et al. (2008) points out that artificial hard structure may provide habitat for unwanted, invasive species.

The influence of introduced hard substrate on local benthic communities would depend on site-specific conditions such as previous availability of hard-bottom habitat in the project area. Although steel and concrete project structures would likely lack the surface heterogeneity and chemical composition to ultimately support the diverse communities associated with natural rocky reef, discarded steel and concrete have often been used to construct artificial reefs (Steimle and Zetlin 2000). The quality of project structures as artificial reef could be strongly influenced by the use of anti-fouling paint or coatings applied to their surfaces (Petersen and Malm 2006).

Fouling communities that colonized wave or current energy devices could be damaged or destroyed during periodic maintenance cleaning (USDOE 2008; Nelson et al. 2008). Sessile organisms would likely be killed, while some motile organisms may simply be displaced. Additional physical damage and disturbance to these communities would occur during the decommissioning phase of a project when structures may be removed. Some project structures may also be converted to permanent artificial reef during decommissioning.

8.6 AREAS OF SPECIAL CONCERN

The Northeast region contains a number of areas of special concern to biological resources. This includes areas that are currently protected under legislation or regulations, and other areas of particular ecological significance that are not currently designated for protection. These areas could be exposed to certain impacts from offshore alternative energy facilities. Areas of special concern, most of which fall under the definition of Marine Protected Areas (MPAs), are discussed in detail in Section 3.6. MPAs include the following: National Marine Sanctuaries (NMS), National Wildlife Refuges (NWR), National Estuarine Research Reserve System (NERRS), National Parks, and estuaries within the National Estuary Program of the Atlantic. MPAs within the northeast region that have been formally recognized are listed in Table 3.10.

8.6.1 Potential Impacts

Potential impacts to biological resources from offshore wind, wave, and ocean current energy facilities are detailed in earlier sections of this report, and the information available to characterize those impacts would be the same for areas of special concern. Hence, this section provides a just a brief discussion of considerations specifically relevant to areas of special concern.

MPAs have mechanisms in place for the reduction or avoidance of potential impacts. Section 388 of the Code of Federal Regulations (CFR) prohibits alternative energy leasing in any area of the Outer Continental Shelf (OCS) within the exterior boundaries of any unit of the National Park System, National Wildlife Refuge System and National Marine Sanctuary System and any National Monument (43 USC 1337 [p] [10]; USDOI, MMS 2007). Each MPA's designation (listed in the CFR) also contains language that restricts and/or prohibits energy development-related activities such as disturbance of, construction on, or alteration of the seabed; exploration for, development of, or production of oil, gas, or minerals; the disturbance of marine mammals, seabirds, or sea turtles; operation of aircraft in certain zones; use of personal watercraft; mineral mining; discharge of materials; and anchoring of vessels (USDOC, NOAA 2009).

Despite the limitations described above, potential impacts to MPAs could stem from activities that disturb habitat or affect biological resources within the protected areas, or that affect other values for which the area of concern was established, such as cultural or historical values (USDOI, MMS 2007). Potential impacts to biological resources that could occur within MPAs collectively include the types of impacts discussed below for the SBNMS.

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary

The SBNMS is the largest federally protected MPA in the northeast region; biological resources within this sanctuary include invertebrate organisms, fish, seabirds, sea turtles, and marine mammals. This sanctuary has been well-studied and provides some of the most complete data sets for biological resources in the northeast region (USDOC, NOAA 1993; USDOC, NOAA 1995; USDOC, NOAA 2006; NMSP 2007; USDOC, NOAA 2008; SBNMS 2009). Federally listed species that have been observed within SBNMS waters include the endangered Atlantic or Kemp's ridley sea turtle, the leatherback sea turtle, and seven species of endangered whales (blue, fin, humpback, sei, beluga, North Atlantic right, and sperm whales) (USDOC, NOAAS 2008; SBNMS 2009).

Permitting limitations would preclude actual installation of most physical structures (USDOC, NOAA 2009); however, the potential for increased boat traffic from projects sited nearby could result in higher noise levels, higher collision risks, and increased risk for accidental spills of hazardous materials (Michel et al. 2007). Placement of minimal types of associated items such as transmission cables or attachment gear could also result in potential impacts (Michel et al. 2007). Such project activities could result in physical disturbance of habitat, sediment suspension and redistribution, electromagnetic fields from transmission cables, noise, and introduction of artificial substrate. Potential impacts to invertebrates, fish, birds, sea turtles and marine mammals could include habitat alteration or disturbance; collision or entanglement risks; and behavioral changes such as displacement, disorientation, or avoidance (Michel et al. 2007).

Other Areas of Special Concern

In addition to MPAs, other areas of special concern in the northeast region include areas of particular ecological significance that are not currently designated for protection. Detailed analyses of potential impacts to such areas would be conducted as part of any site-specific permitting process. Considerations regarding impacts to these areas would be as discussed for individual biological resources, and would vary based on project-specific activities and site-specific conditions.

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9. CHEMICAL OCEANOGRAPHY

This section addresses the direct, indirect, and cumulative impacts of offshore energy technologies that may happen during site surveying, construction, operation, and decommissioning of alternative energy facilities to the chemicals and chemical processes that occur along the Atlantic Outer Continental Shelf (OCS).

9.1 OFFSHORE ENERGY TECHNOLOGY OVERVIEW

9.1.1 Site Characterization

The process of selecting appropriate sites for offshore energy facilities would require a suite of testing and sampling activities (characterization surveys) to determine the local and regional depth contours and sediment types. The information gathered from the tests and samples is factored into selecting the type of structure and the corresponding foundation, as well as identifying preferred routes for the underwater cables that carry electricity between towers and back to shore (Hiscock et al. 2002). The sediment sampling would necessitate the use of work boats and ships. The process of anchoring the vessels and removing anchors would cause intermittent disturbance of the seafloor, with movement of sediment into the water column (USDOI, MMS 2007).

The site characterization surveys are likely to involve sediment coring, geological surveys, and geophysical surveys. Geophysical surveys are unlikely to cause impacts, but sediment coring and ecological monitoring would cause temporary disturbance of the seafloor and introduction of sediment and associated material into the water column. To the extent that sediment samples are collected by well drilling equipment that uses drilling fluids, the disposition of the used drilling fluids and the sediment core material itself could cause short-term impacts to chemical resources (USDOI, MMS 2007).

Each proposed wind park may install a meteorological tower to collect wind speed and direction data and other weather-related information prior to facility installation. If construction of the tower uses a foundation, sediment will likely be introduced into the water column for the period of construction (USDOI, MMS 2007).

9.1.2 Construction

The types of impacts anticipated during a construction phase are similar to those described for the site characterization phase. Because a construction phase of a project would involve more vessels for longer periods of time than the site characterization phase, there would be a potential for larger or more frequent releases of oil or other chemicals found on the vessels through bilge discharges, leaks, or oil spills. Additionally, there will be increased air pollution from the vessels' engines. Vessels traversing the area and anchored during the construction phase will be an added source of contaminants associated with burning fossil fuels where the activity is occurring. The vessels would most likely be anchored for longer periods of time or use more significant anchoring structures (e.g., pilings or jack-up rigs) to allow preparation and installation of facilities (Hiscock et al. 2002).

For the next 5 to 7 years, facilities in water depths of less than 15 m (50 ft) are likely to be mounted on towers supported by steel monopile foundations. The monopiles are hammered, drilled, or vibrated into the seabed. The installation process will temporarily disturb some sediment. If larger steel or concrete foundation structures are utilized, the excavations required for the foundation will occupy tens to hundreds of square meters of seafloor area and will be drilled tens of meters deep into the sediment (Elcock 2007). These types of foundations will disturb and displace more of the sediment than monopile foundations would (USDOI, MMS 2007).

If the area being considered has sediments that are already contaminated, the construction activities will resuspend the sediments and cause some of the contaminants to enter the water column.

If the process of preparing the foundation involves rotary well drilling equipment that uses drilling fluids, the disposition of the used drilling fluids and the drilled material itself could impact chemical resources. The volume of drilled material will be substantially greater than the sediment cores collected in the site characterization phase. Because the foundations will be shallow holes compared to oil and gas wells, drillers should be able to use environmentally friendly water-based drilling fluids that pose minimal water quality impacts or use drilling techniques that do not require drilling fluids (USDOI, MMS 2007).

During installation of the infrastructure, the towers may be fastened into the foundation with cement. Excess cement could be released to the seafloor or water column. Installation of the alternative energy technologies could involve minor releases of lubricants, solvents, or other chemical products. Unless containers of materials are accidentally spilled, the quantities of these released through normal operation should be very small. Cables will be installed by jet plowing, which will create some disturbance along the cable corridor (USDOI, MMS 2007).

9.1.3 Operation

Once the offshore energy facilities are in operation, they are likely to pose only minor impact on chemical resources. Discharges are not anticipated, but if they do occur, they would be regulated under National Pollutant Discharge Elimination System (NPDES) permits (USDOI, MMS 2007).

The static structures of offshore facilities will cause turbulence in the water column as tidal currents flow around them, modifying the local area's natural mixing capabilities. Modification is likely to include a diminished pycnocline, allowing water from depths to enter photic, hence productive, waters. Scouring around foundations could release sediment and the chemicals associated with it into the water column (USDOI, MMS 2007).

Antifouling products will be necessary to inhibit biological growth on the structures. Typically, chemicals toxic to organisms (biocides) are used in the coatings, thereby preventing colonization. Antifouling products are generally designed to be used on a surface that has a water flow across it, commonly a ship's hull. The water movement would be different for a moored facility and because the products need to be reapplied every few years there could be a legitimate concern for bio-accumulation. There are currently no monitoring results available assessing the actual impacts to chemical resources at existing installations (USDOI, MMS 2007).

Some offshore energy technologies contain lubricating oil and various oils or hydraulic fluids. If a wind park utilizes a central electric service platform (ESP), that platform may house transformers that contain large reservoirs of oil. It is unlikely, but conceivable, that some of that oil could gradually leak out into the sea. The tower and turbine structure may need periodic painting or other maintenance. Through the maintenance activities, minor amounts of paint, solvent, lubricant, or other chemicals could enter the water column (USDOI, MMS 2007).

There is some possibility for chemical resource impacts that are not directly related to facility operation. Instead the impacts would be related to the presence of the structures in the sea. A wind facility containing tens to hundreds of towers presents greater opportunity for collisions by vessels that attempt to navigate between the towers (Hiscock et al. 2002). To reduce this potential impact, institutional controls may be applied to exclude commercial vessels from the area. If commercial vessels are allowed in the area and collisions occur, substantial releases of oil and other chemicals are possible (USDOI, MMS 2007).

9.1.4 Decommissioning

Decommissioning is likely to involve complete removal of structures to 4.6 m (15 ft) below the seafloor. In that case, chemical resource impacts would be related to vessel operations, material dislodged from the structure during removal, oil leaks from wind facility nacelles during removal, and sediment resuspension during the removal of foundations and electrical cables (USDOI, MMS 2007).

9.2 POTENTIAL IMPACTS ON WATER QUALITY PROCESSES

9.2.1 Nutrients

Alternative energy technologies have the potential to indirectly affect nutrient concentrations and processes in the water column. The changes in current flow around the foundations and moorings, modifying near- and far-field turbulence, could change the local area's natural mixing capabilities, affecting nutrient distribution by disrupting the pycnocline and mixing the deeper nutrient-rich waters with surface waters. The modified nutrient profile of the near-field area may impact the surrounding pelagic habitat by changing biological assemblages and productivity. The extent to which this occurs is not addressed in the literature and additional information may be required for the impact on the nutrient resource to be assessed accurately.

Disturbance of the bottom during surveying and construction and scouring during operation may release sediment and nutrients into the water column. (Lohrer and Wetz 2003). Generally, offshore waters will be less sensitive than inshore water bodies to sediment disturbances containing nutrients (Johnson et al. 2008), so in the absence of compelling information the impact is considered likely to be minimal.

9.2.2 Dissolved Oxygen

Disturbance of sediment with high organic content can result in oxygen reduction (hypoxia) or even anaerobic conditions (anoxic) on the bottom and overlying waters, particularly during periods when strong thermoclines are present (Kurland et al. 1994). Structures have the potential to minimally affect dissolved oxygen concentrations in much the same way as they do the nutrients. During construction, resuspension of organic matter may increase productivity in the near-field to the extent that oxygen levels could be measurably decreased. However, research has indicated that reductions in dissolved oxygen levels during offshore sediment disposal are not appreciable or persistent in the general sediment classes found in the northeast region (USDOD, ACE 1982; Fredette and French 2004; USEPA 2004). The physical characteristics of sediment disposal will be similar to those of sediment displacement and hence the effect on oxygen will likely be minimal.

9.2.3 Carbonate System Chemistry and pH

Alternative energy technologies are not expected to directly affect the natural carbonate system in the water column. There is a potential to affect CO_2 release by respiration if the biotic assemblages change due to the change in nutrient dynamics, but no literature was found to address such changes. More information is needed to accurately identify the impact that facilities will have on pH and the carbonate system.

9.2.4 Trace Metals

Trace metal resources in the water column are likely to be only minimally impacted by the construction, operation, and decommissioning of offshore energy structures. Disturbance of sediment areas which have been subjected to anthropogenic pollution deposition may have minimal to moderate impacts due to the release of harmful chemicals during construction and decommissioning of facilities (Pearce 1994). Site-specific information would provide data on whether trace metals are an issue, as the information in the reference database only specifies known dump sites.

9.2.5 Redox Chemicals

The concentration of dimethyl sulfide (DMS), which generally follows a pattern similar to primary production, may experience a localized increase due to an increase in available nutrients. The impact is likely to be negligible to minimal, but assessment is difficult because no measurements of DMS are in the reference database.

Carbonyl sulfide is thought to be the product of sulfide reduction and organic matter decomposition (Cutter and Radford-Knoery 1993). Disturbances in the sediment will likely cause minimal impacts and the impact to concentrations in the water column is likely to be negligible.

9.2.6 Trace Gases

Trace gas profiles of the ocean may be affected by alterations in mixing due to current modification. However, there was no literature found pertaining to the Mid- and North Atlantic continental shelves to resolve concentrations and subsequently to assess if the impact would be significant. It is most likely that any impact would be negligible to minimal.

9.2.7 Radionuclides

Radionuclides in the water column would not be affected directly by the construction of alternative energy technologies. Excess sediment in the water column may scavenge more radionuclides, but to an extent that depends heavily on many factors. These factors are outside of the chemistry of the environment and include the sediment concentration in the water column and ocean currents. Impacts on radionuclides will most likely be negligible to minimal.

9.2.8 Organic Chemicals

Organic matter, including hydrocarbons, will potentially be released from the sediment by construction activities. During operation, alteration in the currents moving around foundation structures may cause bottom scouring and the disturbance of bottom water rich in organic matter. This organic matter will add to the organic material already in the water column, thereby impacting it. The impact is likely to be negligible to minimal, with the most impact occurring during the major periods of sediment disturbance (from construction), and negligible impacts during the operational life of the structure.

9.2.9 Density (temperature and salinity)

Density is discussed in the Physical Oceanography Section 2.4.

9.3 POTENTIAL IMPACTS ON SEDIMENT RESOURCES

9.3.1 Nutrients

Nutrient resources in the sediment will be released during construction of alternative energy technologies. Disturbance of sedimentary processes such as denitrification would be local and not extend to the far-field environment. Adjacent to the foundation structures, sediment scouring by tidal current may cause release of additional nutrients. Nutrient sediment pool and denitrification will be impacted in the immediate vicinity of structures as sediment is disturbed. The impacts will become minimal to negligible progressively further away from structures. Site-specific information should be gathered to accurately assess impacts on the sediment nutrient pool.

9.3.2 Dissolved Oxygen

There is typically little oxygen in the sediment and the waters directly above it because decomposition of organic matter depletes oxygen. Disturbance of the water column and sediment boundary will mix oxygen-rich water into the sediment and bottom water. This will occur only in the immediate vicinity of the facilities, so the impact will likely be minimal. If productivity of the surface waters increases due to nutrient releases, there will be a decrease in oxygen at the bottom due to the increase of organic matter settling at the sediment. More information is needed to assess whether this is of particular concern.

9.3.3 Trace Metals

Heavy metals are sequestered by acid volatile sulfides (AVS) and the total organic carbon (TOC) fraction of marine sediments (USEPA) 2005). Bioavailability is governed by an excess of AVS concentrations relative to the metal concentrations as normalized by TOC (USEPA 2005). Sand and gravel sediments typically contain low TOC and AVS concentrations. Where there is a prominent source of metals, such as at dump sites, coarser sediments could release such contaminants when disturbed. More information is needed to assess how concentrations are affected and what the impact would be on metals in sediment with high AVS and TOC concentrations.

9.3.4 Redox Chemicals

The redox chemistries of the sediment will be impacted by sediment disturbance. The impact will likely be only local and minimal. The presence of oxygen will cease redox chemical activity locally and temporarily. The impact will be dependent on the size of the project. It is reasonable to assume these processes will resume but there is no reference to support this supposition.

9.3.5 Trace Gases

There is the potential for release of trace gases from the disturbance of sediment associated with construction and tidal scouring. There is no literature to assess what gases may be released or their impacts but it is reasonable to assume that impacts would likely be minimal because of the relatively short time spans and small spatial scales involved.

9.3.6 Radionuclides

Radionuclides in the sediment will be released back into the water column when sediment is disturbed. Once in the water column, radionuclides will settle back out with the sediment. Since radionuclides are primarily used as tracers, there is a potential to affect the sediment record downstream from the structure.

9.3.7 Organic Chemicals

Organic pollutants are generally transported to the sea through atmospheric deposition with augmentation by sediment resuspension and export from coastal areas. Once in the water column they tend to attach to particles and settle to the sediment.

The predominant sediment type in the study area is sand. A summarization of the geological Section 4.2.2 which describes sediment types in the study area follows. The surficial sediments in the Gulf of Maine consist of predominately fine-grained materials, ranging from sandy to silty clays as a result of fluvial deposition from glaciation. In Massachusetts Bay the predominant sediment type is sand and gravel with ridges of boulders underlain by coastal plain erosion remnants and glacial till. The surficial sediments along the Long, Block, and Rhode Island Sounds vary from gravel to fine-silty clays. Along the New Jersey shelf grab samples indicate that the surficial sand sediments are composed primarily of well-sorted medium to coarse sand with significant shell content (Goff et al. 2004). The predominant sediment type in the Mid-Atlantic Bight is sand. This sand is the product of bedrock weathering and cross-shelf sediment transport from coastal rivers or storm activities. The sediment type that the organic pollutants may reside in is a controlling factor of the toxicity of those organic pollutants.

Organic pollutants such as polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are sequestered in the TOC fraction of sediments (USEPA 2000; USEPA 2003a; USEPA 2003b; USEPA 2003c). For pollutants like PAHs, the ratio of the concentrations of these contaminants to those of the fractions governs bioavailability and hence toxicity (USEPA 2003a). Sand and gravel sediments typically contain low TOC concentrations. Since most offshore sand and gravel deposits do not have prominent nearby sources of pollutants, these deposits are generally low in contaminants (International Council of Exploration of the Sea (ICES) 1993; Pearce 1994). The disturbance of sand and gravel material typically will not release high levels of contaminants. However, extraction of material where fine material accumulates and where anthropogenic pollution has been deposited is more likely to release harmful chemicals during excavation (Pearce 1994).

In the Gulf of Maine, the majority of PAH compounds are widely distributed, with total concentrations ranging from 10 to 512 ppb (dry weight). These values are an order of magnitude lower than observed values in the coastal zone, but greater than those on Georges Bank. The geographic extent of PCB contamination in the Gulf of Maine has detectable levels at concentrations ranging from trace amounts to 0.13 ppm (dry weight) (Larsen et al. 1985). Dioxins are present in all sedimented areas of Casco Bay, ME. The concentrations were highest near potential input sources.

Organic matter in the sediment will be released by activities resulting in sediment disturbances. The particulate organic matter will settle back to the sediment quickly after it is disturbed but dissolved organic matter will linger in the water column longer. The newly dissolved organic matter will likely increase primary production but to what extent and for how long is not known.

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10. GEOLOGICAL OCEANOGRAPHY

This chapter examines the potential impacts of the geological oceanography of the U.S. Atlantic Coast on alternative energy development. Primarily this chapter will focus on how the geology, sediment transport, and potential geohazards affect alternative energy foundations (e.g. monopile foundations). For a description of the resources associated with geological oceanography along the Atlantic Continental Shelf (ACS) refer to Chapter 4 of this report.

The Atlantic Coast is a wide, flat, passive margin with a relatively static sediment transport regime, and as such the siting and placement of offshore foundations (e.g. gravity structures and piles) would not be expected to have an impact on the geological oceanography of the region. In general, the siting of potential alternative energy development is governed by other factors (e.g. wind, current speed, and socioeconomic factors (DNV 2007; API 2003; and API 2007) and not regional geology. However, the regional geology will impact the design, installation, and cost of foundation systems. Thus, a detailed geotechnical investigation is required to fully assess the impacts of the geology on foundation design and should be performed after initial sites have been identified; therefore only general statements concerning potential impacts are contained herein.

There are two major design guidelines for the construction of offshore foundations that relate to wind turbine foundations. The Det Norske Veritas (DNV 2007) is the current European design standard for offshore wind turbine structures, while the American Petroleum Institute (API) (2003; 2007) is the United States design standard. Both of these standards state that a detailed subsurface investigation is required to evaluate:

- Sediments for adequate bearing strata
- Soil-structure interaction
- Soil reactions on the foundation

Specifically the sediments must be satisfactory for the following:

- Bearing capacity
- Sliding
- Overturning
- Pile pullout
- Large settlements and displacements

10.1 BATHYMETRY

The ACS has gentle bathymetric slopes, with typical inclinations of less than 4 degrees, with most of the shelf region having a slope of less than 0.02 degrees (Goff et al. 2004; Locat et al. 2003; Nordfjord et al. 2005; Divins and Metzger 2008). Additionally, the shelf is a wide margin with few surficial geologic structures that significantly impact the bathymetry of the region. As such the general bathymetry of the ACS is suitable for alternative energy development.

10.2 MARINE GEOLOGY

The DNV (2007) and the API (2003, 2007) specifically state that a detailed subsurface investigation is required for the design of offshore foundations and that some geological structures (e.g. buried erosion channels with soft infill material) require significant design considerations. However, within the ACS only a few geologic structures (e.g. Block Island Valley and Hudson Shelf Valley) present potential impacts for alternative energy foundation placement. These structures do not preclude the possibility of alternative energy development; rather, compared to the flat regions of the ACS, these locales require more detailed investigations and designs, which may adversely affect the cost. Sand ridges and ribbons (Duane et al. 1972; Goff et al. 2004) do not affect the siting or cost of potential structures as these geologic structures are not considered permanent (i.e. they are migratory structures) and are not included in foundation design capacity calculations (DNV 2007).

Sediments are very rarely homogeneous with depth (Terzaghi et al. 1996) and as such the true capacity cannot be determined simply from surficial data. The DNV (2007) and the API (2003; 2007) note that due to the nonhomogeneity laboratory and in situ testing is required to develop realistic strength profile for design considerations. However, presumptive bearing capacities (Ooi et al. 1991) or strength properties can be utilized to determine a rough estimation of a site's potential bearing capacity. A range of such presumptive strengths was utilized in Grilli et al. (2009) to evaluate the stability of the northern U.S. Atlantic Slope.

Sediment types and corresponding strength parameters can have a significant impact on the siting of alternative energy structures (DNV 2007; API 2003; API 2007; Terzaghi et al. 1996; Holtz and Kovacs 1981; Ooi et al. 1991; Pakowski 2004). For example, cohesive (i.e. clay) sediments will typically exhibit higher degrees of settlement and lower bearing capacity than cohesionless (i.e. sands and silts) sediments. Thus, foundations in cohesive sediments are typically larger, in both diameter and pile length, and as such are more costly. The terminal moraines in the New York Bight can yield high quality (i.e. increased bearing capacity) bearing strata. However, terminal moraines can contain boulders, up to several meters in diameter, making installation difficult and potentially increasing costs. Typically shallow sound bedrock is the ideal medium for pile foundations for bearing capacity, prevention of sliding and overturning of the pile, and minimal settlements (Terzaghi et al. 1996).

The sediment type, profile, and strength, may be adequate for resistance for bearing capacity but may not provide adequate support for lateral forces (e.g. wind, waves, and currents) resulting in excessive lateral deflections (DNV 2007; API 2003; API 2007; Terzaghi et al. 1996; Holtz and Kovacs 1981; Ooi et al. 1991) or structural failure. The magnitude of such deflections is dependent on (1) the magnitude of the loads and moments applied to the foundation, and (2) the lateral resistance capacity of the sediment. Typically cohesive and loose, cohesionless sediments are more prone to excessive lateral deflections than are dense sediments (Ooi et al. 1991; Terzaghi et al. 1996; API 2003; DNV 2007). However, due to the variability of sediments, not only between sites but also within each site, the lateral capacity of offshore foundations must be evaluated on a site-by-site basis.

10.3 SEDIMENT TRANSPORT

Sediment transport along the ACS would not be affected by the placement of alternative energy foundations, as no known significant changes to the directionality of the current occur from pile placement or scour mitigation measures (e.g. riprap or artificial sea grass). However, the construction of protective offshore structures (e.g. breakwaters, groins, and jetties) does have significant impact on sediment transport on both a local and a regional scale (USDOD, ACE 2008).

When a foundation is placed in an offshore environment, substantial localized changes occur to the steady currents and passing waves (Sumer and Fredsoe 2002; DNV 2007; USDOD, ACE 2008). These changes create increased localized bottom stresses, which create local scour effects. The extent of these effects is a function of the foundation dimensions and sediment properties. Once the depth of potential scour is determined, the contribution of any sediment above that depth to resist loads is ignored (API 2003; API 2007; DNV 2007). Estimation of the depth of potential scour is more important in areas with cohesionless sediments, as these sediments are more prone to scour than are cohesive sediments (Sumer and Fredsoe, 2002).

10.4 GEOHAZARDS

The construction of foundation systems for alternative energy projects poses a negligible threat to the stability of the continental shelf, as the ACS bathymetric slopes are extremely mild. To generate slope failures, one or more of the following conditions are required: steep slopes, liquefiable sediments with large enough seismic trigger, high pore pressures above hydrostatic conditions causing a reduction in sediment strength or increase in applied load (i.e. construction of an offshore platform or foundation) (Terzaghi et al. 1996; DNV 2007; Duncan and Wright 2005). In the latter case, the expected loading from an offshore foundation is negligible compared to the estimated loading required to generate a failure under static conditions for mild slopes like those along the ACS.

The primary geohazard along the U.S. Atlantic Coast is seismic activity. The degree of seismicity increases as the distance to seismic sources (e.g. Quebec, Canada, and Charlestown, SC) decreases (USDOI, GS 2008). Thus, the greater the seismic hazard the greater the impact on offshore foundation design. Seismicity can increase the size and design cost of the foundation substantially, especially in regions where there is a high degree of liquefaction susceptibility (DNV 2007; API 2003; API 2007; Ooi et al. 1991; Terzaghi et al. 1996; Youd et al. 2001).

Liquefaction is a phenomenon that affects cohesionless sediments and is typically restricted to depths of up to 30-mbsf (meters below sea floor). Additionally, regions that have loose, cohesionless sediment or elevated excess pore pressures are more susceptible to liquefaction (Youd et al. 2001). While liquefaction does not play a significant role in the initial siting of offshore structures, it can have an impact on the final foundation design (DNV 2007; API 2003). However, as the ACS is a passive region, it is expected that few sites are susceptible to increased liquefaction potential. Only a detailed site investigation can determine the extent of a specific site's of liquefaction susceptibility.

Tsunami generation is primarily influenced by the quantity of rapidly displacement water within the water column and the depth of the water column (Grilli et al. 2009). However, slow displacement of water volume will not generate tsunamis. As such the water displaced by offshore foundations is neither great enough in volume nor moving fast enough to generate tsunami effects. Further, there are no known cases where offshore pile installation has resulted in the generation of a tsunami wave. The tsunami hazard from naturally-occurring tsunami sources is very low (Grilli et al. 2009; Geist and Parsons 2009) and would have negligible influence in the siting of alternative energy development.

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11. SOCIOECONOMIC IMPACTS

11.1 ECONOMIC IMPACTS

A large body of socioeconomic research regarding wind facilities and specifically offshore wind facilities has been conducted in the United Kingdom, Denmark, Sweden, Germany and the Netherlands. European countries have had years of experience in the development, installation and maintenance of offshore wind projects, and while the technological and natural environmental aspects of these projects have attracted more attention, there have been some significant studies regarding tourism, attitudes, economic impacts, and public participation. In addition to scholarly research, there are numerous studies conducted by organizations such as the European Wind Energy Association, and independent surveys of local residents that may or may not be transferable to the larger universe. Most academic research in the socioeconomic area has focused on public involvement and planning practices.

Since the United States currently has no operational offshore wind facilities, existing socioeconomic research in this country has focused on attitudes and opinions, public participation, regulatory issues and economic projections. Somewhat more research has been conducted in regard to land-based wind projects, but the utility of these findings in identifying and quantifying offshore impacts is questionable (Northwest Economic Associates 2003).

The following sections will address what has been learned from prior studies, and what remains to be learned in order to facilitate the introduction of offshore wind as an alternative energy source. In the case of socioeconomic issues, there is much to be learned. For one thing, these issues have not been as important as the immediate aspects of technical development, siting, permitting and environmental impact, and, in the United States at least, research in this area is relatively new. Secondly, human beings are not easy to study—particularly when they are confronted with hypotheticals rather than reality. Their actions may not always be consistent with their expressed beliefs, making interviews and surveys an incomplete basis for determining project implementation.

This section, therefore, poses the questions: What can be learned from socioeconomic research conducted in Europe and the United States? What issues are unique to the United States, and therefore require additional inquiry? What socioeconomic aspects of offshore wind energy remain to be explored?

At this time, offshore wind installations are in various stages of planning for Massachusetts, Long Island, New Jersey, Delaware, Virginia and North Carolina. While each of these areas has its own unique features, there are also some general characteristics that can form the basis for overall analysis. However, socioeconomic investigation that is targeted to specific areas will still be necessary to complete the planning process.

11.1.1 Employment

The development of wind facilities generates temporary employment during the construction phase and permanent positions for ongoing operation and maintenance. Some of this employment will draw from local areas, while other, perhaps more specialized employment, will come from outside the area.

> Offshore wind park construction and operation requires an onshore infrastructure. This includes construction facilities for foundations or floating platforms, a harbor with staging areas for foundations, turbines, cables, an appropriate barge with a crane for installation and cable laying vessels and equipment. For shallow water foundations, cable laying vessels and crane barges will need to be able to maneuver in shallow water. Wind parks a distance offshore will require cable laying vessels with significant cable capacity. Appropriate cable laying vessels and cranes with enough capacity and appropriate draught may need to be custom built. Maintenance activities will require smaller specially outfitted craft with a stock of turbine parts and the capability to handle some larger turbine parts. (Rogers et al. 2000)

An example of the European experience with offshore wind facilities is documented in an evaluation of the Horns Rev project in Denmark. Taking this project as a model, "the establishment of an off-shore wind farm with 80, 2-MW turbines creates a total of around 2,000 man-years of domestic employment over the construction period. A tentative estimate indicates that up to one quarter of this will be at the local level. Operation and maintenance over the 20-year life time of the park will create an additional 1,000 man-years of employment. It is expected that three quarters of this will be at the local level" (Ladenburg et al. 2005).

In a report for Cape Wind Associates, Global Insight (2003) calculated that the manufacturing and construction phase of the Cape Wind project in Massachusetts (rated to produce 460 MW of power) would create between 597 and 1,013 direct, indirect and induced full-time jobs, and labor income would increase between $32 million and $52 million annually. The analysis was based on total capital costs of $700 million, including labor and production costs, engineering and design fees, and other contingency costs over a period of 27 months, and was focused on the communities of Barnstable County, particularly Barnstable and Yarmouth. The Global Insight (2003) analysis predicted that most of the labor from a project would come from the local area, although some equipment (and therefore the associated labor) would come from elsewhere. An economic analysis of a potential Virginia offshore facility has predicted that 30 percent of the capital cost of the project would accrue to the local economy (Hagerman 2009).

In the operation phase of the project, it was predicted that there would be an annual permanent employment increase of 154 jobs with an increase of labor income of $6.9 million annually. Significant additional increases in personal and corporate income tax revenues and property tax revenues were also predicted, but would probably result in "no appreciable increase in the demand for locally or state provided government services" (Global Insight 2003).

Despite these employment increases, the Beacon Hill Institute, utilizing the same figures, has predicted that these gains would be offset by the predicted reduction in tourist industry employment of 1,119 to 2,379 jobs (Haughton et al. 2004). The loss of tourism jobs is a significant concern, because most of the Eastern coastal locations that have been proposed for potential wind facilities are in tourist areas. As the Beacon Hill studies have demonstrated, assumptions based on loss of tourism-related jobs can also have a significant impact on calculations of the cost-benefit ratio of the specific project.

Other studies have attempted to project employment gains from construction and operation of offshore wind facilities:

> Bluewater Wind estimates that the proposed offshore facility in Delaware will generate more than 500 local union jobs during construction, with a $200 million direct economic impact for Delaware workers. (Bluewater Wind 2009)
>
> In North Carolina, data from the Renewable Energy Policy Project indicate that "every 100 MW of wind power installed provides 310 full-time equivalent (FTE) manufacturing jobs, 67 contracting and installation jobs, and 9.5 annual jobs in O & M." While these figures were developed for on-shore installations, the report considers them a "lower bound" of direct job impacts for off-shore projects. (North Carolina Coastal Wind Working Group 2009)

Numerous economic studies have examined the potential for savings by choosing wind power over more traditional power generation methods. Based on a study by La Capra Associates "the Cape Wind Project will generate annual savings in wholesale power costs in New England of $25 million, resulting in an annual increase in New England economic output of between $5.1 million and $6.1 million, and a permanent increase employment of between 142 and 215 jobs" (Global Insight 2003).

11.1.2 Economic Output

Benefits vs. Costs

One major question raised by research and other articles related to economic impacts is: What is the benefit-cost ratio of an alternative energy project? In a study commissioned by the BOEMRE for its Programmatic Environmental Impact Statement on Alternative Energy and Alternate Use, Weiss et al. (2007) set out a framework for conducting a benefit-cost analysis for such projects. The framework consists of: (1) describing potential costs and benefits of an alternative energy project; (2) categorizing these costs and benefits by the extent to which they can be quantified in dollar terms ("monetized"); (3) applying quantification techniques to the specific costs and benefits of a particular project. The most difficult task in evaluating alternative energy projects is quantifying the project's "benefits", which can also be conceived as the costs avoided by replacing fossil fuel-generated electricity by alternative energy generation.

Towards this end, Weiss et al. (2007) present a taxonomy of benefits or avoided costs that provides a starting point for the analysis, adapted below (Table 11.1). The authors review the existing literature on quantifying and monetizing costs and apply existing monetization models and data to each of these benefits, where applicable, before finally applying the benefit-cost analysis to hypothetical Atlantic coast alternative energy projects as a means of demonstrating the analysis.

Table 11.1

Taxonomy of Benefits and Avoided Costs for Consideration in Benefit-Cost Analysis

Environmental
Net diminishment or impairment of habitat and ecosystems due to footprint of generating facility
Degradation of ecosystems associated with non-greenhouse gas emissions
Degradation of ecosystems associated with waste production (chemical or thermal)
Ecosystem degradation associated with fuel extraction
Net degradation of ecosystems associated with greenhouse gas emissions
Socioeconomic
Net decrease in economic activity associated with non-greenhouse gas emissions
Net effect on visibility and aesthetic resources
Net decline in tourism or recreation opportunities
Economic impacts of greenhouse gas emissions
Economic activity associated with construction and operation of facilities
Water supply security and flood control
National Energy/Security
Possible target for acts of terrorism
Energy independence
Human Health
Increased human health risks associated with non-greenhouse gas emissions
Human health risk of potentially catastrophic events
Human health risk from potential releases of hazardous materials
Human health risks associated with greenhouse gas emissions

Source: Weiss et al. 2007

In attempting to apply benefit-cost analysis to potential projects, some studies have “hedged” and simply concluded that there can be benefits of offshore wind, but the ratio depends on the costs of constructing and operating the facility (Berlinski and Connors 2005; Massachusetts Technology *Collaborative* 2003). The Beacon Hill Institute, in their cost-benefit analysis, found that costs would exceed benefits by $1,033 million ($1.033 billion), while Global Insight predicted a savings in wholesale power costs in New England of $25 million (Haughton et al. 2004).

Unfortunately all of these cost-benefit studies are based on assumptions which have not been tested in an actual project on the East Coast of the United States. Until these assumptions have been tested, and a body of research is accumulated to support them, it will be difficult to have consistent, meaningful cost-benefit analyses. It is possible that the details of cost-benefit analysis, as conducted for European projects, can provide useful information on the validity, if not the value, of certain assumptions.

The Economics of Wind

European offshore wind project costs generally range between 8 and 15 cents per kilowatt hour, which is almost double that of onshore wind projects, because construction and accessibility are so much more difficult at sea. (Offshore Wind Collaborative Organizing Group 2005). The European Union predicts there will be at least 40,000 MW of offshore wind energy in Europe by 2020, an annual growth rate of 30 percent (Offshore Wind Collaborative Organizing Group 2005).

Offshore wind power plants cost more to install than comparable onshore plants, but because of higher winds offshore, they can produce a greater energy yield. Both of these factors ultimately have an effect on the cost of energy produced by offshore installations. The greater cost of offshore construction is primarily due to higher foundation and undersea cable costs. A review of existing literature indicates that the cost of energy produced offshore in the United States should be in the range of 4 to 5 cents per kilowatt hour (Rogers et al. 2000).

A pilot research project conducted by the Offshore Wind Collaborative in 2005 analyzed detailed temporal wind speed data over long time scales and a wide geographic area. Results indicated that there is significant revenue potential for offshore wind resources in the Northeast, but the net economic performance will depend on the costs of constructing and operating the wind park. In addition, the study noted that "strong winter offshore winds could produce major environmental benefits from avoided emissions from fossil power plants" (Berlinski and Connors 2005).

Massachusetts Institute of Technology has also researched the question of whether, in the Northeastern United States, offshore winds are "substantially better to justify the additional investment and operational costs of developing wind farms further from shore…" (Massachusetts Technology Collaborative 2003).

The proposed Cape Wind project in Massachusetts has generated the most interest in terms of economic costs and returns. Several groups have produced analyses and projections, with mixed results.

The Beacon Hill Institute at Boston University estimated the cost of producing electricity through the Cape Wind Project as 18.8 cents per kilowatt hour, as opposed to the average factory-gate price of electricity in Massachusetts in 2007 of 7 cents per kilowatt hour. The study's authors state that land-based wind energy might be more cost-effective, and the high costs of offshore construction make the feasibility of this type of project questionable (Haughton et al. 2008). They have concluded that:

> "…the Cape Wind Project would not be worth the resources it would cost. The economic costs of the project, which measure the resources used to build and operate the projects, are expected to come to $2,216 million (in 2008 prices). This may be compared with the economic benefits, which are expected to amount

> to $1,184 million. These are the costs and benefits of the project to the public. Based on these numbers, it does not make sense to build the project; it would, in effect, waste $1,033 million in resources…The most fundamental problem with the project is of course the very high cost of producing electricity at sea…" (Haughton et al. 2008).

In a similar benefit-cost analysis, also conducted by the Beacon Hill Institute (Haughton et al. 2004), researchers have predicted benefits of:

• Reduction in fossil fuel consumption	$522 million
• Capital and operating cost savings	$104 million
• Emission reductions	$108 million
• Greater energy independence	$11 million

Costs of the project would include:

• The project itself	$888 million
• Grid integration	$26 million
• Environmental effects	$39 million

Beacon Hill Institute concluded that the main effects would be:

- A reduction in permanent employment of between 1,173 and 2,533
- A fall in earnings of $28 to $61 million annually
- A reduction in local output of $94 to $203 million per year

An economic analysis conducted for Cape Wind by Global Insight (2003) found that "the project will produce annual savings in wholesale electric power costs in New England of $25 million, with the following savings by sector: $7.5 million—residential; $15 million—commercial; and $2.5 million—industrial." They also found that:

> In regard to the Cape Wind project, local purchases might include labor, non-labor goods and services such as concrete and aggregates, steel, and support services such as crew boats and barges used to support offshore construction activities. The purchase of much of the specialized equipment such as rotors, generators and nacelles would probably be out of the project area. Much of the fabrication and assembly of components would probably occur elsewhere, but would benefit significant temporary increases in employment and income those locations. (Global Insight 2003)

A study of a potential wind park off the coast of Hampton Roads, Virginia, has estimated that local fabrication and installation contracts for the project would total $194 million per year and service contracts would total $155 million per year until the project is complete, and that 30 percent of the capital cost would accrue to the local economy (Hagerman 2009).

Because offshore wind facilities are located on submerged lands that are owned by state and federal governments, commercial activity such as generation of electricity will not directly benefit local communities from increased collection of property taxes. The North Carolina Wind Working Group has estimated that North Carolina communities can benefit from offshore wind projects not only through the creation of new jobs and an increase in local services, but also through payment in lieu of property taxes. The group has proposed that communities could benefit economically either through royalty payments or in the form of a direct equity stake (North Carolina Coastal Wind Working Group 2009).

Economic Models

The JEDI (Job and Economic Development) Model was developed by the National Renewable Energy Laboratory in order to quantify the economic impacts associated with wind projects. It is an input-output modeling tool incorporating multipliers derived from IMPLAN, another model that was developed by the U.S. Forest Service to trace supply linkages in an economy.

An example of a JEDI application is a study that has quantified the economic development impacts of wind power in six rural Montana counties (Costanti 2004). Inputs were the project location, year of construction, project size, turbine size, project construction cost, annual operation and maintenance costs and the current dollar year. Outputs included jobs, output (economic activity), earnings, local spending, annual lease payments, and property taxes. JEDI has also been used by the National Renewable Energy Laboratory (NREL) to determine the economic benefits, carbon dioxide emissions reductions and water conservation benefits from new wind power in Massachusetts (NREL 2004).

Since there are currently no offshore wind projects in the United States, the JEDI model has not yet been applied to the case of offshore wind. However, since JEDI is a predictive model, and the required inputs are similar for both onshore and offshore facilities, it is safe to assume that the model can provide useful economic data for project planning in the case of offshore installations.

Although JEDI has not been used for the economic analysis of offshore wind projects, cost benefit methodologies have been utilized in several cases as a means of determining their feasibility. In the case of a project proposed by the Long Island Power Authority (LIPA), a financial analysis of cash inflows and outflows was used to determine the economic feasibility and impacts on the cost of electricity, concluding that the proposed price of electricity was "excessive and not justified by the economics of wind farming" (Greer 2007). Another feasibility study was prepared for LIPA by Pace Global Energy Services. The Pace study concluded that the "levelized green premium for wind-generated power, when spread out over a 20-year period, would come to about $66 million per year or about $2.50 per month for the typical residential consumer who uses 775 kilowatt hours per month" (Environmental Valuation and Cost-Benefit News 2009).

Economists in the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) evaluated the proposed Cape Wind Project using the Offshore Wind Energy Project (OWEP) model, a Microsoft Excel cash flow spreadsheet. In this case, the economic analysis was carried out as a means of comparing alternative sites. Parameters included economic and project finance assumptions, fiscal terms, power output, technical and physical constraints, capital and operating expenses, and decommissioning expenses (Mense 2007).

Variability in the results of these studies indicates the importance of inputs and assumptions. Economists in Louisiana Department of Natural Resources/Technology Assessment Division have determined that even relatively small changes in the assumptions made for economic analysis can lead to very different results (Sprehe and Crouch 2005).

Consumer Utility Rates

There has been little specific investigation into the impact of offshore wind parks on consumer utility rates. Studies of land-based installations have limited utility, since they incorporate such practices as "net metering", where consumers have the power to use their own generation to offset their electricity demand (IEEE 2009). In regard to land-based systems, the State of Missouri has estimated that by 2030, "consumers will experience a savings of $1.65 per month as renewable energy replaces costly fossil-fueled power." The State predicts an initial annual cost from 2011 to 2021, after which there is an annual gain (Missouri Coalition for the Environment 2009).

The dearth of information regarding consumer costs of offshore wind energy is reflected in a quote from Stefanie Brand, Director of the New Jersey State Division of Rate Counsel, who has stated that "Whether wind will be more costly than other forms, we don't know. Constructing a new generation of power sources is expensive. We want them to be as economical as they can be" (Fallon 2008).

The Federal Reserve Bank of Minneapolis has investigated the impact of renewable portfolio standards on electricity rates, noting that "their effects tend to be obscured by other trends in the utility industry" (Davies 2007). Studies in Michigan, Minnesota and Wisconsin have all predicted increases in rates ranging from 1.4 percent to 3.5 percent by 2020, or, in the case of Wisconsin, an addition of 18 cents to the average household's monthly power bill (Davies 2007).

According to the Institute of Electrical and Electronics Engineers (IEEE 2009), "Consumer choice programs have been an extremely effective method for supporting wind energy." These programs have shown that some consumers are willing to pay more to ensure use or development of renewable energy. An example is the We Energies "Energy for Tomorrow" program, where participants pay a 1.37 cents/kWh premium above the cost of their standard electricity bill (IEEE 2009).

11.1.3 Recreation and Tourism

In both Europe and the United States the concern whether offshore wind installations will affect tourism is a significant one. By virtue of the fact that they are constructed on the coast, it is reasonable to expect that there will be either positive or negative impacts on tourism.

European studies regarding tourism have been primarily conducted by government agencies, such as tourist boards; organizations like the British Wind Energy Association; and market researchers. They are frequently conducted for a specific project, either in anticipation of construction, or after the project has been completed. In some cases, local residents are queried regarding their opinions of the impact on tourism. In other cases, tourists themselves are asked about their reactions to the installation.

Results of these European studies are varied. Some studies find that wind facilities are viewed as a tourist attraction, and might actually prove beneficial to tourism, enhancing the location as an environmentally friendly place to visit (NFO System Three, 2002). Others have found that, although the evidence is overwhelming that wind facilities reduce the value of the scenery, the actual impact on tourism would be very small (Riddington et al. 2008). Local residents who are opposed to wind facilities cite destruction of the natural and visual landscape as a negative effect on tourism (The Market Specialists 2005) and suggest that they should be located away from major tourist routes (Riddington et al. 2008).

Some researchers have concluded that improved planning procedures and better public participation would reduce negative attitudes in regard to tourism. One study recommended that planners produce a "Tourist Impact Statement" as part of the Environmental Impact Statement (Riddington et al. 2008).

At times, negative tourist impacts have been mitigated. In the area of the Nysted project in Denmark, a negative influence on sailing resulted in construction of a new entry to the harbor. Despite this, the visitor center in Nysted expects 40,000 visitors per year. In the Horns Rev area, also in Denmark, although locals expressed concern that there would be a negative impact on tourism, research found there was none (Ladenburg et al. 2005). After the erection of the Horns Rev facility:

> …experience shows that the wind park has not alienated the tourists. Tourists still pay visits to the area, and the fear of a decrease in the summerhouse prices has, this far, proven to be groundless; as the prices here have increased concurrently with the equivalent prices applying to other places in the country. (Kuehn 2005)

Researchers who returned to both Nysted and Horns Rev found that time and adaptation to the situation may change attitudes toward offshore wind parks. One year later, "the wind farms were no longer a matter of debate in the local communities" (ECON Analysis 2005).

There are numerous small studies that have documented positive attitudes in regard to tourism. The British Wind Energy Association (2006) has cited surveys, case studies and anecdotal evidence from England, Scotland and Wales supporting this view (NFO World Group 2003; British Wind Energy Association 2006; Glasgow Caledonian University 2007; MORI Scotland 2002).

The proposed Cape Wind project in Massachusetts has generated numerous studies, some of which have dealt with the subject of tourism. The Beacon Hill Institute reports that: "official statistics show that 21% of the 98,000 jobs on Cape Cod were in tourism-related industries (in 2000). If the indirect and induced effects of tourism spending are included, tourism accounts for 40% of the region's employment" (Haughton et al. 2004).

Based on a survey of 497 Cape Cod tourists, assuming that the Cape Wind project was built, 3.2 percent of tourists said they would spend an average of 2.9 fewer days on the Cape, 1.8 percent said they would not visit at all, and 1.0 percent said they would stay longer. In addition, 11 percent said they would pay less for lodging and 1 percent said they would pay more. The calculated net effect was a reduction of $75.15 spending per tourist, with a total reduction of tourist spending of between $57 million and $123 million. This predicted decrease in spending is due to shorter stays and a reduced willingness-to-pay for accommodations (Haughton et al. 2003).

In addition to economic analyses, attitudinal surveys have also revealed rationales for opposing the project. In an overview of groups for and against the Cape Wind project, researchers at Cornell University have identified a number of negative concerns, as expressed by non-governmental organizations. These groups have taken the position that:

> ...the windmills could reduce the number of tourists who come to Cape Cod for recreational activities….One main worry is that if the population of fish decreases, recreational fishermen may have severe restrictions placed on them by the state, and Cape Cod will lose much of its appeal to fishermen…Bird watching would not be plausible if birds are harmed by the windmills or forced to change their migratory patterns. Whale watching is also a popular activity; the effect of the windmills on the whales is an area which has not been extensively studied, but if whales are forced to move out of the region, this recreational activity will be disrupted. (Dyson et al. no date)

In the United States, there have been studies of tourism in Cape Cod and New Jersey. The Beacon Hill Institute found that tourist spending would decrease with the advent of a wind facility, but, despite their concerns about impacts to bird watching, fishing, and whale watching, Cape Cod tourists favored the wind facility overall. Based on the "willingness to pay" concept, one out of seven would be willing to pay to have windmills in Cape Cod Sound (Haughton et al. 2003). New Jersey researchers found that most tourists would be neither deterred nor encouraged to visit the New Jersey shore if there were wind turbines off shore (Mills and Rosen 2006).

In the case of New Jersey, however, a study by the state Department of Environmental Protection (NJDEP 2005) found that "Potential conflicts between offshore wind facilities and tourism include effects on views, birding, and property values. Recreational fishing would also be affected if a wind farm were sited on a shoal area popular for fishing, particularly if they were excluded from these areas. Over a million anglers fish New Jersey's salt waters with over 6.8 million trips of fishing activity a year. The recreational fishery alone is annually worth $1.5 billion to the economy of New Jersey" (NJDEP 2005).

In 2007, a survey of out-of-state beachgoers was conducted to determine the potential effects of offshore wind power development on tourism in Delaware (Blaydes et al. 2007). Respondents were shown a series of wind park simulations, and asked whether their decision to visit the beach would be affected. More than 99 percent of the respondents would return to the same beach if the installation was out of sight, 93.7% would return if the installation was 13.8 miles out, and 73.9% would return if the distance was 6 miles. The study also indicated a potential positive effect on tourism. It found that 65.8% of out-of-state tourists were likely to visit a beach that they did not typically visit if a wind facility was built 6 miles offshore.

The current issue for the United States is: Do tourist surveys based on a concept really provide useful information for the installation of a wind facility? Patel (2003) has pointed out that "The idea of wind farms and renewable energy is favorable to most Americans. The unfortunate fact is that many who support wind farms do not support them in their area…" Is there a difference in the minds of the tourists who have been surveyed between the concept of offshore wind energy and the reality of a wind facility off their favorite shore? It may be that this question cannot be fully answered until a wind facility is constructed. At this point current public opinion, as determined through existing surveys, is characterized by concerns over loss of tourism that has not yet materialized, and, in fact, did not materialize in the European experience.

11.1.4 Commercial Fishing and Other Maritime Industries

In the United Kingdom, special attention has been paid to fishermen, including them as collaborating partners in the planning and development of projects where fishing is a significant enterprise (Mackinson et al. 2006). The British fishing industry employs more than 14,500 regular or part-time fishermen, who landed 738,000 tons of fish in 2001 (Department of Trade and Industry 2002). British planners have conceded that offshore installations may have an impact on the fishing industry, either by excluding fishing activities from certain areas and thus reducing the catch or by presenting obstacles to the passage of fishing vessels. In 2002, a liaison group was established to foster closer relations between the fishing industry and the energy sector (Department of Trade and Industry 2002). In 2008, this group produced detailed guidelines for developers involved in the offshore renewable energy sector when dealing with fishing and fisheries (BERR 2008).

In its study of potential conflicts with commercial fishermen if the contemplated offshore wind installation is constructed, the New Jersey study mentioned above (NJDEP 2005) found:

> …(D)redge fisheries cut into the ocean floor to harvest shellfish. This technique would result in conflicts between the fishery and the wind park industry. Specifically, the fisheries may be closed in the vicinity of the electric transmission cables that would stretch from wind parks to the shore. In addition, otter trawl fishermen, like shellfish dredgers, would not be able to operate in the vicinity of the wind parks because of the risk that the gear they employ could become entangled in the wind park towers. (NJDEP 2005)

In addition, potential impacts on commercial shipping have also been identified. Many ships use the ports that New Jersey shares with New York and Pennsylvania--New York/New Jersey and Philadelphia/ Camden. These ships include "vessels transporting hazardous materials such as oil. Siting of offshore wind farms must avoid port shipping lanes, offshore anchorages, lighting areas, and approaches to navigable inlets" (NJDEP 2005).

Based on the United Kingdom experience, there is no doubt that commercial fishermen and their organizations need to be involved early in the planning process for an offshore facility (Mackinson et al.). Planners in the U.K. have acknowledged that their projects are likely to have an impact on the industry, either by excluding fishing from some areas near the turbines, or by presenting obstacles to fishing vessels. Similar potential conflicts have been identified in New Jersey (NJDEP 2005).

Based on the amount of commercial fishing on the Eastern seaboard in places like Maine, Cape Cod, Long Island Sound, the Delmarva Peninsula, Hampton Roads and the Outer Banks of North Carolina, American planners will also need to provide for involvement of commercial fishermen and their organizations, such as the South Atlantic Fisheries Management Council.

Although no literature has specifically addressed the topic, commercial vessels of all kinds could be impacted by an offshore wind facility, depending on its proximity to shipping lanes.

11.1.5 Land Use Patterns

There are two land use patterns associated with offshore wind facilities; onshore and offshore. The most significant aspect of onshore land use is the concern of residents that land uses they are accustomed to enjoying —beaches, parks, wildlife refuges—will somehow be disturbed or even disappear in the advent of an offshore wind facility (Ridling and Rusch 2005). These amenities and others are found all along the coast, and, in the case of the Cape Wind project, the anticipation of such changes has already led to considerable public protest despite any concrete evidence that such changes will take place.

Siting issues for wind technology are different from those for fossil-fuel based power plants. For obvious reasons, siting options for wind facilities are limited to areas with high winds and close to population centers, either on land or offshore. “The footprints of fossil fuel power plants are much smaller and they can usually be placed in a less conspicuous industrial area. Wind farms have huge structural footprints and are often located in open areas not previously developed.” (Glickel no date).

Some of the aesthetic and life-style aspects of land use associated with off-shore wind facilities are expressed in this commentary on New Jersey’s proposed offshore project:

> People are drawn to New Jersey’s coast by its natural beauty and resources. Miles of open beach offer space for a quiet stroll or a lively family outing. From homes along the edge of the beach, residents have an unobstructed view of open ocean. Protected wetlands host hundreds of thousands of migrating birds, harbor other wildlife, and provide a place for bird watching. Bays and estuaries are home to fish and shellfish, and support commercial fishing.” (Ridling and Rusch 2005)

The amenities of many other ocean-side communities on the Eastern Atlantic Coast could be characterized in the same way. The fear that these amenities will be lost or changed as the result of changing land use patterns is a significant ingredient in public opinions on offshore wind installations.

The issue of land use and property rights—particularly in the case of the Cape Wind project-- is also a significant one. Traditionally, the government has zoned particular areas for commercial development and allowed private parties to bid for the rights, yet no such framework has existed for wind power projects (the BOEMRE's recent release of its regulations governing the processes for leasing and licensing offshore energy tracts will clarify this situation) (USDOI, MMS, 2009). A survey of Cape Cod homeowners and tourists showed overwhelming support for a payment for the right to use public land. "Fully 89 percent of homeowners and 84 percent of tourists say that they believe Cape Wind should be required to make a royalty payment if operating on federal land" (Haughton et al. 2004).

Another land use issue that has potential for conflict is the location of the onshore support facilities for the wind facility. Offshore wind facilities also require an onshore infrastructure. This includes construction facilities for foundations or floating platforms, a harbor with staging areas for foundations, turbines and cables, an appropriate barge with a crane for installation, and cable-laying vessels and equipment. Maintenance activities will require smaller specially outfitted draft with a stock of turbine parts and the capability to handle some larger turbine parts (Rogers et al. 2000).

It is likely that these facilities will be located in areas that are already designated for industrial use, but it could be cause for concern if the location is perceived to be an intrusion on existing amenities. Locations that are selected for offshore installations will most likely have suitable dock and shipyard facilities, but it is possible that there might be a need for additional land for storage and servicing of equipment, as well as a land-based power station. This is one area where the possibility for impacts on at-risk populations exists.

11.1.6 Property Values

According to a recent publication on the market value of coasts and estuaries, there are no systematic estimates of the value of coastal housing to date, although some researchers have attempted to estimate the relationship between housing values and proximity to coasts, estuaries and oceans (Pendleton 2008). One study found that beachfront proximity increased the value of a home by 207 percent compared to a property two blocks away, and a bay front location added 73 percent (Major and Lusht 2004).) If the residential shorefront property also has an uninterrupted view, homeowners and realtors believe that its value is further enhanced (Haughton et al. 2004). The questions here are: What is an uninterrupted view? Is a wind facility miles out to sea a visual disruption to such a view? At what level of visibility? Many Cape Cod homeowners believed this to be true. In this case, only by studying changes in the housing market after an offshore facility is completed can the question be fully answered.

Since there are no wind facilities off the coast of the United States, the impact on property values is speculative and the information is extremely limited. Although there has been some research on the impact of land-based wind facilities on property values, the applicability of that information to the offshore situation is limited because of the typical dollar premiums associated with coastal property (Sterzinger et al. 2003; ECONorthwest 2002).

In 2003, the Renewable Energy Policy Project conducted an analysis of the effect of wind development on property values in nine communities in California, New York, Texas, Vermont, Wisconsin, Pennsylvania, and Iowa. A 2002 report by ECONorthwest analyzed the economic impacts of wind power in Kittitas County, determining that views of wind turbines would not affect property values. The analysis included interviews with tax assessors in 19 locations where projects were located (ECONorthwest 2002). All of these sites are land-based, however, and the analysis has little relevance to offshore wind projects. No research has been conducted in the United States on the impact of offshore wind facilities on property values, for the obvious reason that none of them have been constructed (Sterzinger et al. 2003). This fact is reflected in the Final Environmental Impact Statement for the Cape Wind Project, which states that "Currently available information does not support any firm conclusion with respect to the wind facility's effect on property values" (USDOI, MMS 2009).

The only available information relative to the relationship between property values and offshore wind is either anecdotal, or the result of attitude surveys, which may or may not reflect actual impacts. Historically, oceanfront real estate has been among the most expensive in the United States. A majority of Americans live within 50 miles of the ocean, and 17 of the top 20 fastest growing counties in the country are on the coast (NJDEP 2005). Therefore, it is likely that there will be impacts, but whether they will be positive or negative or neutral is difficult to predict.

Realtors and homeowners along the shore believe that an uninterrupted view has an impact on the property value of a house and without this view they will experience a loss of property value. In a survey of 501 home owners on Cape Cod and Martha's Vineyard, as well as 45 Cape Cod realtors, the Beacon Hill Institute found that the presence of a large scale wind park in Nantucket Sound could indeed be perceived as a loss in amenity value. Sixty-eight percent of home owners surveyed by DAPA Research, Inc. believe that the presence of the wind park would worsen the view of Nantucket Sound. On average, homeowners believe that the wind park would reduce property values by 4.0 % (and among these, households with waterfront property believe that the loss would be 10.9%). When these numbers are extrapolated to represent the six towns likely to be impacted by the wind park, the total loss in property value would be over $1.3 billion. As a result, the authors of the study predict that these six towns stand to lose $8.0 million in property tax revenue" if impacts do, indeed, occur (Haughton et al. 2004).

Researchers at the National Renewable Energy Laboratory have analyzed the limited existing research (seven studies) on the relationship between land-based wind park facilities and property values (Lanz 2009). They found that:

- There is generally insufficient statistical analysis
- The research is often limited in sample size and has insufficient diversity in the study areas
- Most studies tested only one parameter

- Only one study actually visited the sites to evaluate the proximity of turbines and local landscape characteristics
- None of the studies were subject to the rigor of publication in refereed journals

In a recent multi-site analysis, researchers at the Lawrence Berkeley National Laboratory studied impacts on property values from the perspective of three categories: area stigma, scenic vista stigma, and nuisance and health effects (Wiser and Hoen 2008). Although the study sites were all land-based, the framework provides guidance for future studies of offshore facilities. Preliminary conclusions indicate that there is no statistical evidence that homes within four to seven miles of a facility are affected adversely based simply on proximity; there is no statistical evidence that homes with a view of turbines have different values than homes without; and more data is needed to reliably test the claim that wind installations are a nuisance and have negative health impacts (Wiser and Hoen 2008).

It should be noted, however, that history has shown perceptions regarding housing values can become “self-fulfilling prophecies” regardless of the facts. Residents’ perceptions of property value impacts should not be ignored by project planners, simply on the basis of factual information. In addition, property value impacts can be created simply by the anticipation of a potentially disruptive project; once the project is under construction and later in operation, the dynamics will likely change.

11.2 SOCIOCULTURAL IMPACTS

11.2.1 Visual/Aesthetic Values

With many offshore wind facilities already in place and operational, European researchers have been able to assess public response to visual and aesthetic values. Studies have determined attitudes toward the appearance of wind facilities, as well as the willingness of residents to pay to have the project located farther out at sea. Negative impacts are referred to as “visual disamenities.”

Distance appears to be an important variable related to visual impacts. A study in the United Kingdom found that distance and contrast were found to be good predictors of potential impacts (Bishop and Miller 2007). When asked about their willingness to pay for moving wind parks farther away, most respondents were positive (Ladenburg et al. 2005). However, willingness to pay varied significantly with age of respondents and experience with offshore wind parks (Ladenburg and Dubgaard 2007). Ladenburg (2009) has found that people with experience from offshore wind parks located far from the coast have a significantly more positive perception than people with experiences from wind parks closer to the coast. Results from this study indicated that “future acceptance is not independent of the location of existing and proposed wind farms” (Ladenburg and Dubgaard 2007).

In a study of Danish citizens based on the willingness-to-pay concept, results indicated that marginal benefits are derived from increasing the distance from the shore. “Assuming that marginal costs of power generation are increasing significantly as a function of the distance to the coast, this indicates that, from a visual disamenity point of view, the socially optimal location of offshore wind farms is unlikely to be greater than approximately 18 km from the shore" (Ladenburg and Dubgaard 2007).

Another analysis of research from European Union countries found that people who are favorably disposed to the development of wind energy accept the sight of wind turbines much more easily than people who are opposed to it from the beginning. In the same studies, it was also found that wind parks are visually more acceptable to people who have been informed of the benefits derived from their use (Binopoulos and Haviaropoulos no date).

As the prior research indicates, previous experience with wind facilities is also likely to generate more favorable attitudes toward wind parks in general, as well as toward the visual features (Ladenburg and Dubgaard 2007).

Of necessity, research regarding the visual aspects of offshore wind facilities in the United States is conducted using hypothetical examples and/or visual simulations, since few respondents have actually seen an offshore wind park. According to a report by the Beacon Hill Institute:

> One of the issues closest to the citizens of Cape Cod is the threat the windmills pose to their ocean view and more importantly their property values. Many people feel that 'the beauty of the region' and 'the ocean views' are the major assets of the areas, and are two important factors when buying a home. People feel that the addition of the windmills, which will be visible on the horizon, will significantly impact the ocean views, perhaps because of the large size of the project. An uninterrupted view has an impact on the property value of a house; without these views, realtors and homeowner along the shore believe that they will experience a loss of 10.9% of their property values, and those inshore 4%. (Haughton et al. 2003)

Some objections to the aesthetic appearance of offshore wind projects are related to the landscape (or seascape) as a whole, rather than the appearance of the windmills themselves. Residents of both Massachusetts and New Jersey, when surveyed for their opinions, expressed the idea that the ocean was sacred, and therefore should remain pristine and untouched by the view of a wind park. According to Kempton and others, who surveyed residents of Cape Cod "…our analysis suggests that concern expressed as 'the view' is not only visual or aesthetic; it is more importantly a gloss for the value that the ocean is special and humans should not intrude on it, and the value that Cape Cod should be protected from the excessive development that residents feel is destroying its character" (Kempton et al. 2005).

New Jersey residents expressed the opinion that "The ocean represents one of the only remaining New Jersey viewsheds with few manmade structures. Large numbers of visitors are drawn to the shore every year to enjoy this uninterrupted view of nature" (NJDEP 2005).

11.2.2 At-Risk Populations

Federal guidance from the U.S. EPA Office of Environmental Justice defines "at-risk" groups as those who might experience unfair treatment because of their race, color, national origin or income as the result of a specific proposed action. Other at-risk groups might include the elderly (those 65 years of age and over), handicapped, or otherwise disadvantaged. Any minority group can be considered an at-risk population if the potential exists for them to be more adversely affected than other groups.

The relationship between demographic characteristics and acceptance has been a topic of interest in Europe. Several studies have found that younger residents are more accepting of wind parks than older residents (Ladenburg 2007; Ek 2005; NOP World Consumer 2005). There is also some evidence from research in Denmark that residents with a higher degree of knowledge are more receptive (Damborg 2003). In the United States, "Cape Wind supporters appear to be younger, better educated, and more likely to own their own homes; while opponents are more likely to earn over $200,000/year and more likely to expect to see the project from their daily routine" (Dyson et al. no date).

A recent analysis of census data in North Carolina has revealed that there are many migrants to the coastal areas of North Carolina from New York, New Jersey, Pennsylvania, South Carolina, Florida, Ohio, Maryland, Connecticut and Michigan, as well as migration of in-state residents, resulting in significant population changes (Mitchell 2008). In the over-60 population in these coastal areas, 44 percent of the non-movers, 27.7 percent of the interstate movers, and 44.8 percent of the intrastate movers are disabled (see Figure 11.1).

No research has been identified, either in Europe or the United States that is targeted specifically to impacts of offshore wind projects on at-risk populations: elderly, low-income, minority or handicapped. In cases of land-based utility installations, these at-risk populations have been identified and studied, because of the tendency to locate undesirable projects where the residents are powerless to keep them away. Since the impacts of offshore wind facilities are mostly at sea, these concerns have not been as urgent.

As part of an examination of socioeconomic impacts, some assumptions can be tested relative to the relationship between at-risk populations and the placement of the wind facility: Is the view of the project presented to at-risk populations more detrimental to their property values than to the property of residents in another location? Does the placement of onshore support facilities disproportionately impact at-risk populations? Are low-income residents unduly affected by the placement of the turbines, perhaps because of their concentration in affected industries like commercial fishing or processing? For example, the Bureau of Labor Statistics estimates that fishers and related fishing workers at the national level have a mean hourly wage of $13.68 and a mean annual wage of $28,460 (USDOL, BLS 2008). Whether the average fisherman will be considered at-risk in a specific project area will depend on the economic data for that particular area. On the other hand, in the Albemarle-Pamlico Sound Area of North Carolina, the median household income for fishermen was approximately $40,000, which is very close to the State median household income of $40,572 (Crosson 2007). These and other questions would be answered in the context of a project-specific socioeconomic analysis.

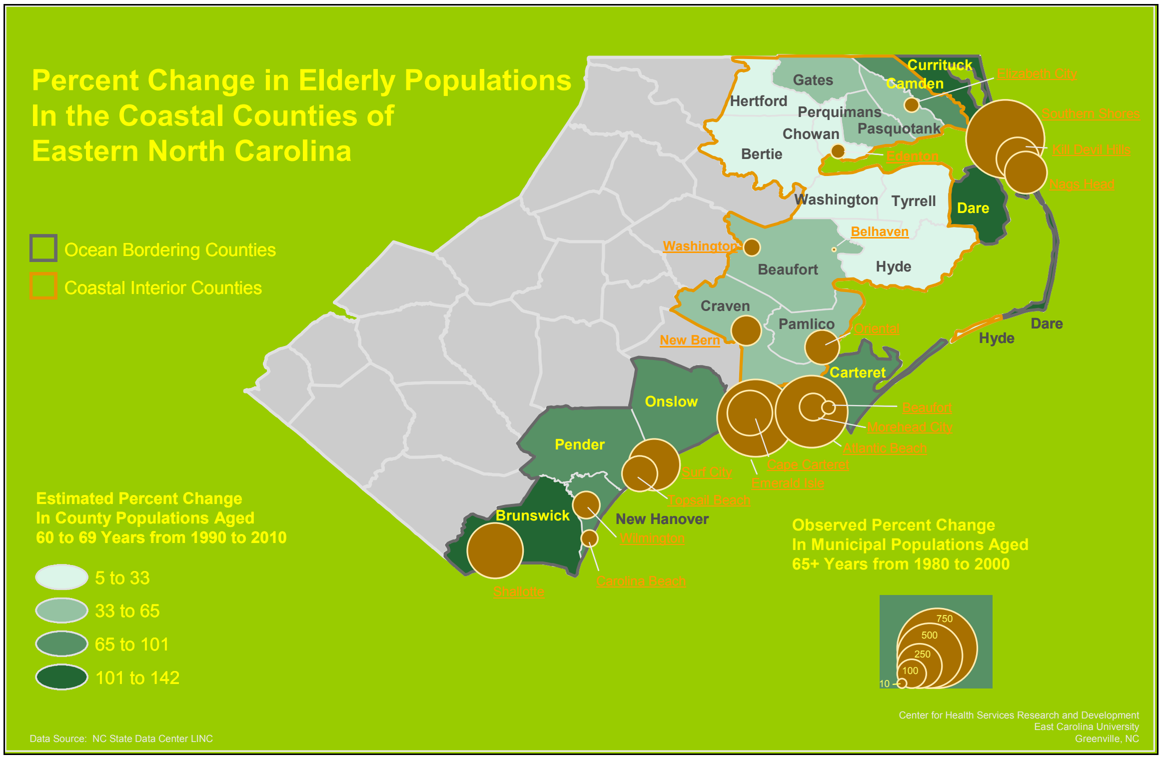

Figure 11.1. Percent Change in Elderly Populations in the Coastal Counties of Eastern North Carolina (Mitchell 2008). Map created by staff in the ECU Center for Health Services Research.

It is tempting to take the results of European research and extrapolate them to the U.S. environment. However, it should be noted that these are primarily attitudinal studies, and do not reflect any actual impacts that might accrue to at-risk populations.

11.2.3 Public Acceptance

The greatest number of research studies, articles, reports and surveys in both Europe and the United States can be found in the areas of public opinion and attitudes, and their relationship to project acceptance. The existence of numerous offshore wind installations in Europe makes possible both pre-and post-examinations of attitudes. In the United States, attitudinal studies are confined to the examination of public attitudes toward the imminent or future possibility of wind facilities.

In all parts of the world where offshore wind installations are being constructed or have been constructed, there appear to be strong relationships between public attitudes, public involvement and acceptance. Many studies have found that greater public involvement leads to more positive attitudes toward the construction of a wind facility. Researchers in Denmark, for example, found that, “while public involvement is time-consuming and expensive, it is necessary to the success of the project by mitigating protest efforts and increasing confidence” (Sorensen et al. 2002).

Based on in-depth studies of wind projects in England, Wales and Denmark, “projects with a high level of participatory planning are more likely to be successful” (Loring 2007). Researchers in Greece, Germany, the Netherlands and Sweden have also identified the relationship between participation and positive attitudes (Kaldellis 2005; Jobert et al. 2007; Agterbosch et al. 2008; Johansson and Laike 2007). Various strategies for involving the public have been mentioned, including meetings, demonstrations, tours, and information in all formats.

European researchers have also attempted to identify characteristics of both projects and people that are likely to influence acceptance. Many studies have cited factors related to visual impact—distance from the shore, number and size of turbines, etc. Ladenburg has found that offshore development is preferable to on-shore development, although residents living closer to wind parks did not appear to be more negative than those living farther away (Ladenburg 2007). At least one study has found that the number of turbines has no negative effect (Damborg 2003).

In attempting to understand the acceptance or rejection of wind projects, Wolsink (2007) found that the difference between an individual’s perception of wind facilities as a concept or as a reality helps to explain discrepancies between attitudes and level of acceptance. Many respondents, especially those who are most supportive of alternative energy, are positive about the idea of wind power. However, when there is a specific proposal for wind power within their view, they are less sanguine—a phenomenon known as “NIMBY” or “Not in My Back Yard.”

Researchers in both Europe and the United States have explored the significance of the NIMBY (Not In My Backyard) syndrome. There is some evidence that, where knowledge levels are low, the NIMBY syndrome has an effect on public acceptance (Krohn and Damborg 1999). However, most studies have shown that, while NIMBY may be a factor, is it but one of many influences on public behavior (Glickel no date). The NIMBY factor is also influential in American perceptions regarding wind installations, both land-based and offshore. According to Patel (2003), **“**The idea of wind farms and renewable energy is favorable to most Americans. The unfortunate fact is that many who support wind farms do not support them in their area where they will use resources of the community.”

Warren and colleagues determined that local people become more favorable toward wind parks after they have been constructed, and that their degree of acceptance increases with proximity to them (Warren et al. 2005). A compilation of European surveys produced by Damborg (2003) for the Danish Wind Industry Association revealed that acceptance increases with level of information and prior experience. A sociological investigation of the Nysted and Horns Rev wind parks in Denmark found that time and adjustment to the situation may change attitudes to a greater level of acceptance (Kuehn 2005). Using data from polling activities in the United States, the United Kingdom and Canada, the American Wind Energy Association has concluded that “…public opinion in support of wind usually shifts to become even more strongly in favor once the wind turbines are installed and operating” (Gray 2009).

In their studies of public responses to the Cape Wind project on Nantucket, researchers at the University of Delaware have proposed that certain underlying values are responsible for much of the negative response to the project. They present the argument that when respondents refer to "the view" they are really expressing a more subtle concept: that "the ocean is special, and humans should not intrude on it" (Kempton et al. 2005).

> Underlying the current debate are several basic value questions and tradeoffs. For example, the value of protecting the ocean and keeping it free from human intrusion; the value of cleaner air and less human infirmity and mortality; the value of traditions like sailing and fishing in New England; whether there is a right to a local seascape that residents assumed would be there forever. (Kempton et al. 2005)

A similar sentiment has been expressed by a conservation group opposed to the Cape Wind project which is committed to "preventing the development of wind farms in Nantucket sound because it believes Nantucket sound is a 'natural treasure' that should be preserved" (Patel 2003).

There will be a portion of the public that favors reduced fossil fuel consumption and greater energy independence at any cost—especially as it relates to global warming—but as researchers from the University of Delaware discovered, a very small percentage of the people they interviewed were even aware of the global warming benefits of the project (Firestone and Kempton 2007). In their survey of Cape Cod residents they found that far more residents (40%-50%) thought the project would negatively impact aesthetics, community harmony, property value, bird life, marine life, tourism and boating (Firestone and Kempton 2007).

The Delaware researchers have also proposed a second concept as "first of many", meaning the willingness of the population in a project area to absorb the negative aspects of wind development in order to set an example for addressing climate change, a challenge that they cannot meet alone. They surmise that "an important part of the opposition to offshore wind power projects is that the proponents have not always successfully articulated a larger vision—that offshore wind is abundant in many areas of the world, including this region, off the US East Coast, and that large scale development is a plausible outcome of individual successful projects" (Dyson et al. no date).

In a comparative study of Cape Wind and a proposed Delaware offshore wind park, researchers found that "support increases significantly when there is a vision of transformation, even though respondents in both areas knew that as one of the first sites, they inherently would take additional risk and some cost" (Firestone et al. 2008a). This research supports the claim that residents are likely to view a project more favorably if they see it as part of a "big picture" (Firestone and Kempton 2007).

Another important finding in the University of Delaware research is the difference between the public's perception of "facts" and scientific information. In their interviews of Cape Cod residents, researchers found that "the public is stunningly at odds with analysts and the scientific literature, even if not literally 'incorrect." For example, only 4% of respondents gave climate change as a factor in accepting or rejecting the project, and 41% said it would have no impact on climate change (Firestone and Kempton 2007).

Residents in the area of the Cape Wind proposed project have also expressed a number of other objections to the project: (1) It is wrong for a private company to benefit from a public resource; (2) the federal government does not have the appropriate regulatory and zoning safeguards in place to protect the Outer Continental Shelf from overzealous developers; (3) Nantucket Sound is no place to experiment with untested technology; (4) the 'industrialization' of a treasure; and (5) decrease in property values leads to increased taxes (Dyson et al. no date). In addition, "More than half think that the project will have negative impacts on aesthetics, community harmony, the local fishing industry and recreational boating. In addition over 40% believe the project will have negative impacts on property values, bird life, marine life, and tourism" (Firestone and Kempton 2007).

Some studies in Europe and the United States have examined the economic aspects of offshore wind energy using the concept of "willingness to pay" as a means of putting a value on non-quantifiable benefits such as clean air or an uninterrupted view. In a survey of homeowners and tourists on Cape Cod, researchers for the Beacon Hill Institute asked how much they would be willing to pay to have or not have wind turbines in Nantucket Sound (Haughton et al. 2003). They found that:

- 22 percent of homeowners would be willing to pay not to have wind turbines, as opposed to 9 percent who would pay to encourage them;
- Homeowners would pay between \$5 million and \$12 million to keep wind turbines out; and
- Tourists would be willing to pay to have wind turbines in Nantucket Sound, perhaps \$5-\$14 per visiting family, or a total of between \$3 and \$8 million

Despite some willingness to pay for wind turbines on the part of tourists, a greater number responded that they would spend fewer days on the Cape if the wind turbines were erected, therefore spending less money.

Based on surveys of both tourists and homeowners, the majority of respondents felt that Cape Wind should be required to pay a rent or royalty. "Yes" responses were obtained from 89 percent of homeowners and 84 percent of tourists, respondents indicating that royalties should be about 8 percent of revenue (Haughton et al. 2003).

In New Jersey, a survey of more than 4,000 residents of Monmouth, Ocean, Atlantic and Cape May counties found that nearly half are in favor of a New Jersey Offshore Wind project. Other findings: (1) Opposition diminishes with distance from the shore; (2) Residents' and visitors' reactions to wind turbines are fairly equal; (3) Residents familiar with the concept are most apt to be in favor of it; (4) Primary benefits are environmental; and (5) Primary disadvantage was aesthetics (Mills and Rosen 2006).

In Delaware, researchers found that 78 percent of Delaware residents would support the development of a large offshore wind park six miles from the Delaware coast. Very little concern was expressed over the effect of offshore wind power on tourism (Firestone et al. 2008a). In fact, researchers have noted that "the high numbers expressing curiosity and desire to visit a beach with a wind park in view suggest possibilities for new services such as recreational boat trips to tour a wind farm, a tourist-oriented visitor center, and new possibilities for marketing Delaware beaches outside the state" (Firestone et al. 2008a).

And in North Carolina, a survey of residents of 18 coastal counties in eastern North Carolina determined that (1) More than three out of four respondents would prefer to see more of their future electricity derived from solar and wind; (2) Approximately seven out of ten support the placement of turbines on the coastal mainland, offshore, and with existing towers. When asked about ten or more turbines clustered together at these locations, support does not decline significantly and (3) Two out of three expressed support for turbines even if they were visible from the respondents' home (Grady and Cousino 2004).

11.2.4 Project Planning and Public Participation

Authors of "The Case Study of European Offshore Wind Farms" gathered and evaluated experiences from eight offshore wind parks: Egmond Aan Zee in the Netherlands, Thornton Park in Belgium, Borkum West and Butendiek in Germany, Great Gabbard and Scroby Sands in the United Kingdom, and Horns Rev and Nysted in Denmark in order to identify the factors that lead to successful projects. Public participation was a common characteristic that was strongly related to project success. They found that "Stakeholder involvement and implementation of the media strategy can avoid many potential conflicts, and thus preclude opposition to projects. Stakeholder involvement should be given high priority in the pre-planning phase of a project" (Gerdes et al. 2006).

They also recommended that "A professional media strategy is helpful for increasing public awareness of offshore wind farms in general, and also for specific projects. Media campaigns can be valuable for raising public acceptance, particularly with regard to tourism and nature impact issues" (Gerdes et al. 2006). Economic benefits might be an important topic, as at least one research study has found that the local perception of economic benefits is an important factor in successful outcomes (Toke 2005).

In their analysis of experiences from the Middelgrunden offshore wind park in Denmark, the authors recommend that "An open public dialogue already from the very beginning of a planning phase is crucial for achieving social acceptance…" (Larsen et al. 2005). They express the view that, although public involvement requires time and resources, it may help to mitigate general protests that block or delay projects and may also increase future confidence, acceptance and support for future projects (Larsen et al. 2005).

Stakeholder involvement is a common theme in analyses of existing European wind facilities, numerous studies citing the need to involve local populations early in the planning process. (Sorensen et al. 2002; Eltham et al. 2008; Kaldellis 2005; Johansson and Laike 2007). Some planning organizations have developed strategies and protocols for stakeholder involvement, such as that produced in Wales by the Centre for Sustainable Energy (2007). The Centre proposed the following "principles of effective public engagement":

- Access to information

- The opportunity to contribute ideas
- The opportunity to take an active part in developing proposals and options
- The opportunity to be consulted and make representations on formal proposals and policies.
- The opportunity to receive feedback and be informed about progress and outcomes

As part of their analysis of the Cape Wind project on Cape Cod, University of Delaware researchers identified four points as rarely addressed or mentioned. They include: (1) the health effects of reducing power plant operations; (2) the process of decision-making (e.g. there is a widespread belief that the fate of a wind proposal should be decided by nearby residents); (3) the scale of the project; and (4) trade-offs of developing offshore wind power (Kempton, et al. 2005). They identify a number of trade-offs related to the Cape Wind project: the value of protecting the ocean and keeping it free from human intrusion, the value of cleaner air, the value of New England traditions such as fishing and sailing, and whether residents are willing to absorb the negatives of the project now, in order to set an example for future projects (Kempton et al. 2005).

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12. RESEARCH AND DEVELOPMENT TECHNOLOGY

The research and development technology section of this report focuses on the three major offshore renewable energy technologies originally identified in the scope of this project. These technologies include wind, wave and ocean current energy sources. Tidal current energy technology is not included in this report since there are no offshore sites with sufficient tidal velocities (~1.5 m/s). These high tidal currents only occur where the shoreline configuration or bathymetry, such as in straits or tidal rivers that connect bodies of water having sufficiently different tidal characteristics (amplitude or phase), causes a large amount of water to pass at relatively high speed through the constriction. Wind, wave and ocean current energy systems will be presented separately in the sections to follow. Each technology section begins with a description of the state of the technologies used, then the research and development activities will be presented, including research into the siting of such systems as well as anticipated technological development. This is followed by the engineering challenges facing each type of technology, including geologic hazards, high current speeds, and high water levels due to waves (short period) and events that cause storm surge.

12.1 WIND ENERGY

12.1.1 Research and Development Activities

The nascent U.S. offshore wind energy industry, with no wind turbines in the water to date, is well aware of and learning from the European experience. Over a decade of experience has now been gained from the European offshore wind parks operating commercially and documentation for that information is just beginning to appear (USDOI, MMS 2007a). Table 12.1 presents a list of all commercial European offshore wind parks in operation and Table 12.2 presents those under construction. Table 12.3 presents a list of the current wind park project development activity in the Mid- and North Atlantic Planning Areas, while a more detailed table of the current status of the U.S. offshore wind industry by state as compiled by the U.S. Offshore Wind Collaborative, can be found at http://www.usowc.org/pdfs/Stateoffshorewind.pdf.

In response to a U.S. Department of Energy (USDOE) request for information regarding the proceedings of the 20 percent Wind Energy by 2030 Workshop, the American Wind Energy Association (AWEA) Offshore Wind Working Group developed a prioritized list of areas in the offshore wind industry in need of research and development (AWEA 2009). The list was ranked by need and potential impact to the offshore development process, identifying twelve specific areas for research and development (R&D). These are, in order:

- fundamental design evaluation for 5-to-10-MW offshore machines
- large-scale national offshore wind-testing facilities
- offshore design computer codes and methods
- cost-effective offshore wind foundations
- marine grid, power conditioning, and infrastructure development
- certification and standards development
- improved data on the offshore wind resource and development constraints

- offshore wind park arrays
- potential effect of offshore wind development on coastal tourism
- advanced deployment and maintenance strategies
- integration of large offshore power into eastern grid
- avian and marine ecology research

Table 12.1

Operational Offshore European Wind Parks

Wind Park	Planned Capacity (MW)	Country	No. of Turbines/Model	Commission Date
Arklow Bank	25	Ireland	7 x 3.6 GE	2004
Barrow Offshore Wind	90	UK	Vestas V90-3MWx 30	2006
Beatrice	10	UK	REpower 5M x 2	2007
Blyth	4	UK	Vestas V66-2MWx 2	2000
Bockstigen	2.75	Sweden	NEG Micon 550kWx5	1998
Burbo Bank Wind Farm	90	UK	Siemens 3.6-107 x 25	2007
Egmond aan Zee	108	Netherlands	Vestas V90-3MWx 36	2006
Frederikshavn	11	Denmark	4	2003
Horns Rev	160	Denmark	Vestas V80-2MWx 80	2002
Irene Vorrink	16.8	Netherlands	NEG Micon 600kW x 28	1996
Kemi Ajos I+II	24	Finland	WinWinD 3MW x 8	2008
Kentish Flats	90	UK	Vestas V90-3MW x 30	2005
Lely	2	Netherlands	NEG Micon x 4	1994
Lillgrund	110	Sweden	Siemens 2.3 x 48	2007
Lynn and Inner Dowsing	194	UK	Siemens 3.6-107 x 54	2008
Middelgrunden	40	Denmark	Bonus 2MW x 20	2001
North Hoyle	60	UK	Vestas V80-2MW x 30	2003
Nysted Wind Farm	166	Denmark	Siemens 2.3 x 72	2003
Princess Amalia Wind Farm	120	Netherlands	Vestas V80-2MW x 60	2008
Samsø	23	Denmark	Siemens 2.3 x 10	2003
Scroby Sands	60	UK	Vestas V80-2MW x 30	2004
Thornton Bank I	30	Belgium	REpower 5 MW x 6	2008
Tunø Knob	5	Denmark	Vestas 500kW x 10	1995
Utgrunden	10.5	Sweden	GE 1.5 x 5	2001
Vindeby	5	Denmark	Siemens 450 x 11	1991
Yttre Stengrund	10	Sweden	NEG Micon 2MW x 5	2002

Source: AWEA 2009

Table 12.2

Offshore European Wind Parks Under Construction

Wind Park	Planned Capacity (MW)	Country	No. of Turbines/Model	Completion Expected
Alpha Ventus	60	Germany	6 x REpower 5M, 6 x Multibrid M5000	2009
Avedore	7.2	Denmark	2	2009
Baltic 1	48	Germany	21	2010
BARD Offshore 1	400	Germany	80	2010
Borkum Riffgat	220	Germany		2012
Frederikshavn	12	Denmark	4	2010
Gasslingegrund	30	Sweden	10	2009
Greater Gabbard	500	UK	Siemens 3.6-107 x 140	2011
Gunfleet Sands 1 and 2	172	UK	Siemens 3.6-107 x 48	2010
Horns Rev 2	209	Denmark	Siemens 2.3 x 91	2010
Ormonde	150	UK	30	2010
Rhyl Flats	90	UK	Siemens 3.6-107 x 25	2009
Rodsand 2	200	Denmark	89	2010
Robin Rigg (/Solway Firth)	180	UK	Vestas V90-3MW x 60	2009
Sprogo	21	Denmark	7	2009
Thanet Offshore Wind Project	300	UK	Vestas V90-3MW x 100	2010

Source: AWEA 2009

Table 12.3

Offshore Wind Park Development Activity for U.S. Waters

State	Wind Park Developer	Location	Planned Capacity (MW)
Massachusetts	Town of Hull	Harding's Ledge	14
Massachusetts	Cape Winds	Nantucket Sound	468
Massachusetts	Patriot Renewables	Buzzards Bay	300
Rhode Island	Deepwater Wind	Block Island	20
Rhode Island	Deepwater Wind	Rhode Island Sound	400
New York	Deepwater Wind	Long Island	300
New Jersey	Fisherman's Energy	Atlantic City	350
New Jersey	Deepwater Wind	Atlantic City	345
New Jersey	Bluewater Wind	Atlantic City	348
Delaware	Bluewater Wind	Off Delaware Coast	200

Source: OffshoreWind.net 2009

The focus of offshore research for wind power production is presently along several lines, the most important of which is the development of reliable foundations, towers, and turbines specifically designed for the harsher marine environment. To date, the tower and turbine technology used offshore has been essentially the same as that used onshore, with some minor modifications. An example of an offshore wind turbine on monopile foundation is shown in Figure 12.1.

For offshore wind development in the United States, water depth is a more confining issue than for the European counterparts (USDOE 2009). A number of studies have been performed to evaluate the total accessible offshore area in the BOEMRE North and Mid-Atlantic planning regions (ATM 2007; University of Delaware 2008). A map of the model-predicted, annual average, Mid-Atlantic and Northeast states' offshore wind speed is shown in Figure 12.2. The purple, red, and dark blue areas indicate winds over 7.5 m/s. These areas are potentially good candidate areas for development of wind power. For estimation of offshore development potential only these areas are considered on the combined wind resource and bathymetry maps that follow. On first review, these maps appear to include only ocean winds but actually they show wind speeds over both land and ocean. Along the U.S. East Coast, as in much of the coastal areas of the world, the larger wind resource is over ocean rather than over land. In fact, the map stops at 50 nautical miles, where many areas are just moving into dark blue (indicating class 7 winds, with an annual average speed of 8.8 m/s). Thus there is much more energy resource farther out than is shown here (From University of Delaware Graduate College of Marine Studies, original images produced by AWS TrueWind).

Figure 12.1. Horns Rev Offshore Wind Park, Denmark. Source: Dong Energy 2009. Photo credit: Elsam.

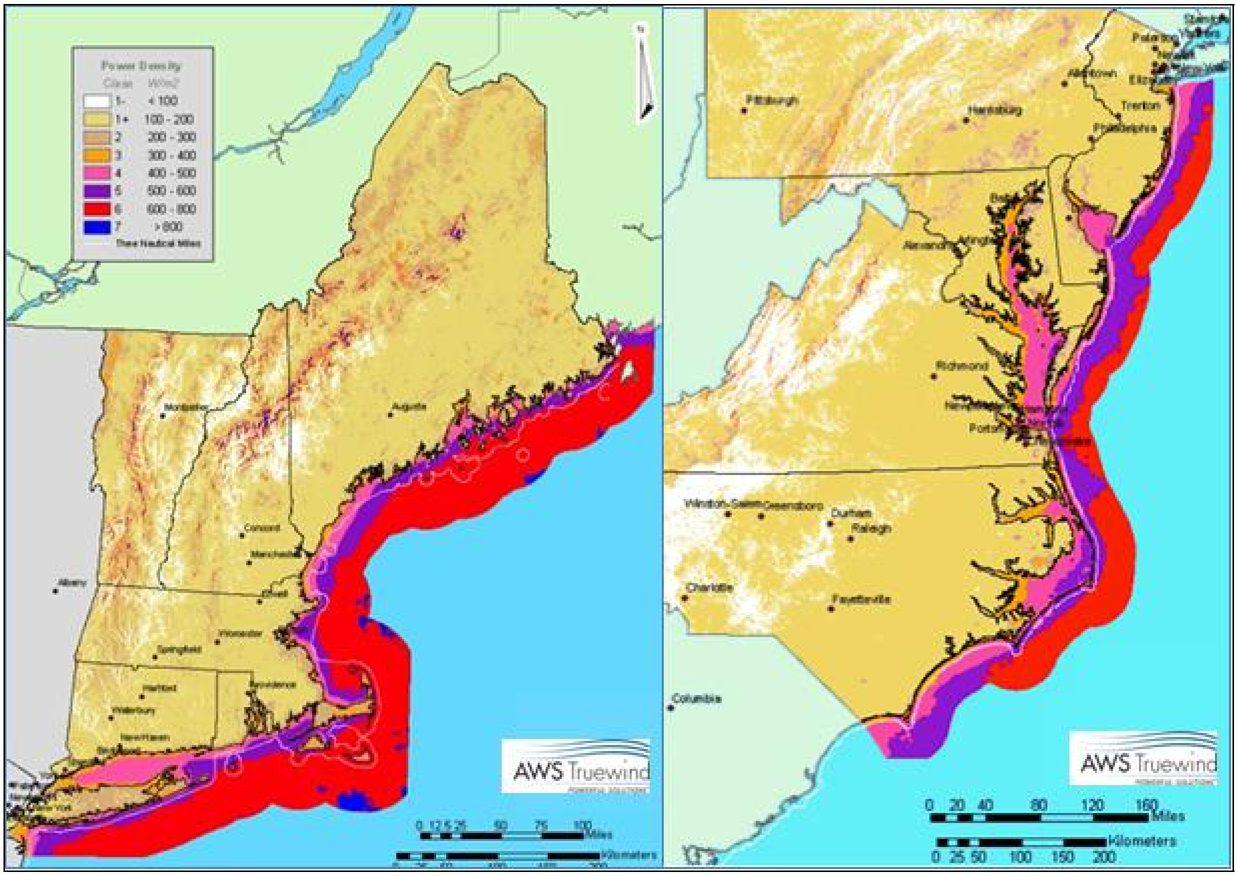

Figure 12.2. Model-predicted annual average wind speed for the Mid- and North Atlantic offshore planning areas (University of Delaware 2008). Used by permission of AWS TrueWind.

Currently, all of the offshore installed wind energy production capacity is supported on monopile foundations, which are practically viable for water depths 20 m or less, while some go to 30 m. Figure 12.3 shows the coastal bathymetry for areas where the depth is 20 m or less (all but dark blue areas). The dark blue areas are not buildable using current, commercially available technology.

Overlaying areas of wind resource of at least 7.5 m/s with water depths up to 20 m gives a narrow band of areas that are currently practically accessible for offshore wind park development using commercially available technologies (Figure 12.4). In the figure, yellow indicates the areas that have winds over 7.5 m/s and depths 20 m or less. Given the relatively small size of the areas it is clear that the buildable areas are capable of harvesting only a fraction the total offshore resource.

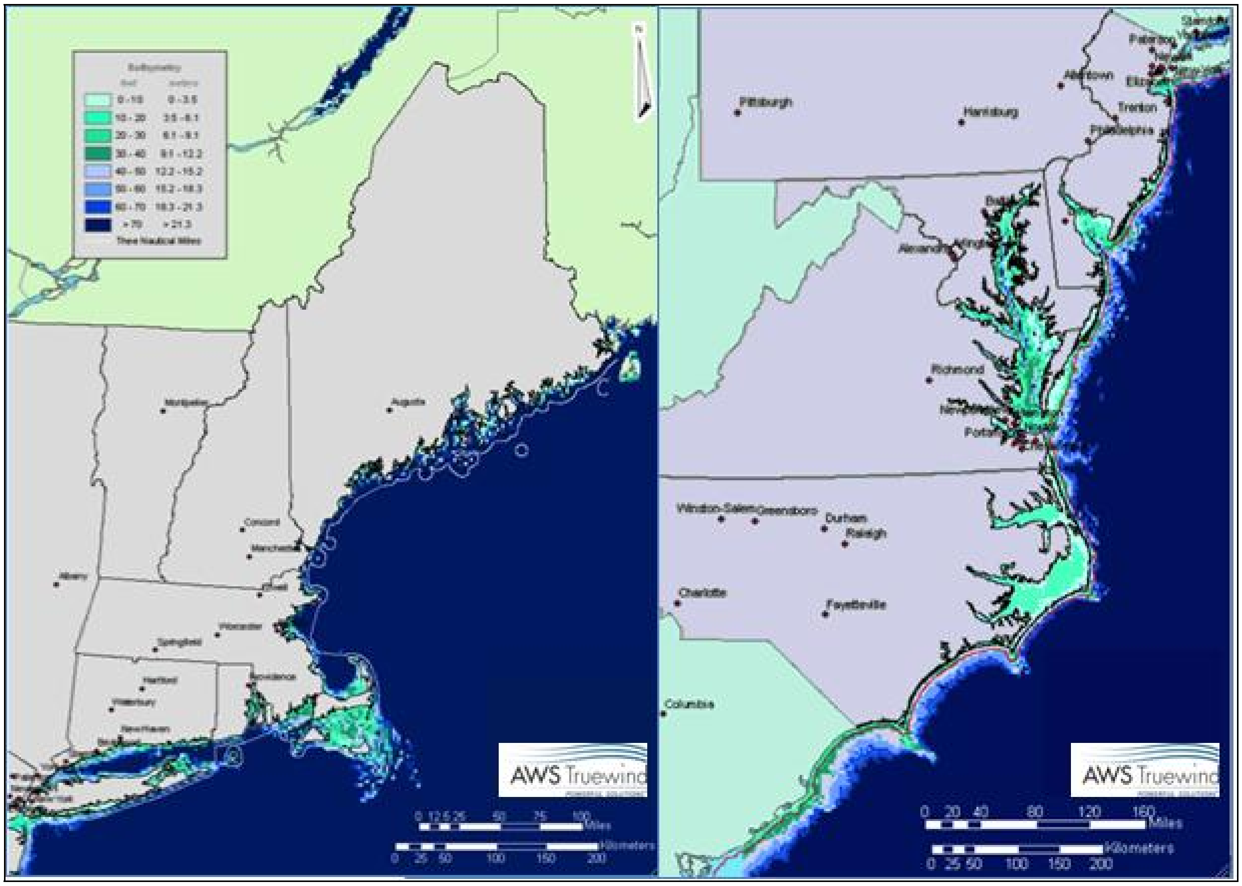

Figure 12.3. Offshore water depths for the Mid- and North Atlantic offshore planning areas (from Unversity of Delaware 2008). Used by permission of AWS TrueWind.

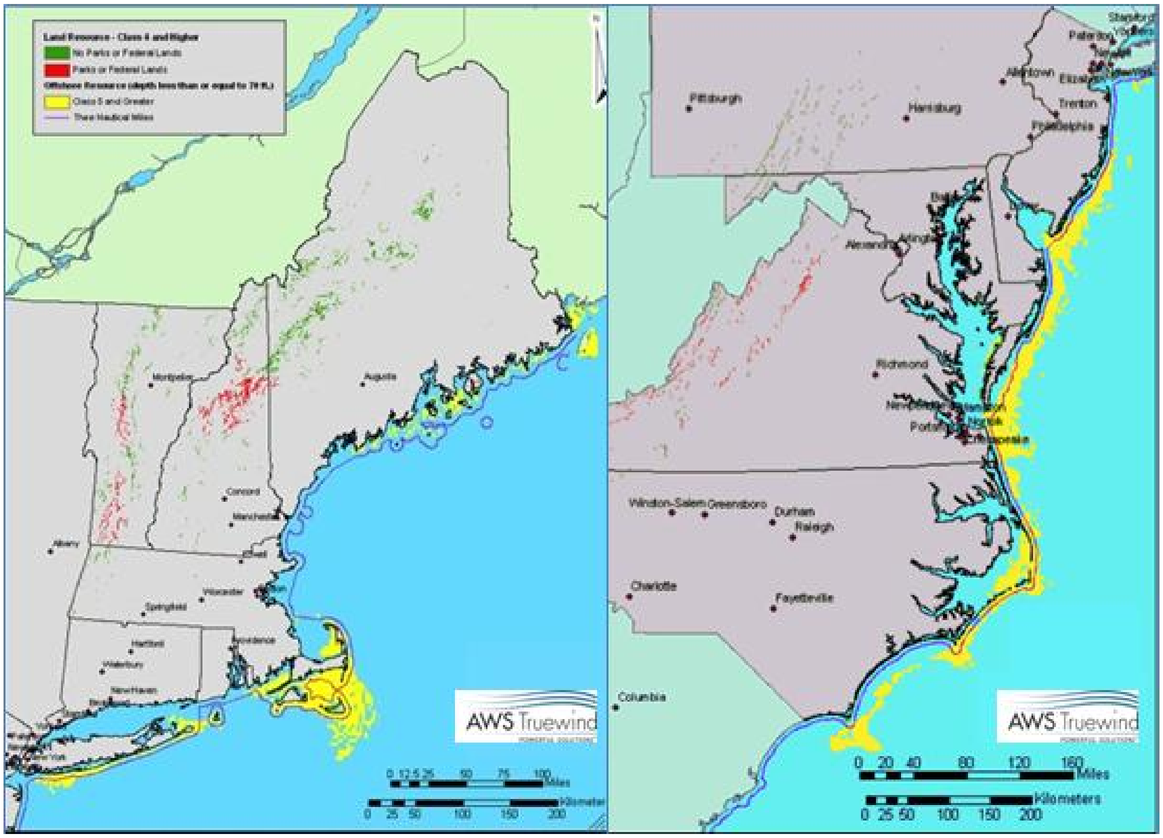

Figure 12.4. Wind speeds greater than 7.5 m/s overlaid on water depths 20 m or less indicating offshore areas in the Mid- and North Atlantic offshore planning areas that are buildable with currently available commercial technology (from Unversity of Delaware 2008). Used by permission of AWS TrueWind.

12.1.1.1 Exploration Research

Understanding the full context in the planning of an offshore wind project is very important, including production potential and the range of siting issues, as the marine environment is somewhat more complex than for onshore sites and the costs of offshore development are greater. Exploration research is therefore focused on better quantifying the potential resources, understanding the issues associated with siting and reducing the uncertainties of the development process.

Resource Modeling

Modeling the national potential for wind power has been an ongoing effort for many years now, but the research focus has moved offshore, where the driving factors and constraints are somewhat different than onshore (Short and Sullivan 2007, Musial et al. 2006). To better identify locations within a selected study area with potential natural energy resources of sufficient energy densities, a number of researchers are focusing on developing more detailed mesoscale and microscale meteorological modeling techniques for offshore resource assessment (USDOE 2008c; Bailey and Freedman 2008; Giebel et al. 2007; Phillips et al. 2006). Areas of focus include the sea breeze effect (Freedman 2009) and the influence of local topography and overland heating and cooling on the development of the boundary layer and turbulent energy production for nearshore sites (Kelley and Jonkman 2008; Lange et al. 2004).

Discrepancies have been found between predicted and observed offshore wind park power production (Barthelmie et al. 2006). New algorithms for wind park layout optimization incorporating detailed wake effect are also being developed to assist in offshore wind park design and planning and in the estimation of the power production potential for a particular site (Elkinton et al. 2008).

Project Siting

A major development area for ocean planning is the development of site screening methodologies for identifying and evaluating the multiple and potentially conflicting uses of offshore areas (MAEOEEA 2009; Fugate 2008; Rodgers and Olmsted 2008; ATM 2007; Dhanju et al. 2008). In addition to the necessary wind resource assessment, the screening procedures often include collecting environmental data on such things as bathymetry, bottom geology, wave climate, pelagic and benthic fish habitats, marine mammal feeding and migration, and avian feeding and migration. Screening procedures also include anthropogenic uses of the potential project area including shipping and transit routes, cable areas, marine fisheries, Federal Aviation Administration exclusion zones for airport approach and a number of other site-specific exclusion areas. The product of the screening assessment allows state and Federal agencies as well as developers to determine the more productive and constructible sites within the planning areas.

Data Acquisition

Offshore planning and development, while not new, have received renewed focus as a result of the offshore wind energy development process. As the industry has developed, the lack of detailed data, both geophysical and biological, has highlighted the need for more detailed offshore observations. Part of the reason for the paucity of data to date is the difficulty of obtaining observations, including installation, maintenance, and cost of instrumentation. At present, installation of a fixed, offshore meteorological observation tower is a multimillion dollar investment. Buoy-mounted LIDAR systems that can both withstand both the harsh marine environment and maintain useable signal-to-noise ratio in the constant oscillation of offshore wave conditions are being developed. The cost is also high for photo, radar, sonar and other systems used to detect the presence or passage of birds above the water surface and fish and mammals below. Smaller, multicomponent systems that can be attached directly to existing structures are being developed and tested.

12.1.1.2 Anticipated Development and Engineering Challenges

The two major environmental factors that drive the technical difficulty of offshore wind energy development are water depth and the harsh marine conditions. The latter includes high average and maximum wind speeds; significant waves, defined as the average of the one-third largest waves; extreme waves, defined as greater than twice the significant wave; ocean currents and the corrosive salt water environment, all of which serve to increase the cost of offshore development.

The majority of research and development projects under way focus on various aspects and engineering solutions to address these conditions.

Foundation Design

There is a great deal of interest in overcoming the limits of constructible water depth (driven primarily by the present monopile foundation technology as shown in Figure 12.5), which would allow development of a far larger offshore area than is presently available (Robinson and Musial 2006, Musial et al. 2006).

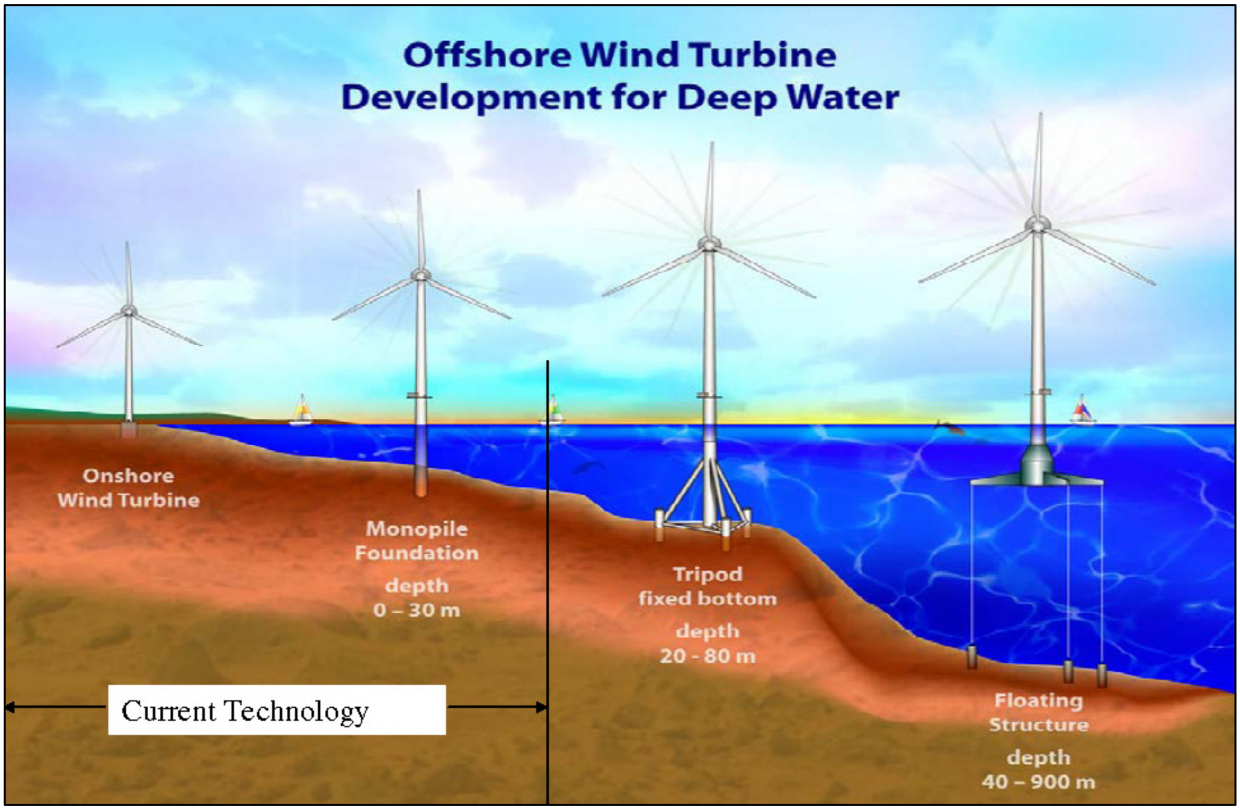

Figure 12.5. Example offshore wind turbine foundation types for a range of water depths (Robinson and Musial 2006).

Foundation design engineering and bottom impact has been a major part of the research effort as wind parks attempt to develop sites in greater depths than those in which the current commercial monopile system can reliably perform. The new designs include updated monopile types, hybrid, tripod, jacket, semi-submersible, floating, tension line, and moored (Schaumann and Keindorf 2008; Musial et al. 2007; USDOI, MMS 2007a; Argyriadis and Marchus 2007; Achmus et al. 2007; Kleineidam and Schaumann 2006). Figures 12.6 and 12.7 show a number of new offshore foundation types under consideration.

Figure 12.6 Example offshore wind turbine foundation types for transitional depths, 30-90 m (Robinson and Musial 2006).

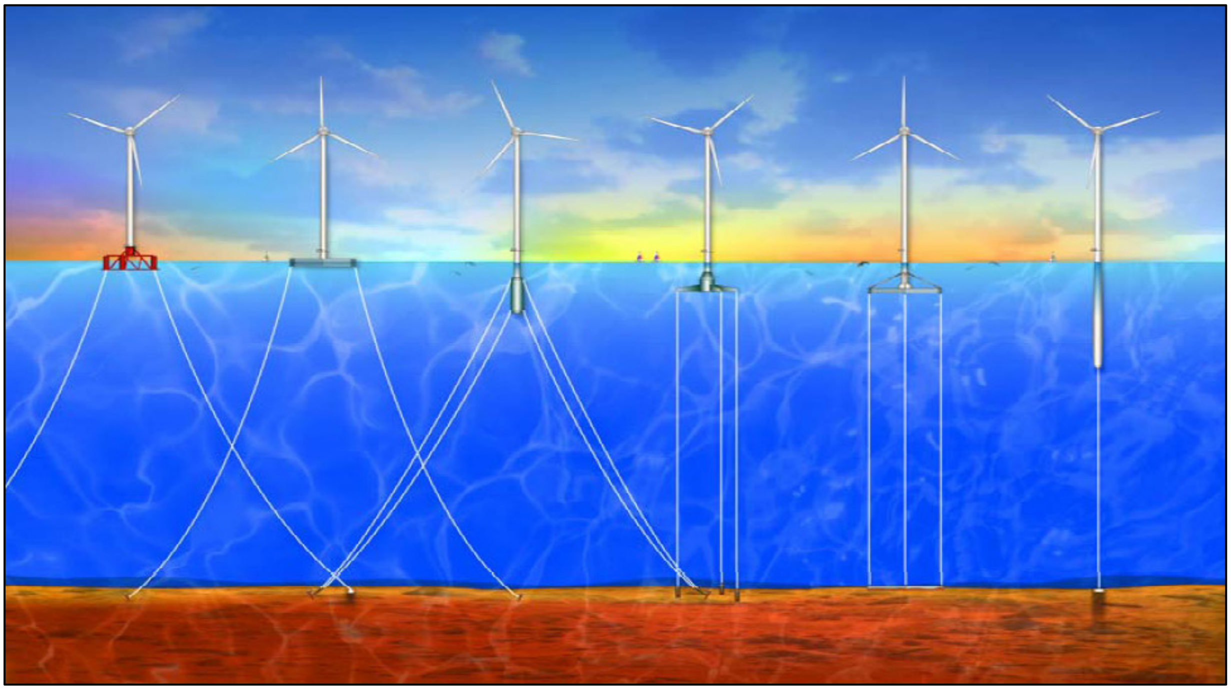

Figure 12.7 Example foundation types for offshore wind turbine at depths greater than 60 m (Robinson and Musial 2006).

Learning from the offshore oil and gas industry, a number of alternative foundation and tower designs to increase the constructible water depth have been proposed and are being tested. The potential energy development for a single wind turbine installation is significantly smaller than for each fossil fuel platform, leading to more stringent economic constraints and a direct technology transfer is economically feasible so new innovations are necessary.

One potential solution to the present depth constraint with far-reaching implications is the development of a floating platform foundation for the deepwater offshore areas. The advent of a floating system would dramatically increase the potential buildable area and allow for the farther removal of a wind park from near shore use conflicts and visibility issues.

The development of a stable floating tower and turbine design has provided a potent engineering challenge and has been a major focus of R&D in this sector (Butterfield et al. 2007, Robinson and Musial 2006). Environmental factors that affect the floating system design are the high wave climate, strong currents and bottom geology for the mooring system.

Larger Systems

Development of offshore wind power is more expensive per turbine installed than is development of similar sized wind parks onshore (Black & Veatch 2007; Fingersh et al. 2006). Several development paths, including generator, blade and tower technologies, are focused on improving the economics of offshore installation. The primary focus is the development of larger turbines, in the range of 5-10 MW (Robinson and Musial 2006).

In order to increase the size of the wind turbine generators to the 5-10 MW range, the rotor diameter (i.e. blade length) will have to increase in size correspondingly. Blade design analyses for the larger offshore wind turbine generators, including aero-elastic simulation codes, are being developed to assist design and evaluation of the new systems (Passon et al. 2007, Kanemoto et al. 2007, Toshiak et al. 2006). Some of the innovations may include alternatives to conventional 3-blade rotors, because these blades will have difficulties with the floating systems, where the tower may be expected to oscillate more dynamically than the fixed foundation types.

Design Standards

To date design standards for wind turbines have focused on those for onshore use. The offshore environment presents some obvious and some more subtle challenges for wind turbines in that environment, and an effort is being made to update and upgrade present standards for the offshore environment (AWEA 2009; USDOE 2008a; IEC 2005). These challenges are discussed in the next section.

The following two sections are associated with the research necessary for the development of design standards that are more focused on meeting the demands of the offshore environment.

Forces and Loads on the System

High waves and associated tower oscillations dramatically impact the turbine rotor and create complex dynamic response in the blades. Computer models are being developed to simulate the coupled turbine blade and tower dynamic response to loading to assist in design and evaluation of new systems (Jonkman and Buhl 2007a; Jonkman and Buhl 2007b; Bir and Jonkman 2007; Jonkman and Sclavounos 2006; Wayman et al. 2006).

The additional forces and the dynamic action of the waves and increased wind turbulence offshore will serve to reduce the expected lifetime of an offshore system. Floating wind turbine generators will be more affected, prompting research on the engineering, modeling and life cycle assessment of those systems (Sclavounos 2008; Sangyun and Kim 2008; Shimada et al. 2007; Hong and Kim 2004).

A great deal of the research effort has been on wind turbine blade development and testing for systems better able to withstand the more turbulent and dynamic offshore environment (Koichi et al. 2008; Cotrell et al. 2006). The additional forces and dynamic loads acting on a floating turbine will increase the need for new materials and designs specifically addressing the complex dynamic conditions. Figure 12.8 presents a schematic of the environmental forces that offshore wind turbine designs need to address.

Wind and wave load also affect fixed foundation systems and research on foundation properties for support structures, fatigue load stress mitigation and damage prediction modeling has progressed (Huhn and Herion 2006; Yamashita and Sekita 2004; Zaaijer 2004; Henderson and Zaaijer 2004). In addition, component and construction materials used in the offshore systems are being refined to withstand the more dynamic and corrosive environment, including steel, fiberglass composite, carbon fiber composite, coatings, grout, and concrete (Klose et al. 2008; Lücken et al. 2007) covering all components of the system.

A number of the planned offshore wind parks are located on waters offshore of the northern states where icing and ice load on foundations can be a serious problem. Recent studies address ice load estimation and mitigation measures (Mróz et al. 2008; Barker et al. 2005). Dynamic models are being developed to assess the loads and failure modes along with passive and active mitigation alternatives.

System Reliability

Offshore systems are also significantly more difficult to operate and maintain than those onshore, because of the logistics of transporting personnel and equipment to the towers offshore and due to the harsher marine environmental conditions. This has prompted the need for research to improve system reliability in areas such as the gearbox (Musial et al. 2007) and LIDAR control that enhance turbine capabilities and thus, productivity (Harris et al. 2006).

Offshore, subsurface cable reliability and installation has received significant attention as an important area for research and development. Electrical collection and transmission from large scale offshore wind parks are particularly vulnerable to moisture penetration in the offshore environment and require specific design considerations (Green et al. 2007).

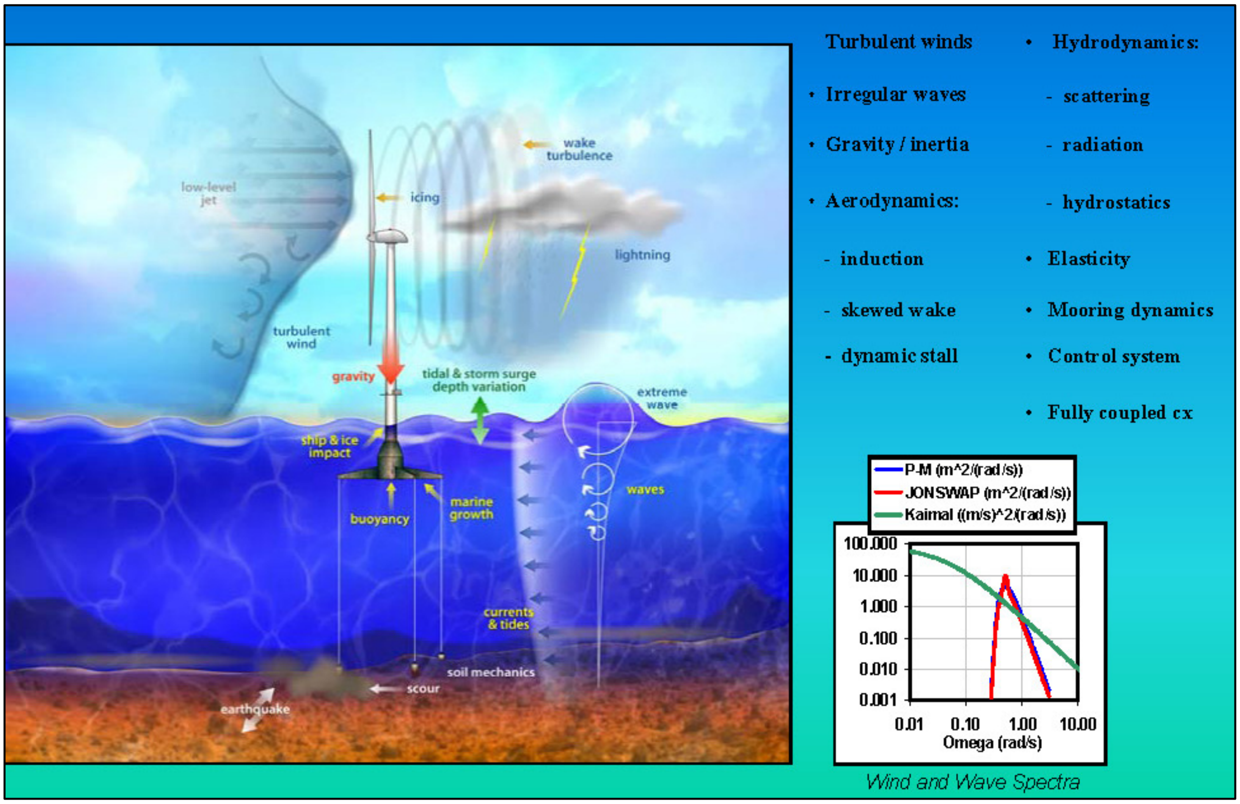

Figure 12.8 Schematic representation of the environmental aspects of the technical challenges facing the research and development of offshore wind turbines in general and specifically for floating foundations (Robinson and Musial 2006).

Due to the intermittent nature of the wind, power generation from multiple large offshore wind parks will have a destabilizing effect in the grid. Power stability modeling for grid integration of large scale intermittent power (Pinson et al. 2008; Bialasiewicz and Muljadi 2006) and variable speed wind turbine dynamic models for grid integration studies (Behnke 2007) are being developed and applied to help understand the potential impacts to the system, as well as assisting in the design and evaluation of mitigation measures.

12.2 WAVE ENERGY

Wave energy conversion (WEC) technologies are emerging, although there are presently no operational projects in the Mid- or North Atlantic Continental Shelf, defined as the area seaward from shore to the 100 m isobath. The Federal Energy Regulatory Commission (FERC) has licensing jurisdiction over renewable energy based on hydrokinetic principles, including wave, tidal current and ocean current systems, via a recently published (9 April 2009) Memorandum of Understanding between it and the U.S. Department of the Interior, acting for the Minerals Management Service (MMS) (Salazar and Wellinghoff 2009).

FERC licensing is a multistep process with permits issued for site studies and licenses issued for pilot studies and full long-term operations. From the FERC website (USDOE, FERC 2009), as of 6 April 2009, there are 11 pending permits, 11 permits issued and 1 license issued in U.S.

waters. Of the 11 pending permits, four are on the Atlantic shelf; of the 11 permits issued, only one is on the Atlantic shelf; and no licenses have been issued on the East Coast of the United States. Table 12.4 summarizes the locations by state.

Table 12.4

Locations by State of Pending and Issued FERC Permits for WEC Systems.

State	Pending to	Issued to
Massachusetts	Grays Harbor Ocean Energy Company, LLC	
Rhode Island	Grays Harbor Ocean Energy Company, LLC	Energetech America LLC
New York	Grays Harbor Ocean Energy Company, LLC	
New Jersey	Grays Harbor Ocean Energy Company, LLC	

Although the Grays Harbor pending permits are for WEC systems, the applications to FERC state that coincident wind energy systems are likely to provide the bulk of the power. The Energetech America permit has not been activated as the developer is focusing on other sites with higher power potential.

12.2.1 Research and Development Activities

The recent focus on offshore renewable energy sources has generated considerable interest among developers to design a WEC system that will generate small and/or utility-scale electricity as well as withstand the sometimes extreme environmental conditions in the offshore environment, including the Mid- and North Atlantic Continental Shelf areas. In fact these areas are subject to lower energy waves than other U.S. areas such as the Pacific coast, southern Alaska and northern Hawaii (Bedard et al. 2005). Western European interest in wave energy has been active for some time (Wilson and Downie 2003), preceding that in the United States.

U.S. Federal agencies such as the USDOE, the BOEMRE, and FERC, all have programs devoted to offshore renewable energy and wave energy in particular. USDOE supports an online database known as the Marine and Hydrokinetic Technology Database (USDOE 2008d) that strives to provide up-to-date information on the many technological approaches to generating power from waves, both in the United States and around the world. It can be queried online to provide information by projects in a geographic area, technology type, generation capacity and the stage (research, development, testing, or operational).

The BOEMRE has prepared a number of documents focused on renewable energy and wave energy in particular, with descriptions of the types of technology approaches used. These include those focused directly on wave energy (USDOI, MMS 2006b) as well as programmatic environmental impact statements (USDOI, MMS 2007b) and syntheses of environmental effects (USDOI, MMS 2007a).

In addition the Electric Power Research Institute (EPRI) has conducted a number of studies of ocean energy in general (Bedard et al. 2007), and wave energy in particular (Bedard et al. 2005).

Wave Energy Technologies

WEC technologies can be classed into four basic types, summarized below. Details of the technologies can be found in Bedard et al. (2005), USDOI, MMS (2007a), USDOI, MMS (2007b), and the USDOE database, among others. A short description of the technologies follows, based on the presentation in the BOEMRE documents cited.

Terminators

Terminator devices extend perpendicular to the direction of wave travel and capture or reflect the power of the wave. These devices are typically installed onshore or nearshore although floating versions have been designed for offshore applications. The oscillating water column (OWC) is a form of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. The wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a generator.

Attenuators

Attenuators are long multisegment floating structures oriented parallel to the direction of wave travel. The differing heights of waves along the length of the device causes flexing where the segments connect, which drives hydraulic pumps built into the joints that ultimately power a generator.

Point Absorbers

Point absorbers are floating structures that have a small horizontal dimension compared with the vertical dimension and utilize the rise and fall of the wave height at a single point. The wave energy is used to pressurize a fluid that in turn drives a generator.

Overtopping Devices

Overtopping devices have reservoirs that are filled by impinging waves to levels above the average surrounding ocean. The released reservoir water is used to drive a generator. Overtopping devices have been designed and tested for both onshore and floating offshore applications.

12.2.1.1 Exploration Research

As is typical for all offshore renewable energy types, the primary drivers of exploration are identifying sites with the highest energy density, or power potential, along with the shortest distance-to-shore to minimize transmission costs. Power potential is a function of wave height and period, which can vary dramatically at some sites due to local and remote wind patterns. It is expressed as power per unit length along a wave crest (kW/m). Although highly variable, it is possible to assess the likely distribution of wave energy by analyzing observed time series of waves at potential sites, or by using model-generated databases such as the U.S. Army Corps of Engineers Wave Information Study (WIS). In general the wave energy increases in deeper water (greater than 200 m for regular smooth waves, or swells) where the frictional effects of the bottom on the wave are not important (USDOI, MMS 2006b). At 20-m depth a wave has lost approximately one third of its energy compared to deep water. Therefore, on shallow shelves, the distance offshore to reach sufficient depths may make the energy transmission costs prohibitive.

The wave climate on the Atlantic shelf is not energetic enough to encourage development, as evidenced by the FERC permitting and licensing activity summarized in Section 12.2. Hagerman (2001) performed a wave energy resource assessment for southern New England (Portland, ME to New Jersey) using the WIS data and NOAA offshore buoy observations and found that most areas have low wave energies, about 26 kW/m compared to the 60 kW/m off the west coast of the British Isles. Bedard et al. (2005) found that the U.S. continental west coast, south Alaskan coast, and northern Hawaiian coast are preferred over the Atlantic coast due to their greater wave power potential. Hagerman (2001) also developed a ratio of average wave energy flux to storm wave energy flux to determine a "wave energy development index", which provides a numerical estimate of the cost of designing and installing a wave power plant to that of a plant that must withstand extreme waves.

In 2008, USDOE funded a series of renewable energy studies as part of its ongoing support to investigate advanced water power energy generation technologies (USDOE 2008b). One study presently being conducted by EPRI is known as the Wave Energy Resource Assessment and GIS Database for the United States Its goal is to determine the naturally available resource base and the maximum practicable wave energy extractable from it in the United States, as well as the determination of annual electrical energy which could be produced by typical wave energy conversion devices from that resource. In 2009 USDOE will continue funding renewable energy-related studies at a level of $40 million.

12.2.1.2 Anticipated Development and Engineering Challenges

Development activities in WEC technologies are significantly behind the wind industry in terms of commercially viable systems. Reduction of cost per kW power production is the basis for the majority of development efforts. Performance, cost and economic models show that a commercial-scale wave power plant's economic viability will depend largely on the wave power density at the deployment location (Previsic and Bedard 2007). While there is much information available for the deepwater wave energy resource off many coastal areas, the wave climate in suitable deployment locations is not always well understood. Further modeling could greatly enhance the understanding of the wave energy resource in the most suitable deployment locations. Data acquisition and analysis as well as analytical model development and application techniques that serve to better characterize and evaluate the best wave power sites are a focus of recent development activities.

Clearly the most challenging aspect of the development of offshore WEC devices is overcoming the large and dynamic ocean forces and the general corrosive nature of moving salt water. Technology is still in an immature stage and there is much uncertainty regarding environmental impacts. These issues are being addressed using targeted R&D and in-ocean testing (Previsic and Bedard 2007).

The environmental challenge arises in the difficulty of developing cost-effective technology options. Wave power will only be competitive when the total cost of generation is reduced. The total cost includes the primary converter, the power takeoff system, the mooring system, installation & maintenance cost, and electricity delivery costs. An effort is being made to increase the ability to model the performance, survivability, operational requirements, cost and economics of various technologies (Previsic and Bedard 2007). As with most novel technology, environmental impacts are at present uncertain and will need to be assessed as a parallel effort to technology deployments.

Foundation Design

The influence of wind and current forces superimposed upon the wave regime means that WEC devices may not necessarily align with the wave direction in mixed conditions, (DTI 2007a). Directionality remains and issues for some systems. Many mooring options have been considered to address that and other issues. Mooring configurations that allow the buoy to move freely to avoid load and perform effectively are necessary but the downside is that this requires a considerable amount of sea space. Research and development in mooring configuration is necessary and continuing.

Unlike access to WTGs, access onto offshore floating buoys or other foundation configurations will be extremely difficult and therefore provide a challenge to the design of maintenance systems for the machines (Previsic and Bedard 2007, Wolfram 2006, DTI 2007a).

Mooring system configuration is very important for WEC devices. In particular work is being done to evaluate and improve the ability of mooring systems to respond to extreme waves (DTI 2007a). To construct devices that can survive storm damage and saltwater corrosion, designers must overcome likely sources of failure, including seized bearings, broken welds, and snapped mooring lines. Knowing this, designers may create prototypes that are so overbuilt that materials costs prohibit affordable production.

Larger Systems

The quest for a commercially viable system that can be used for the development of large offshore systems is still under way (DTI 2006). Unlike the wind industry, which has coalesced around a specific system design, the field of contenders is still winnowing at present. Development of practical, productive, reliable systems is a focus (Wolfram 2006). Cost for a small demonstration or production site, where a few WEC devices could be tested is heavily dependent on electrical interconnection costs. Subsea cabling cost will have a minimal impact at a 100 MW+ scale for most locations considered (Previsic and Bedard 2007).

Development of forecasting skills including a strong correlation between predictions and near-shore buoy locations offer a wave energy forecasting capability that wave power plant owners could use for making days-ahead wave power commitments, thus enhancing the value of wave power to the electricity grid. Work is being done to evaluate the effectiveness of implementing such a system using NOAA's operational Wavewatch III model system (Bedard 2008).

Efficiently converting wave motion into electricity is difficult due to the nature of wave dynamics, as wave power is basically available in low-speed, high forces, and the motion of forces is not in a single direction. Most readily-available electric generators, however, operate at higher speeds, and most readily-available turbines require a constant, steady flow.

Grid integration will be an issue if large scale wave facilities are developed. This is manifest both in the distance from shore and the intermittent nature of the power production. Further study of grid-interconnection limitations is being researched (Previsic and Bedard 2007).

Design Standards

Each type of WEC device has many different performance characteristics (DTI 2007b). At present there is little standardization of design criteria for WEC machines for categories including acceptable power production, system reliability and longevity, and accessibility.

System reliability and availability are key issues and continuing topics for research and development (Wolfram 2006). Much of the research activity is focused on the harsh marine environment, including issues of external water pressure, the corrosive and damp saline environment, temperature variations, and variable direction oscillations. In addition, access onto offshore floating buoys will be extremely limited so that a maintenance strategy has to be devised that requires little or no intervention (Previsic and Bedard 2007, Wolfram 2006, DTI 2007a).

In many places the most energetic wave climates may not provide the most cost-effective sites for wave energy devices, by virtue of the fact that the larger extremes pose significant loading problems, but the energy in these extremes cannot be economically captured (DTI 2007a).

A framework for the evaluation of availability and reliability is desirable so that competing devices can be evaluated and compared on a common basis (Wolfram 2006). Research is currently focused on several aspects of the reliability issue, including a framework for that assessment, a reliability database for WEC devices, component and subsystem testing, and structural mooring system and foundation assessment (Wolfram 2006).

12.3 OCEAN CURRENT ENERGY

The development of ocean current technologies is lagging that of wave technologies, and there are presently no operational projects in the Mid- or North Atlantic continental shelf. From the FERC website (USDOE, FERC 2009), as of 6 April 2009, there are three pending permits, one permit issued and no licenses issued. None of the three pending permits are on the Mid- or North Atlantic shelf areas; the lone permit issued was to Manaook Associates in Maine. Closer inspection of the actual application reveals that the permit was actually for a tidal current energy system driven by the reversing tides in the Manan Channel off the coast of Maine. Thus there are no ocean current energy conversion (CEC) systems in any stage of permitting or licensing in the Mid- or North Atlantic shelf areas. This is not unexpected, since the minimum ocean current speed necessary for system operation is approximately 1.5 m/s, and no known sites exist on the U.S. East Coast except for the Gulf Stream, running north along the east Florida coast, where two of the three pending permits are located.

In contrast there are seven pending permits for tidal current energy systems, three in Maine and one in New York. There have been 36 permits issued, seven in Maine, two in New Hampshire, three in Massachusetts, seven in New York, one in New Jersey and one in Delaware. Thus while current energy systems have a role on the Mid- or North Atlantic shelf areas, they are all tidal and located in near-shore areas.

12.3.1 Research and Development Activities

Current Energy Technologies

From USDOI, MMS (2006c) ocean CEC technology is at an early stage of development, with only a small number of prototypes and demonstration units tested in this environment. The technology is similar however to in-river or tidal current energy systems, sometimes identical.

Submerged Turbines

Energy can be extracted from the ocean currents using submerged turbines that are similar in function to wind turbines, capturing energy through the processes of hydrodynamic, rather than aerodynamic, lift or drag. These turbines have rotor blades and a generator for converting the rotational energy into electricity. Turbines can have either horizontal (like wind turbines) or vertical axes of rotation. Mechanisms such as posts, cables, or anchors are required to keep the turbines stationary relative to the currents with which they interact. Prototype horizontal axis turbines, similar to wind turbines, have been built and tested. Vertical axis turbines are either drag or lift designs. The lift devices seem to offer more potential (e.g., the Darrieus-design turbine design, with three or four thin blades of aerofoil cross-section, has been tested in the Kurushima Straits off Japan) (WEC 2001).

Biological Mimicry

A unique current (as well as tidal and wave) power conversion system is based on the propulsion of Thunniform-mode swimming species, such as shark, tuna, and mackerel. The system mimics the shape and motion characteristics of these species but is a bottom-fixed device in a moving stream. In this configuration the propulsion mechanism is reversed and the energy in the passing flow is used to drive the device motion against the resisting torque of an electrical generator. Due to the single point of rotation, this device can align with the flow in any direction, and can assume a streamlined configuration to avoid excess loading in extreme conditions.

The USDOE database known as the Marine and Hydrokinetic Technology Database (USDOE 2008d) provides up-to-date information on the many technological approaches to generate power from currents both in the United States and around the world. It can be queried online to provide information by projects in a geographic area, technology type, generation capacity and the stage (research, development, testing, and operational).

12.3.1.1 Exploration Research

As described in USDOI, MMS (2006c) ocean currents are primarily driven by wind and solar heating of the waters near the equator. These currents are relatively constant and flow in one direction only. Some examples of ocean currents are the Gulf Stream, Florida Straits Current, and California Current, none located in the Mid- or North Atlantic Outer Continental Shelf area. Since the minimum speed required for these systems is 1.5 m/s and there is no offshore location in the Mid- or North Atlantic shelf area it is not likely that any sites will be identified there. This is not true for tidal current systems that are located in nearshore areas.

12.3.1.2 Anticipated Development and Engineering Challenges

Marine CEC systems are by their nature similar to tidal current systems so it is expected that development of the systems will parallel one another to an extent. Unlike either wind power production or WEC power production, CEC power generation can be a very stable and predictable renewable energy source if there are sufficient current speeds (Jo et al. 2007). The technology for offshore current systems is still in the early stages and research and development paths are working toward a commercially viable system (USDOI, MMS 2007a).

The greatest challenge for offshore CEC systems is the marine environment itself. As with wave energy machines, much of the development is focused on reliable, productive and cost-effective systems that can survive the harsh forces and environmental conditions in the open ocean (USDOI, MMS 2007a). A few studies have been directed at determining the performance and ultimate power production potential for these offshore devices, while others are developing models to simulate and assess specific designs and the application of those systems (Bahaj et al. 2007, DTI 2006, Meyers and Bahaj 2005). A number of projects are focusing on system development to improve reliability of the systems; the goal of one project was also to develop a method for installation and maintenance that does not require direct underwater activities (DTI 2006).

Foundation Design

While there may be some development activity in the tidal current and WEC arenas, there does not appear to be much emphasis on research of the foundations for offshore CEC systems specifically (USDOI, MMS 2007a).

The development of foundation technology will be as important to offshore current installations as to tidal current and wave systems. While there may be some development activity in the tidal current and wave energy conversion arenas, the foundation, mooring and tethering systems would potentially need to be significantly different to handle the greater offshore depths and the fact that the stronger currents are likely near the surface (USDOI, MMS 2007a).

Larger Systems

A number of studies are focusing on model simulation tools to assess various aspects of the design and implementation of offshore CEC systems. Researchers and developers alike are still focused on developing the best design and installation system for use in commercially viable power production. Some are developing model systems to simulate and assess specific designs and the application of those systems (Myers and Bahaj 2005). Other studies are assessing the interaction of multi-arrayed current power generation (Jo et al. 2007). There are still many areas where additional research is needed to better understand the characteristics of current power generation in actual installations. One potential system calls for a unit with multiple rotors;

however, the interference between rotors may affect the performance of the system (Jo et al. 2007).

Multi-turbine array systems present some immediate design challenges in terms of system stability and the potential for interference between the rotors. This wake effect, while also a concern in wind turbine arrays, has greater potential to affect the performance of the current system than in the atmosphere because the water density is so much greater (Jo et al. 2007).

Design Standards

There are a number of efforts that seek to improve and optimize the power curve associated with CEC devices. Much of the system design activity is devoted to the various rotor types including both vertical and horizontal axes and variations in the blade design itself (Falcao De Campos 2007; Coiro et al. 2005). Theoretical analysis and numerical prediction of performance is compared and validated with experimental test results on both model and real-scale turbines. Numerical model codes are being developed to simulate the systems and compare them with experimental investigations, including sea deployment and tank tests, of the vertical axis hydro turbines (Tadashi et al. 2007; Guido et al. 2006; Coiro et al. 2005). Similarly, tests are being developed for experimental verifications of numerical predictions for the hydrodynamic performance of horizontal axis marine current turbines (Bahaj et al. 2007) and other systems (Schönborn and Chantzidakis 2007).

The technology for offshore CEC devices is still in the early stages of development and there are no coherent standards for assessing and inter-comparing the systems. No commercially viable systems have been deployed or are planned for deployment (USDOI, MMS 2007a), so a system type to which design standards could be written does not yet exist.

12.4 SPILL TECHNOLOGIES

The BOEMRE regulates all offshore facilities that handle, store or transport oil on the OCS and requires every owner or operator of such facilities to submit for approval an Oil-Spill Response Plan (OSRP) under 30 CFR 254. This requirement extends to renewable energy facilities such as the proposed Cape Wind Energy Project in Nantucket Sound as evidenced by an OSRP included in the Final Environmental Impact Statement for the project (USDOI, MMS 2009). The renewable energy industry, particularly as it moves from prototype to commercial (utility) scale activities, with many individual energy generating devices, will likely incorporate a central structure which links the devices before the energy is transmitted to shore. The Cape Wind Energy Project will consist of 130 wind turbine generators (WTGs), an electric service platform (ESP) and a series of cables connecting the WTGs to the ESP and a pair of cables from the ESP to shore. The ESP will include a 150,000 L storage tank for electrical insulating oil used in the WTGs (USDOI, MMS 2009).

Since most of the efforts to prevent and control spills have focused on the oil industry, it is instructive to review that work and its application to wind, wave and current renewable energy industry.

12.4.1 Spill Prevention

Prevention of oil spills from renewable energy facilities, following the lead of the oil industry, is achieved by sound engineering design, construction and operating practices, facility maintenance integrity and high levels of environmental awareness, and staff training and commitment (APPEA undated). From the engineering design perspective, each piece of equipment with the potential to cause a spill must be designed to both minimize potential leakage from component or complete failure and use automatic shutdown devices. Preventive maintenance programs must be designed to ensure that critical equipment that could ultimately cause a spill is inspected on a schedule to minimize risk. Staff training to perform inspections and maintenance with the awareness of the environmental consequences of failure is also critical. Operational training is similarly important since many environmental risks also pose health and safety risks to operators.

12.4.2 Spill Response

A recent comprehensive review of innovation and research in the areas of oil and chemical spill response technology was conducted for the National Plan Environmental Working Group of the Australian Maritime Safety Authority by APASA/TEL (2003). The scope was limited to new and emerging technologies relevant to marine waters and did not review the extensive body of information on commercially available equipment that uses existing technology. The sections of this review include the following:

- Spill preparation, testing and training
- Spill detection, surveillance, tracking and measurement including local-scale sentry systems, wide-scale remote sensing systems, detection of submerged oil slicks, innovations in the detection of oil in and under ice, and innovations in the identification of oils
- Electronic spill prediction and response management systems including oil spill trajectory and fates models, data assimilation to improve trajectory and fates modeling, and electronic spill management software
- Containment devices including performance testing, and containment technology
- Oil recovery devices including performance testing, fast water oil recovery, oil recovery in high wave conditions, testing and development of skimmer performance for problem oil types, pumping and handling of high viscosity oils, and emulsion-handling
- Oily-waste treatment, handling and recycling
- *In situ* burning of oil spills
- Chemical oil spill treatment agents including chemical dispersants and decision support for dispersant application and surface washing agents
- Shoreline clean-up including bioremediation
- Wildlife impact management and minimization including oiled wildlife care facilities and oiled wildlife protection
- Developments in chemical spill response

There has also been investigation into the progress and benefits of technology development in oil spill response (Etkin and Tebeau 2003). The authors developed a simple approach in quantifying the value of technology improvement for the three most significant oil removal technologies: mechanical recovery, dispersant application and *in situ* burning. They found that the analysis is highly dependent on the specific circumstances of the spill and developed a hindcast technique that was applied to known spills with the assumption they would occur in the future to determine oil recovery and cost savings.

12.5 STORAGE TECHNOLOGIES

A major issue for offshore renewable energy sources is that the energy is not always produced when there is demand for it. To address the intermittent and sometimes unpredictable nature of energy production from these sources, methods for the interim storage of excess alternative energy must be developed. Two methods have been identified, although neither is in commercial use. The first is pumped storage where the generated electricity is used to either pump water into an elevated tank or structure, or more likely, water is pumped out of a tank or structure below mean sea level. In theory the storage facilities can be located offshore (most likely) or onshore. The second method is the use of hydrogen (H_2) as an energy storage medium where the generated electricity is used to convert seawater via electrolysis and then stored as a gas or liquid. The generation and storage of hydrogen can be located either offshore or onshore.

Other energy storage technologies, such as batteries, flywheels, superconducting magnetic energy, compressed air, and supercapacitors are theoretically possible, but none appear to have been considered for use in offshore power generation thus far, except for powering of relatively small or single structures such as data buoys. Therefore only pumped and hydrogen storage methods are described in more detail in the following sections.

12.5.1 Pumped Storage

The concept of pumped storage for renewable energy systems is identical to the approach used to balance generation with load in traditional energy systems although at different time scales. For instance, energy from fossil fuel facilities can be used during low-demand periods (i.e. late-night hours) to pump water into storage reservoirs, which can then be in a hydropower mode to generate electricity via turbines from the head difference of the filled reservoir, with the resulting energy supplied to the grid during higher-demand periods.

Studies have been conducted to evaluate the ability to supply sustainable energy from renewable sources by integration with pumped storage. One such study analyzes the ability of wind parks in Germany to supply continuous power with onshore pumped storage called a “wind and water” approach (Leonhard and Grobe 2004). They found that such a scheme, while technically feasible, would require a very large storage capacity which would be difficult to site, based on topography, but impossible to build based on environmental and cost reasons. Another study (Geetha et al. 2007) did not assume 100 percent renewable energy and found that a combination of wind, wave and tidal currents along with distributed pumped storage could significantly reduce the need for nonrenewable energy in an island environment. The authors assert that using variable frequency transformers to control the power will keep costs competitive with nonrenewable sources.

One recent study has looked at the economics of large offshore storage basins as part of the solution to increased energy needs over the next five decades (Lemperiere 2008). Assuming that fossil-based energy sources will only contribute 10 percent of the energy supply worldwide by 2050, an estimate is made that using 20 percent of the wind potential plus a small amount of solar photovoltaic potential will make up the difference. This approach would only work if large offshore basins are used with a total capacity equal to the present capacity in hydro reservoirs. The author estimates that the basins would be used several times a week to balance the intermittency in wind and solar supply, and the costs of building these structures along with the wind and solar facilities still provides an economically competitive alternative. He calls these "green" offshore structures "Emerald Lakes" which he asserts could last for centuries.

Another recent study investigated the feasibility of an inverse offshore pump accumulation station (IOPAC) which consists of an artificial island with a ring of dykes surrounding a dredged reservoir 50 m below mean sea level (de Boer et al. 2007). Power would be generated and exported during the filling of the reservoir. Using the characteristics of a site off the coast of the Netherlands, a conceptual design was presented for a 60 km^2 reservoir that would have a maximum pump/turbine power rate of 2,500 MW. It was sized to compensate for the imbalance due to wind forecast errors as well as to store wind generated energy at night.

Both the Lemperiere (2008) and de Boer et al. (2007) studies do not consider the significant environmental impacts of offshore storage reservoirs. It is doubtful that the environmental concern present in the United States would allow this type of design to be built. Finding sufficient space onshore for the storage reservoirs would also be a challenge.

12.5.2 Hydrogen (Storage and Transmission)

The use of hydrogen as energy storage has long been recognized (Justi 1987; Ogden 1999) as a potential solution to the usual mismatch between renewable (as well as fossil and nuclear) energy production and energy demand, although it could not economically compete with natural gas turbine peaking plants. Its potential use is again being actively reconsidered due to three factors: (1) the long-term potential of renewable energy as its generating costs are reduced; (2) concern about climate change and the desire to find non-carbon based energy sources; and (3) developments in fuel cell technology using hydrogen as a low-polluting fuel (Anderson and Leach 2004).

The 2006 MMS white paper (USDOI, MMS 2006a) provides a useful description, which is summarized below, of the use of hydrogen for the storage and transmission of energy generated by alternative energy sources from the Outer Continental Shelf. The energy source (wind, wave, or current) is immaterial to the use of hydrogen. Hydrogen can be generated on location on a variety of scales: it can then be compressed and stored in tanks, transported in tanks or pipelines to shore, and later consumed by vehicles for power or by industrial facilities or generating stations to produce process steam or provide electricity.

There are a variety of approaches to the use of hydrogen that can be used (USDOI, MMS 2006a). For example, hydrogen could be produced offshore at the point of energy generation in a co-located facility or it could be produced at an onshore location. Hydrogen production at a co-located facility would require additional construction in a marine environment and equipment capable of long-term function in an offshore setting. Additionally, if multiple power generation units were involved (such as the individual turbines found on a wind energy facility), a hydrogen production unit could be associated either with each turbine or with the entire facility. In the former case, consolidation of the hydrogen would be necessary for shipment off-site; in the latter case, electrical connections between the individual turbines and the hydrogen production unit would be required.

Hydrogen production at a nearby onshore location would offer particular advantages when operated in conjunction with offshore energy sources already connected to a land-based electric power grid. In such systems, electricity from OCS sources could be diverted for use in hydrogen production when available energy on the grid from conventional sources was sufficient to meet existing power demands.

Hydrogen Generation

Wind, wave and current energy sources discussed in previous sections involve technologies that directly produce electricity. For this energy to be stored the electrical energy must be converted into hydrogen. This conversion can be accomplished using electrolysis.

Electrolysis is the process of producing hydrogen and oxygen from water in an electrochemical cell. An electrolyzer immerses the two electrodes into an aqueous electrolyte and a voltage is applied across the electrodes. The resulting migration of ions in solution results in the production of hydrogen and oxygen. Currently, the best conversion efficiency (i.e., overall system efficiency for converting electrical power to power stored as hydrogen) for commercial electrolyzers is approximately 70 percent (Ivy 2004; USDOE 2005a).

Hydrogen Transmission

Offshore-generated hydrogen can be delivered to onshore facilities through transport as gaseous hydrogen, transport as liquid hydrogen, and transport after incorporation into a solid or liquid "hydrogen carrier" (USDOI, MMS 2006a). In the first two pathways, hydrogen would be transferred to shore-based facilities in its molecular form (H_2), either as compressed gas or as liquid, via pipeline, tanker, or a ship. The third (carrier) pathway would use materials that would transport hydrogen in a form other than free molecules such as liquid hydrocarbons, absorbents, metal hydrides, and other hydrogen-rich compounds.

Transport as Gaseous Hydrogen

For economic reasons, hydrogen would be compressed to be transported ashore in gaseous form. The actual hydrogen transport could be through a pipeline that runs between an offshore generating facility and an onshore receiving facility. Currently, approximately 1,000 km of dedicated hydrogen transmission pipelines exist in the United States (USDOE 2005b). Compressed hydrogen can also be transported to shore in pressurized containers loaded on ships or in specially designed tankers.

Transport as Liquid Hydrogen

The transportation of hydrogen as a liquid in molecular form requires liquefaction, which is a well-understood but costly operation. The liquefaction process involves cooling gaseous hydrogen to below −253°C using liquid nitrogen and a series of compression and expansion steps, a very energy-intensive process. With current technologies, this process can consume one-third or more of the energy contained in the hydrogen (FCFP 2005). Once liquefied, hydrogen would need to be stored and transported at cryogenic temperatures until it is ready to be vaporized to a high-pressure gaseous form for dispensing. The present state of the use of offshore cryogenic pipelines are lengths of order 7 km for LNG transport (WCE 2009) so the only practical pathway from offshore would be via ship or tanker.

Transport via Hydrogen Carrier

A hydrogen carrier is any substance that can be used to store and transport hydrogen in a chemical state other than as free hydrogen molecules. A one- or two-way carrier could be employed. In a one-way carrier, hydrogen is added to the carrier at the point of initial charge and remains with the carrier until it reaches its point of use. At the point of use, the carrier/hydrogen combination is decomposed to yield hydrogen and an environmentally benign substance with no economic value. Hydrogen is used, and the remaining by-product is lost to the environment. An example of a one-way carrier would be ammonia (USDOE 2005b). The by-product material would be nitrogen. In a two-way system, the carrier would be charged with hydrogen at an offshore hydrogen generation station and transported back to shore. On shore, the carrier would be stripped of its hydrogen and sent back offshore for recharging. Whether the carrier is one-way or two-way, it could be transported between the offshore generating station and an onshore facility by pipeline (if it is in a liquid or slurry state) or by ship or tanker.

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13. GAPS IN CURRENT UNDERSTANDING

The sections below summarize the gaps in current understanding by discipline, the exploration of which could provide valuable guidance on the status of existing oceanographic resources and the nature and extent of potential impacts from alternative energy development.

13.1 PHYSICAL OCEANOGRAPHY

Data gaps in the area of physical oceanography include the following:

13.1.1 Winds and the Atmospheric Boundary Layer

Resource Data Gaps

- Spatial structure, with respect to distance offshore and height above sea level, of increases in wind speed
- Spatial structure, with respect to distance offshore and height above sea level, of changes to atmospheric turbulence
- Sensitivity of air-sea exchange of heat and moisture to differences in wave conditions

Impacts Data Gaps

- The nature of WTG generation of atmospheric turbulence in the near-field wake, and how the mixing layer height responds
- Effects of groups of WTG collectively on turbulence at far-field and remote scales
- Relative importance of reduced wind speed and increased turbulence effects of WTGs on air-sea exchanges of heat and moisture
- Alteration of air-sea exchanges due to parks of WECs with large areal coverage of the sea surface

13.1.2 Waves

Resource Data Gaps

- Geographic distribution of wave characteristics (significant wave height, direction of origin) on scales of km to tens of km
- Relative importance, in shaping these distributions, of processes: directional spread, shoaling, refraction, dissipation, and interaction with ambient currents

Impacts Data Gaps

- Dependence of magnitude and spatial extent of wave energy reduction, due to reduced wind speed downstream of WTG park, on number and spacing of WTGs
- Alteration of wave magnitude and direction in lee of WEC park

13.1.3 Currents

Resource Data Gaps

- Annual-mean currents and seasonal variability on the inner OCS south of New England, to the west of Nantucket Shoals
- Interannual variability in low-frequency currents and the driving factors
- Tidal currents: vertical structure and temporal variability due to changes in ambient stratification and low-frequency flow
- How widespread tidally-driven solibores are, and their role in mixing and tidal energetics

Impacts Data Gaps

- Spatial extent of reduced currents in lee of CEC farm
- Extent to which vertically sheared currents become more vertically uniform over the water column as a result of increased turbulence due to wake effects of alternative energy platforms

13.1.4 Water Properties and Density Stratification

Resource Data Gaps

- Geographic locations, seasonal evolution, interannual variability, and vertical structure of tidal mixing fronts and mid-shelf fronts
- Roles of wind, vertically sheared ambient currents, and estuarine/riverine freshwater delivery in the seasonal development and breakdown of density stratification

Impacts Data Gaps

- Bounds on magnitude of ocean thermal stratification changes due to wind park alteration of air-sea heat fluxes
- Sensitivity of positions of tidal mixing front, buoyant outflow front, and shelf-break front to alteration of wind and current fields

13.1.5 Sea Level

- Storm surge characteristics on scales of tens of km over the OCS

13.1.6 Dispersion

Resource Data Gaps

- Spatial and temporal patterns in horizontal and vertical dispersion rates and pathways
- Relationship of density stratification to dispersion processes
- Roles of surface and bottom boundary layers in dispersion

Impacts Data Gaps

- Dependence of horizontal dispersion in the atmosphere on reduced winds and increased turbulence in lee of wind parks
- Nature of changes to horizontal oceanic dispersion due to extraction of energy by CEC farm

13.2 BIOLOGICAL OCEANOGRAPHY

13.2.1 Marine Mammals

Marine mammals utilize the waters of the North and Central Atlantic Ocean for multiple activities. Their habitat ranges can be vast, spanning the entire coastline from Cape Hatteras to the Canadian border for a single species throughout the year. Marine mammals utilize the entire water column for feeding, from near shore to the continental shelf edge. Some areas within these regions are more heavily used than others, depending on the time of year.

The most significant impacts to marine mammals are from the potential for collisions with vessels resulting in fatality and from the sound pressure levels of pile driving. These risks are present for all marine mammals, but are particularly salient to the endangered species above. The risk of vessel collision with marine mammals is unavoidable, and present during all phases of offshore energy projects. However, decreasing vessel speed to 10 knots and using designated shipping lanes (as in the Grand Manan Conservation Area) will decrease the risk.

Resource Data Gaps

Information on some of the commonly sighted and easily studied species can be plentiful (e.g. bottlenose dolphin). However, more biological data are needed on those species that are less commonly seen and more difficult to study in captivity (e.g. mysticetes and beaked whales). For some species, data are lacking on hearing capabilities and migration, which are topics of relevance to impact assessments.

Impact Data Gaps

According to Madsen et al. (2006), there are several important unresolved issues regarding propagation of sound (both pile-driving and turbine), including the fact that propagation conditions in one area will rarely be applicable to other areas. Madsen et al. (2006) recommends actual measurements of frequency-dependent sound propagation for both continuous (turbine) and transient (pile driving) sounds at each wind park site, coupled with any effects of these sounds on the animals and what received levels they incur.

Madsen et al. (2006) also added the following reservation to the conclusion that the sound impacts from wind turbines on small odontocetes is likely to be minor. “Reported noise levels from operating wind turbines are low, and are not likely to impair hearing in marine mammals. The impact zones for marine mammals from operating wind turbines depend on the low-frequency hearing abilities of the species in question, on sound propagation conditions, and on the presence of other noise sources such as shipping” (Madsen et al. 2006). The impact on small-toothed whales (of known noise levels to date) is “likely to be minor because of their poor low-frequency hearing capabilities" (Madsen et al. 2006). A reservation to this conclusion is that sound measurements made to date have not taken into account any possible directional effects (i.e. acoustic measurements made in different directions and areas from wind parks could vary significantly), nor have they considered that cumulative effects of an array of turbines may lead to significantly higher received levels at long ranges. Also, larger and potentially noisier turbines may radically change this conclusion (Madsen et al. 2006).

Additionally, "all available data suggest that the impact of pile driving is significant at long ranges, and that further data are needed on dose-response and mitigation measures" (Madsen et al. 2006). Madsen et al. (2006) also recommend actual measurements of frequency-dependent sound propagation for both continuous and transient sounds at each wind park site. However, such measurements will enable reliable assessment of impacts only when coupled with better knowledge of the effects of these sounds on the animals, and at what received levels they occur (Madsen et al. 2006).

13.2.2 Marine and Coastal Birds

Numerous species of marine and coastal birds rely on habitats of the Northeast Shelf LME for feeding. Many of these species also migrate above offshore waters along the Atlantic Coastal flyway, as do many species of waterfowl, passerines, and some raptors. Some bat species may also use the offshore aerial habitat of the northeast region.

Offshore alternative energy projects in the northeast region could impact birds and bats if these flying animals collide with above-water structures such as wind turbines. Marine and coastal birds could also be impacted by temporary disturbance and permanent habitat alterations that affect prey availability and foraging behavior.

Resource Data Gaps

Due to their status as the two federally protected bird species in the region, roseate terns and piping plovers have been closely examined since their listing and their current and historic population levels, migration and nesting patterns are documented; however, ongoing studies continue to collect information that will assist in the assessment of potential impacts to these species from potential offshore energy facilities. The candidate species red knot has also been closely studied and data is available for this species, although ongoing research continues. Sufficient general information on coastal and marine bird populations exists to identify their potential use of the Northeast Shelf LME. Nonetheless, life history information for many species is limited. Marine birds present a difficulty in studying, since the significant amount of time they spend over open water limits observation opportunities.

Although information on the Atlantic flyway migration corridor exists, it is mostly focused on waterfowl or shorebirds. Information that specifically addresses either passerine or raptor species that migrate over offshore waters of the Northeast Shelf LME is limited. Knowledge of the use of offshore habitat by bats is also very limited and requires further study. Site-specific studies could address important data gaps in the use of offshore flyways by birds and bats, and will be essential to assessing potential impacts from offshore wind facilities.

Impact Data Gaps

As noted in the sections above, although birds' and bats' interactions with onshore alternative energy technologies have been examined, the results are not always conclusive or complete and the situation is not absolutely applicable to the offshore environment. With this in mind, the U.S. Government Accountability Office (GAO) developed a report to Congress on wind power impacts in order to identify the most significant data gaps that exist in assessing the affects of wind power on wildlife and birds (GAO 2005). This report listed the following conclusions: (1) Few post-construction monitoring studies have been conducted or are available and more are needed to determine those species that are being affected; (2) Most research on wind power in the United States has been conducted in the western part of the country and little is known about the impacts of the hundreds of facilities that exist in the eastern part of the country; (3) There is a lack of long-term data that is applicable in light of changing turbine technology; (4) There is a lack of complete and definitive information on interactions between bats and wind turbines, including why bats collide with the structures instead of avoiding them; and (5) There is a lack of understanding of what factors make wind structures more hazardous to bird and bat species, as well as an overall lack of understanding of bird and bat migration and population sizes (GAO 2005). In response to this report, USFWS Division of Bird Habitat Conservation and Division of Migratory Bird Management and the U.S. Geological Survey have initiated a series of nationwide studies of bird and bat migration behaviors that will include radar surveys; these studies are currently unpublished; however, additional information on these efforts can be reviewed on the USGS Patuxent Wildlife Research Center's website: http://www.pwrc.usgs.gov/. Also, the National Academy of Sciences as well as the National Wind Coordinating Committee and the American Wind Energy Association have been given funding to study these topics (GAO 2005).

13.2.3 Sea Turtles

Sea turtles utilize various habitats within the North and Central Atlantic Region for many purposes including foraging in coastal waters from North Carolina to Maine; migration, which can be near shore as well as farther offshore; and nesting on North Carolina beaches. Hatchlings and juveniles are vulnerable to disorientation from offshore lighting and entrainment due to their undeveloped swimming abilities. Additional threats to sea turtles include entanglement in nets and bycatch in trawls, vessel strike, and anthropogenic noise and pollution.

During offshore wind, wave, and ocean current energy projects, sea turtles may be affected by risk of collision with vessels and underwater rotor blades, elevated sound pressure levels (seismic site surveys, pile driving, energy device operation, and vessel noise), increased turbidity, artificial lighting, and changes in ocean currents. Due to their poor swimming abilities and passive reliance on ocean currents, hatchlings are the most vulnerable to these potential impacts. Location of nesting beaches and coastal feeding grounds should be identified and avoided as potential offshore energy sites, particularly current energy projects, which may entrain hatchlings within those currents.

Resource Data Gaps

Several topics of research in sea turtle biology are relevant to understanding potential impacts to sea turtles from offshore alternative energy facilities. More information is needed on hearing capabilities and electromagnetic field sensitivity of sea turtles. Also, population estimates are made difficult by the solitary nature and wide distribution of these long-lived animals.

Impact Data Gaps

More information on hearing ability in sea turtles (for all life stages) and behavioral responses to anthropogenic noise, sensitivity to EMF, and offshore artificial lighting are needed. "The biological importance of behavioral responses to construction noise (e.g. effects on energetics, survival, reproduction, and population status) is unknown, and there is little information regarding short-term or long-term effects of behavioral reactions on sea turtle populations" (USDOI, MMS 2007).

13.2.4 Fish

Fish are a resource of great ecological and economic importance to the Northeast Shelf region. Various species support valuable commercial and recreational fisheries or provide the prey base for other fish or for many marine and coastal birds and marine mammals. The two federally listed fish species that occur within the region, Atlantic salmon and shortnose sturgeon, rely mostly on habitats that would not be impacted by offshore alternative energy facilities.

Fish resources in the Northeast Shelf region could be affected by habitat alteration, noise, electromagnetic fields, and other potential impacts from the development of offshore alternative energy projects. The nature of any impacts to fish resources or habitat would depend on the location, timing, and proposed actions associated with a specific offshore alternative energy facility.

Resource Data Gaps

Commercially important species and certain other high-profile species in the region are relatively well-studied. Basic life history information is generally available to characterize the distribution, movements, trophic relationships, and habitat requirements for the various life stages of these species. Nonetheless, even for these well-studied fishes, information on important aspects of their basic biology is often lacking. For example, temperature preferences of individual species are generally not available (Gabriel 1992). This information could be used to confirm the influence of water temperature on observed species distribution patterns. Furthermore, the site-specific information needed to assess potential impacts of a proposed offshore alternative energy project typically is not available or may be outdated. The majority of fish that occur within the region are not within the high-profile category that has received attention from researchers. These species, for which basic natural history information is often not available, play important roles in the Northeast Shelf ecosystem and deserve further study (Link 2007).

Impact Data Gaps

Much remains unknown about potential impacts of offshore alternative energy projects on fish. A better understanding is needed of how impacts from habitat alteration influence species composition and population levels, including information on the significance of incremental contributions from large numbers of individually minor habitat alterations to long-term conditions. Additional information is also needed to identify the best habitat rehabilitation and mitigation options. The potential benefit of offshore energy facility structures as artificial reef is also very poorly understood. For example, it is not known whether artificial reef or FADs benefit certain fish species resulting in higher populations, or simply attract and aggregate fish to a common location (Nelson et al. 2008). Hastings and Popper (2005) noted the significant information gaps and the lack of peer-reviewed literature on the impacts of pile-driving noise on fish. The authors prepared a list of research priorities on the topic that included investigations into immediate and delayed mortality, hearing impacts, impacts to non-auditory tissues, effects on early life stages (eggs and larvae), and behavioral responses. Hastings and Popper (2005) also recommended efforts to identify interim guidelines on hearing thresholds for protection of fish from pile-driving sound. Potential impacts to EM-sensitive species from the presence of EMFs generated by subsea power cables are not well understood and research on this topic is needed (Gill et al. 2005). There is little current evidence to determine the nature or implications of any potential impacts to fish from EMFs generated by power cables for offshore alternative energy facilities (Gill et al. 2005; Ohman et al. 2007; USDOI, MMS 2007).

13.2.5 Benthic Resources

The Northeast Shelf region includes benthic resources of great economic and ecological value. Invertebrate fisheries are the most valuable commercial fisheries in the region and the benthos provides the prey base to support higher trophic levels including fish, sea turtles, marine and coastal birds, and marine mammals.

Benthic resources in the Northeast Shelf region could be affected by physical disturbance, habitat alteration, noise, electromagnetic fields, and other potential impacts from the development of offshore alternative energy projects. Although impacts to soft-bottom communities would all be considered adverse, certain hard-bottom communities could potentially benefit from the artificial substrate introduced by project structures. The nature of any impacts to benthic resources or habitat would depend on the location, timing, and proposed actions associated with a specific offshore alternative energy facility.

Resource Data Gaps

Despite over 100 years of research, many critical gaps exist in the understanding of benthic communities and their roles in the Northeast Shelf LME (Steimle et al. 1995). Basic biological and life history information is lacking for even many of the dominant species. Data on food uptake, growth, reproduction, recruitment, and survival is needed. More information is also needed on the consequences of anthropogenic activities. Thresholds of disturbance or pollution tolerance by benthic species must be better defined, and ecological models that assess the role of natural disturbance events on the functioning and biodiversity of benthic communities need to be refined. Also, more information on causal mechanisms leading to changes in population size and abundance, including a better understanding of habitat associations at the species and community levels is needed. Furthermore, the importance of benthic habitat to fishery resources, and the consequences of habitat modifications including the introduction of artificial reefs must be further investigated.

Impact Data Gaps

Much remains unknown about potential impacts from offshore alternative energy projects to benthic resources. Recovery times and recolonization processes for benthic communities following physical disturbance of the seafloor need further study. The implications of offshore energy facility structures as artificial reef in the Northeast Region are also not well understood. In addition, very little information exists to assess potential impacts from noise or EMF to benthic invertebrates.

13.2.6 Areas of Special Concern

The MPAs described herein are well defined, and, in most cases, relatively well-studied areas due to their identification, creation, and management under their respective Federal, state, local or tribal agencies. The Gerry E. Studds Stellwagen Bank National Marine Sanctuary (SBNMS) is the only National Marine Sanctuary located within waters of the Northeast Shelf region, and the largest federally protected MPA in the region. It provides important habitat for many species of benthic invertebrates, fish, seabirds, sea turtles, and marine mammals.

MPAs have been designated to protect a number of areas of special concern in the Northeast Shelf region. These represent some of the most valuable areas for conservation of biological resources in the region, and existing protections in these areas would limit potential impacts from offshore alternative energy facilities.

Resource Data Gaps

Additional work is needed to further identify and characterize ecologically significant areas within the Northeast Shelf region that are not currently protected, and to identify and prioritize key areas for conservation efforts.

Impact Data Gaps

Nonetheless, impacts associated with activities that may be allowed within MPAs include several potential impacts that require further study. Much work is needed to better understand potential impacts to marine organisms from noise, electromagnetic fields, and habitat alteration including the introduction of structures that could function as artificial reefs or fish attracting devices. This research is especially important for protection of the unique and valuable resources that inhabit areas of special concern in the northeast region.

13.3 CHEMICAL OCEANOGRAPHY

Impact Data Gaps

There is a dearth of literature directly related to the scientific understanding of impacts of alternative energy structures on chemical resources.

Research that would be helpful in addressing impact issues should focus on:

- The change in nutrient dynamics due to the structures
    - Mixing of the water column

    - Release of nutrients from the sediment during construction and service
- The change in oxygen levels at the at the bottom of the water column
- The determination of the extent of material release from sediment during the lifetime of the structures
    - Metals
    - Organics
    - PAH
    - PCB
- The change in CO_2 chemistry
- The release of biocides from antifouling products

13.4 GEOLOGICAL OCEANOGRAPHY

The primary knowledge gap in geological oceanography concerning the U.S. Atlantic coast is in understanding the variability of sediment data (type, physical properties, thickness, depth to bedrock, etc.) with depth. The majority of available sediment data is limited to surficial grab samples and shallow piston and gravity cores. Furthermore, the current sediment data does not provide information regarding strength properties. Only in cases where there are adequate borings and good quality recovery is sediment strength properties available. For these rare cases, the data is not applicable beyond a very localized region.

It is evident from the few deep borings within and near the study region (ODP Leg 150X and 174A; Miller et al. 1996; Austin et al. 1998, respectively) that there is significant sediment variability with depth. This uncertainty plays a major role in identifying competent bearing strata and designing foundations for alternative energy projects. There is also a high degree of variability regarding the variation of sediment data laterally. As evident in usSEABED and CONMAP databases (Fig. 5-2 to 5-5) there exists a larger degree of variability in sediment data from the north (Gulf of Maine) to the south (Carolina Trough).

13.5 SOCIOECONOMICS

In the U.S., the lack of any commercial-scale offshore alternative energy development means that virtually the entire process of conducting socioeconomic analysis is speculative, based on either interpolating survey-derived predictions of behavior or application of onshore wind or offshore European projects of impacts to U.S. projects, or both. Such speculative analyses can provide some guidance, but they must be supplemented by examining actual economic impacts and carefully modifying or accepting assumptions in applying those impacts of proposed actions.

The areas where actual impact analysis of existing (in this case, European) projects can be most helpful are in the areas of commercial fishing, recreational impacts, economic development, and visual resources. In addition to measuring the actual impacts of projects on these resources, it would be useful to calibrate those impacts against prior predictions based on survey results and develop models that enable future survey results to be used to better predict actual impacts.

13.5.1 Commercial and Recreational Fisheries

The significance of impacts to commercial fisheries must be assessed by examining the spatial and temporal nature of fishing activities of fishers. Databases maintained by the Atlantic States Marine Fish Commission (ASMFC) are useful in this respect.

With respect to recreational fisheries, the Marine Recreational Fisheries Statistics Survey (MRFSS) generates independent estimates of effort and catch through two separate survey components, a bimonthly household telephone survey, and a continuous onsite access point intercept survey of angler fishing trips. Data on species caught, lengths and weights, various demographics and trip activity data and economic data are collected from each angler.

13.5.2 Visual Resources and Aesthetics

Description of the visual resources potentially affected by proposed offshore alternative energy development involves establishing landscape types and scenic quality in the areas in which energy facilities would be located, followed by an assessment of the potential sensitivity to changes in the visual environment, including the likely number of viewers. Visual impact assessments will need to be conducted for selected viewpoints that include historic properties and onshore recreational sites (mostly beaches) and offshore sites. These assessments should include field surveys to collect information on seascape quality, sensitivity, value, and capacity to accommodate change of these viewpoints. In addition, computer-generated simulations and photomontages can illustrate how the facility would appear under different conditions. Guidance documents (e.g., Department of Trade and Industry 2002; National Research Council 2007) have been developed on how to address seascape and visual impacts during environmental reviews for offshore wind parks, and the methods presented in these documents could also be used to address seascape and visual impacts of wave and tidal energy projects.

13.5.3 Transportation and Navigation

Assessment must be conducted to assess if areas selected for development impact existing water and air navigation or transportation routes. For water navigation, collection of marine traffic data in the vicinity of a proposed project could include current activity by military craft (Navy and Coast Guard), commercial business craft (freighters, tug boats, fishing vessels, ferries, and cruise passenger ships), commercial recreational craft (cruise ships and fishing/sight-seeing charters), research vessels, and personal craft (fishing boats, house boats, yachts, and other pleasure craft). Possible data sources of marine traffic in the vicinity of a proposed project include Vesseltracker.com (2009). Information on the types of navigation hazards that offshore alternative energy development may pose is available from collision incident data collected by the Minerals Management Service (USDOI, MMS 2008).

Impacts to commercial and recreational boating would be addressed through a full navigation risk assessment, often coordinated with the U.S. Coast Guard. Tuholski et al. (2002) describe a standard approach to risk assessment, which seeks to identify hazards as sources of risks, and then examines how the hazards might give rise to accidents. Accidents are categorized both in terms of the severity of their effects (i.e., consequences in terms of harm to people or the environment, damage to assets and other economic losses) and the likelihood of the harm occurring. In addition, mitigation measures to reduce risks to more acceptable levels are identified.

A general air navigation concern is associated with tall structures. The Federal Aviation Administration (FAA) will need to review potential impacts to air navigation for structures greater than 200 ft (61 m) in height above sea level. Another FAA criterion triggering a notice of proposed construction is whether the project would be located within 20,000 ft (6,096 m) or less of an existing public or military airport (depending upon the type of airport or heliport). If the potential site for an offshore alternative energy development project is known, an Internet database such as AirNav.com can be searched online to obtain this information.

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