OCS STUDY
MMS 2007- 038

Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf

July 2007

MMS U.S. Department of the Interior
Minerals Management Service

OCS Report
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List of Abbreviations and Acronyms

A	ampere
AAM	Active Acoustic Monitoring
AC	alternating current
ANOVA	analysis of variance
BACI	before-after control-impact
BWEA	British Wind Energy Association
CETAP	Cetacean and Turtle Assessment Program
dB	decibel
µPa	microPascal
DC	direct current
DEIS	draft environmental impact statement
DOI	Department of the Interior
DTI	Department of Trade & Industry
EEZ	Exclusive Economic Zone
E-fields	electric field
EIA	environmental impact assessment
EIR	environmental impact report
EIS	environmental impact statement
EMEC	European Marine Energy Centre
EMF	electromagnetic field
ENFA	Ecological Niche Factor Analysis
ESP	energy service platform
FAA	Federal Aviation Administration
FAD	fish attraction device
FERC	Federal Energy Regulatory Commission
FlaSH	Florida Shelf Habitat Map project
FLOWW	Fishing Liaison with Offshore Wind and Wet renewables
FMC	Fishery Management Council

FWRI	Florida Fish and Wildlife Research Institute
GIS	geographic information system
GW	gigawatt
Hz	hertz
IAPEME	International Advisory Panel of Experts on Marine Ecology
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
kg	kilogram
kHz	kilohertz
km	kilometer
km/h	kilometer per hour
km^2	square kilometer
kV	kilovolt
kW	kilowatt
LIOWP	Long Island Offshore Wind Park
m	meter
MANEM	Mid-Atlantic/New England/Maritimes Region
MEPA	Massachusetts Environmental Protection Act
mm	millimeter
MMS	Minerals Management Service
MPA	Marine Protected Area
m/s	meters per second
MW	megawatt
NCCOS	National Centers for Coastal Ocean Science
NEPA	National Environmental Protection Act
nm	nautical mile
nm^2	square nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
nV/cm	nanovolt per centimeter

OCS	Outer Continental Shelf
ORED	Offshore Renewable Energy Development
OWC	oscillating water column
PAM	Passive Acoustic Monitoring
PTS	permanent threshold shift
PV	photovoltaic
RAG	Research Advisory Group
re 1 Pa @	relative to 1 Pascal at
RMS	root mean square
RSPB	Royal Society for the Protection of Birds
s	second
SEA	Strategic Environmental Assessment
SEAFISH	Sea Fish Industry Authority
SPL	sound pressure level
SPLASH	Structure of Populations, Levels of Abundance, and Status of Humpbacks
T-POD	Porpoise Click Detector
TTS	temporary threshold shift
μV/cm	microvolt per centimeter
UK	United Kingdom
U.S.	United States
USGS	U.S. Geological Survey
V/m	volt per meter
VHF	very high frequency
WIS	wave information study
WTP	willingness to pay

List of Conversion Factors

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSTIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
LENGTH				
In	inches	2.54	centimeters	cm
Ft	feet	0.305	meters	m
ft^2	square feet	0.093	square meters	m^2
Mi	miles	1.61	kilometers	km
nm	nautical mile	1.852	kilometers	km
mi^2	square miles	2.59	square kilometers	km^2
nm^2	square nautical mile			
		AREA		
ft^2	square feet	0.093	square meters	m^2
Ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
APPROXIMATE CONVERSATIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
cm	centimeters	0.394	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
km	kilometers	0.54	nautical miles	nm
		AREA		
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
km^2	square kilometers	2.59	square kilometers	km^2
Ha	hectares	2.47	acres	ac

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

1. Introduction

1.1 Background of the Study

The Minerals Management Service (MMS) is charged with environmentally responsible management of federal Outer Continental Shelf (OCS) resources (e.g., oil and gas, sand and gravel, other mineral resources). 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. The seaward extent of state jurisdiction is mostly 3 nautical miles, although in Texas and the Gulf coast of Florida, it is 3 marine leagues (9 nautical miles) and in Louisiana it is 3 imperial nautical miles. Federal jurisdiction extends to the farthest of 200 nautical miles or, if the continental shelf can be shown to exceed 200 nautical miles, a distance not greater than a line 100 nautical miles from the 2,500-meter isobath or a line 350 nautical miles from the baseline.

Section 388 of the Energy Policy Act of 2005 granted the Department of the Interior (Department) discretionary authority to issue leases, easements, or rights-of-way for activities on the OCS that 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 MMS. Examples of the general types of alternative energy project activities that MMS has the discretion to authorize include, but are not limited to: wind energy, wave energy, ocean current energy, solar energy, and hydrogen production. The MMS 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.

Under this new responsibility, MMS is working to establish an MMS Alternative Energy and Alternate Use Program that will provide for sound multiple-use management of federal offshore lands for nontraditional energy and related uses. Alternative energy sources that could be developed on the OCS under MMS stewardship include wind, ocean wave, ocean current, solar, and hydrogen. Large-scale nearshore wind projects are already in operation internationally, and in the United States projects are in the preplanning and permitting stages. OCS project development is yet to be accomplished. In the OCS, ocean wave technology is deployed on a small, prototype scale at a few locations, but the technology is still in its infancy. Ocean current technology is based on tidal technology and is in the pre-planning stages. Solar and hydrogen technologies are still in the conceptual stage.

1.2 Study Objectives

MMS has a long-established practice of using sound science, engineering, and environmental protection principles to support timely, streamlined, and environmentally and fiscally responsible decisions to access OCS resources. MMS has a lengthy history of conducting scientific assessments and studies to improve understanding of likely effects of offshore development projects and to support decisionmaking for best management of resources. To guide MMS in its development of a research program to support alternative energy uses in the OCS, MMS sponsored this synthesis and analysis report to review existing data on environmental effects of alternative energy uses and identify information needs.

The objectives of this study are to identify, collect, evaluate, and synthesize existing information on offshore alternative energy activities for the following topics:

- Current offshore energy technologies and future trends
- How public acceptance of existing projects was or was not achieved
- Potential direct, indirect, and cumulative environmental impacts of offshore energy technologies
- Previously used mitigation measures that could avoid, minimize, rectify, eliminate, or compensate for environmental impacts
- Current physical and numerical models designed to determine environmental impacts
- Information needs to address gaps in our current understanding of environmental impacts

The results of this synthesis report will be used as input for a workshop to be held in June 2007. Workshop participants will identify data needs and outline potential studies for the MMS Environmental Studies Program and its partners.

2. Study Methods

2.1 Literature Search

A comprehensive literature search was completed to identify all existing information on the potential environmental impacts of offshore alternative energy projects. The literature search was focused specifically on potential impacts, rather than general information on natural resources.

The first steps of the literature search involved researching commercial online databases. The search was conducted using DIALOG^{R} Classic, and specifically included searches of the databases listed below:

- Aquatic Science & Fisheries Abstracts
- ANTE: Abstracts in New Technology & Engineering
- BIOSIS Previews
- Biological & Agriculture Index
- CSA Life Sciences Abstracts
- Ei Compendex
- Ei EnCompassLit™
- Environmental Engineering Abstracts
- Environmental Sciences
- Enviroline(R)
- Energy SciTec
- Fluidex
- Inside Conferences
- Inspec
- National Technical Information Service (NTIS)
- Oceanic Abstracts
- Pascal
- Pollution Abstracts
- ToxFile
- Tulsa (Petroleum Abstracts)
- Water Resources Abstracts
- Wilson Applied Science & Technology Abstracts

The databases included above provide the ability to search dissertations, scientific proceedings, government reports, and academic papers. The search terms were based on the following general areas:

- Alternative energy technologies, including wind, wave, ocean, current, solar, tidal, biomass or hydrogen *and* energy, power or electricity
- Marine resources (general and specific terms including: birds, avian, butterflies, bats, benthic, biota, plankton, marine mammal, seals, whales, dolphins, porpoises, fish, aesthetics, sea turtles)
- Impacts, effects, affects, damage

The second step in the literature research was a broad Internet search using search terms similar to the online database searches. The product of these two searches is a list of existing and proposed offshore alternative technology projects.

The only existing full-scale offshore alternative energy projects were the European wind parks. The literature search was refined to focus on monitoring reports for the existing wind parks and environmental impact assessments for the wind, wave, current, solar, and hydrogen projects that were available from the permitting process.

In addition, the research sought direct contacts and requests for information from various regulators, academic institutions, and industry representatives to obtain additional information and updates on the status of existing and proposed projects.

Wave and current technologies are developed enough to be in the permitting or prototype stage. Solar and hydrogen technologies are still in the earliest conceptual phases, and thus, no information on potential environmental effects was available for inclusion in this synthesis.

2.2 Database and Web Site Development

Based on discussions with MMS staff, a Microsoft Access 2003 database was created for tracking information and making it available at a Web site interface. The basic relational database structure uses individual tables for discreet information that is keyed to the central database table containing information about documents located through the literature search. Information includes basic citation information such as authors, titles, and page numbers; keywords and categories or classifications of the information gathered; and summaries of the information prepared by the technical project staff. This information was managed by project staff directly through the Microsoft Access application. For broader use during the literature synthesis, a Web site was developed that allowed other users to view the information contained in the database. The Web site, developed based on models of other MMS database Web site interfaces, uses a common platform with Active Server Pages, Visual Basic scripts, and JavaScript. This configuration will facilitate continued operation by MMS after the conclusion of the project.

3. Current Offshore Alternative Energy Technologies and Future Trends

This section on current offshore alternative energy technologies and future trends provides the following information:

- Descriptions of alternative energy technologies that might be used on the Outer Continental Shelf (OCS)
- Geographic distribution of each type of alternative energy resource and locations where alternative energy development is best suited on the OCS of the United States
- Potential trends in alternative energy technologies that could be used on the OCS

The descriptions of each type of technology are meant to provide sufficient detail to allow assessment of the potential environmental impacts. The design, installation, and operational characteristics of the operating wind parks in Europe served as a basis of the discussion for wind energy technology. Because no full-scale operational systems for wave, ocean current, solar, and hydrogen technologies are in place, descriptions and references are for design prototypes and pilot studies.

3.1 Wind Technology

3.1.1 General Overview

Offshore wind parks have been developed successfully, and they have been connected to electrical grids in the shallow offshore waters adjacent to northwestern Europe including Denmark, England, Ireland, Holland, Sweden, and Wales. In the United States, full-scale, offshore wind parks are only in the permitting stage. Throughout the United States and Europe onshore wind parks are operational, but development of offshore sites would offer the advantage of stronger and more consistent wind resources. In 2000 the total worldwide wind capacity was approximately 17,500 megawatts (MW) (WEC, 2001). In Denmark, location of the largest operational wind parks, onshore and offshore wind technology provided 19 percent of total electricity consumption in 2004 (Ladenburg, 2006). The London Array off the English coast is the largest proposed wind park, which would provide electricity for 750,000 homes (RPS, June 2005).

Following is a list of the current primary economic and technical feasibility determinants that affect the choice of sites for offshore wind parks:

- Availability of a substantial, relatively constant wind resource
- Shallow water (less than 30 meters [m] deep)
- Proximity to an area of high electricity consumption
- Distance to shore

In addition to the water depth limitations of technology as of 2007, significant economic concerns are associated with the distance from shore and the length of subsea electrical cable required to reach the onshore electrical grid.

Although available wind turbine designs allow installation in waters less than 30 m deep, wind parks operating in Europe are in shallower coastal areas (water depths of approximately 15 m). In the United States, wind parks are likely to be developed along the Atlantic seaboard and the Gulf of Mexico. Along the narrow shelf of the Pacific coast, waters of the OCS would be too deep. Several shallow water locations are in the permitting stage including Long Island, NY, Cape Cod, MA, and Padre Island, TX. In the near future it is likely that technology will be developed to make it technologically and economically feasible to install wind parks in deeper waters farther offshore.

3.1.2 Description of Technology and Infrastructure

To date, operational and proposed wind turbines have been of similar design. This section describes the design currently in place and how the design likely will be modified in the future, mainly to allow siting in deeper waters.

A wind turbine comprises five parts: rotor with blades, nacelle, tower, transition piece, and foundation. A schematic of a typical turbine is shown in figure 3-1. Tower height typically is 60 to 80 m high, and the rotor blades are 30 to 40 m long (BWEA, 2005). The wind turbine rotor diameters typically are 76 to 107 m for offshore parks (MMS, 2006). The tip speed of the turbine blades is about six times the wind speed. The wave regime at a particular project location will be accounted for in the specific design for each project.

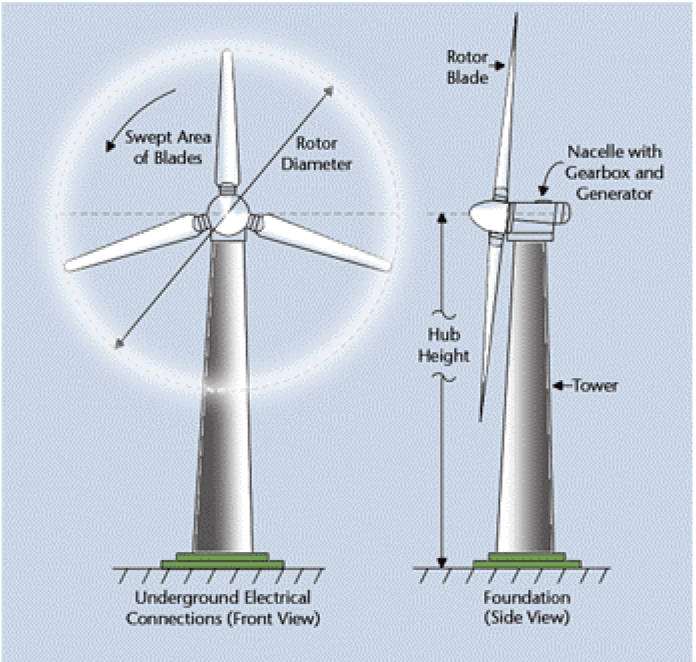
Wind turbines typically are sited in groups known as “wind parks.” The turbines must be spaced to avoid overlapping wind turbulence fields. Offshore, the turbines must be spaced the length of two to four rotor diameters apart. Turbines typically are spaced approximately 0.5 kilometers (km) apart.

Most wind turbines have two or three blades, and the blades and rotor attach to the nacelle, which sits atop the tower. The nacelle includes the gear box, low- and high-speed shafts, generator, controller, and brake. The transition piece sits between the tower and the foundation, and it includes an access platform.

Water depth is a critical design element that currently limits installation in deeper waters because of technology and economic constraints. Existing wind parks in Europe are installed in very shallow water (up to 15 m deep). Most North American wind resources are in water greater than 30 m deep, requiring development of economically feasible new technologies for wind turbine structures that can withstand wave and wind action in deeper areas.

Existing and proposed wind parks in shallow water typically use or would use monopile foundations. The monopile consists of a large diameter pile (4 to 5 m) driven 15 to 30 m into the seabed. Monopiles could also be installed using drilling methods in harder substrates, although most existing projects have used pile-driving methods.

Gravity foundations sometimes are used in harder seabeds. They have a shallower installation depth (below seabed grade) and a larger footprint; however, they are not suitable for larger offshore wind parks. They would need a nearby shipyard and dry dock during construction. In addition, gravity foundations have greater environmental impact because of a larger diameter.



Source: http://www.daviddarling.info/images/wind_turbine_blades.gif.

Figure 3-1: Schematic of a typical wind turbine.

The installation process requires floating foundations to the site, excavating the seafloor to create a level surface, and sinking the foundations into the seabed. All types of foundations generally require scour protection in the form of large stones, erosion control mats, or other designs.

Multipod foundations are still in the conceptual phase, and they likely will be capable of installation in deeper waters. Conceptual designs for deeper water installation also include floating structures installed with anchors in the seabed. These types of prototypical designs would result in a more limited benthic footprint.

A 2000 report by the British Wind Energy Association (BWEA) indicated that wind turbine noise is typically 50 to 60 decibels (dB) at a distance of approximately 40 m from the turbines (BWEA, 2000). Another study by the Scottish Office Environmental Department indicates noise from a typical wind park would be equivalent to a quiet room (35 to 45 dB) 350 m from the turbines (The Scottish Office, 2004).

3.1.3 Operational Projects

Operational offshore wind parks are located in Denmark, England, Wales, Ireland, Holland, and Sweden. Table 3-1 summarizes these projects including the number of turbines, the energy output in megawatts, and the startup year.

The first large-scale offshore wind projects were developed at Horns Rev and Nysted in Denmark. These projects were considered the first phase of a larger Danish program to develop offshore wind energy; the next phase includes development of two larger projects, Horns Rev II and Rødsand II. These proposed projects are described under the section on planned projects.

Table 3-1: Operational offshore wind energy projects as of February 2007.

Wind Park	Country	Turbines	Energy Output (MW)	Start-Up Year
Frederikshaven	Denmark	4	10	2003
Horns Rev	Denmark	80	160	2002
Middelgrunden	Denmark	20	40	2001
Nysted/Rødsand	Denmark	72	158	2003
Samsø	Denmark	10	23	2003
Tuno Knob	Denmark	10	5	1995
Vindeby	Denmark	11	5	1991
Barrow	England	30	90	2006
Blyth Harbour	England	9	3	1992
Blyth Offshore	England	2	4	2000
Kentish Flats	England	30	90	2005
Scroby Sands	England	30	60	2004
North Hoyle	Wales	30	60	2003
Arklow Bank Wind Park	Ireland	7	25	2004
Dronten (IJsselmeer)	Holland	19	11	1996
Gotland-Bockstigen	Sweden	5	3	1997
Utgrunden, Kalmar Sound	Sweden	7	10	2001
Yttre Stengrund	Sweden	5	10	2001

More detailed descriptions of three of the larger operational wind parks in Denmark and the United Kingdom (UK) follow.

The **Horns Rev** wind park was constructed in 2002. It occupies a 20 square kilometer (km^2) area located approximately 14 to 20 km off the coast of Denmark in the North Sea, west of Blåvands Huk. The depth of water in this area ranges from 6 to 14 m. The wind park consists of 80, 2 MW wind turbines spaced approximately 560 m apart, and it has a total output of approximately 160 MW. A 36-kilovolt (kV) cable net connects the turbines, and the cables are connected to a substation located in the northeastern part of the offshore wind park. A 150-kV cable connects the substation to the grid onshore. The turbines are secured in the seabed on monopile foundations with diameters between 3.4 and 4.0 m driven up to 25 m into the seabed (Elsamprojekt A/S, 2000). Scour protection consists of large stones placed out to 25 m around the base of the turbine foundations (Leonhard, 2006).

The **Nysted** wind park at Rødsand was constructed in 2003. It is located about 10 km south of Nysted and 13 km west of Gedser off the coast of Denmark. The wind park covers an area of approximately 24 km^2 with a 200-m wide exclusion zone around it, resulting in an overall area of approximately 28 km^2. The depth of water in the area varies between 6 and 9.5 m. The wind park consists of 72, 2.3 MW turbines placed in a parallelogram—eight rows of nine wind turbines each. The eight rows of wind turbines are spaced approximately 850 m apart, and each wind turbine within a row is spaced approximately 480 m apart. The total wind park output is 160 MW, and the turbines are interconnected with a 33-kV cable approximately 48 km in length buried at a depth of 1 m. The turbines use gravity foundations composed of concrete, and stone and gravel filled cells are built into the base of the foundations to protect from ice and erosion (Elsam Engineering and Energi E2, 2005; Birklund, 2004).

The **North Hoyle** wind park was built in 2003. It comprises 30 wind turbines, each rated at 2 MW, and the total wind park output is 60 MW. Located approximately 6 to 8 km off the North Wales coast between Rhyl and Prestatyn, the wind park covers an area of approximately 10 km^2. The water depth ranges from 7 to 11 m. The distance between turbines is 350 m from north to south and 800 m from east to west. The turbines are secured in the seabed on 4-m diameter monopile foundations. Scour protection was not installed with these foundations (Npower Renewables, 2007). Submarine cables totaling 38.3 km in length are used to connect the turbines together and to carry the generated electricity to shore (Npower Renewables, 2006).

3.1.4 Planned Projects

Table 3-2 shows a partial list of offshore wind parks proposed worldwide and their status in the design, permitting, and development stages. About two dozen projects are in the planning stages worldwide. Both Denmark and the United Kingdom are in the second stages of implementing large offshore projects. Denmark has issued tenders for two 200-MW projects at Horns Rev II and Rødsand II. The United Kingdom also has issued tenders for Round 2 of offshore wind projects including 15 projects with a total output of up to 7.2 gigawatts (GW) of output (BWEA, 2006). The United Kingdom Round 2 includes the London Array which, at 1,000 MW, will be the largest project to date. Offshore wind projects are also proposed in Germany, Wales, Scotland, Sweden, Holland, Spain, and Belgium.

In the United States, the Cape Wind project offshore of Massachusetts and the Long Island Offshore Wind Park (LIOWP) offshore New York are in the environmental impact statement (EIS) stage, and other projects are planned along the northern and central U.S. coast. In addition, two leases have been granted by the State of Texas to develop wind parks off the coastline of Padre Island and Galveston Island. Additional projects are in the early planning stages along the U.S. east coast and Gulf of Mexico.

Table 3-2: Summary of proposed offshore wind projects.

Wind Park	Location	Country	Turbines	Energy (MW)	Status
Belgium					
Thorton Bank	37 km off Oostende	Belgium	NA	200	Proposed
Denmark					
Grena	NA	Denmark	NA	NA	Proposed
Rødsand II	Rødsand	Denmark	NA	200	Proposed
Horns Rev II	Horns Rev	Denmark	NA	200	Proposed
England					
Burbo	5.2 km Crosby, Burbo Bank in Liverpool Bay	England	25	90	Under construction
Walney	North West	England	30	450	Under Construction
Cromer	7 km off Cromer	England	30	108	Approved
Gunfleet Sands	7 km off Clacton-on-Sea	England	30	108	Approved

Table 3-2: Summary of proposed offshore wind projects.

Wind Park	Location	Country	Turbines	Energy (MW)	Status
Inner Dowsing	5.2 km Ingoldmells	England	30	90	Approved
London Array	20 km off the Kent and Essex coasts	England	270	1000	Approved
Lynn	5.2 km off Skegness in North Sea	England	30	90	Approved
Thanet	Thames Estuary	England	60 to 100	300	Approved
Greater Gabbard	Thames Estuary	England	140	500	Submitted
Ormonde	Cumbria	England	30	108	Submitted
Shell Flat	7 km off Cleveleys	England	90	270	Submitted
Sheringham Shoal	Sheringham, Greater Wash	England		315	Submitted
Teesside/Redcar	1.5 km northeast of Teesmouth	England	30	90	Submitted
West Duddon	North West	England	NA	500	Submitted
Germany					
Borkum West	North Sea, 43 km northern Borkum	Germany	12	60	Approved 2001
Butendiek	North Sea, 35 km westerly Sylt	Germany	80	NA	Approved 2002
Borkum Riffgrund West	North Sea, 40 km northwest of Borkum	Germany	80	NA	Approved 2004
Borkum Riffgrund	North Sea, 34 km northern Borkum	Germany	77	NA	Approved 2004
Amrumbank West	North Sea, 37 km westerly Amrum	Germany	80	NA	Approved 2004
Nordsee Ost	North Sea, 35 km northwest of Helgoland	Germany	80	NA	Approved 2004
Sandbank 24	North Sea, 100 km westerly Sylt	Germany	80	NA	Approved 2004
ENOVA Offshore North Sea Windpower	North Sea, 40 km northern Juist	Germany	48	NA	Approved 2005
DanTysk	North Sea, 70 km westerly Sylt	Germany	80	NA	Approved 2005
Kriegers Flak	Baltic Sea, 30 km northern Rügen	Germany	80	NA	Approved 2005
Nördlicher Grund	North Sea, 84 km westerly Sylt	Germany	80	NA	Approved 2005
Global Tech I	North Sea, 93 km north of Juist	Germany	80	NA	Approved 2006
Hochsee Windpark Nordsee	North Sea, 90 km north of Borkum	Germany	80	NA	Approved 2006
Godewind	North Sea, 38 km	Germany	80	NA	Approved 2006

Table 3-2: Summary of proposed offshore wind projects.

Wind Park	Location	Country	Turbines	Energy (MW)	Status
	north of Juist				
Arkona-Becken Südost	Baltic Sea, 35 km northeast of Rügen	Germany	80	NA	Approved 2006
Holland					
IJmuiden	NA	Holland	NA	120	Proposed
Mouth of W. Scheldt River	NA	Holland	NA	100	Proposed
Ireland					
Arklow II	Irish Sea	Ireland	NA	NA	Proposed
Kish Bank	Dublin	Ireland	NA	250	Proposed
Scotland					
Beatrice	Beatrice Oilfield, Moray Firth	Scotland	2	10	Under construction
Solway Firth/Robin Rigg A	8.5 km off Rock Cliffe	Scotland	30	90	Approved
Solway Firth/Robin Rigg B	8.5 km off Rock Cliffe	Scotland	30	90	Approved
Spain					
Cape Trafalgar	Southwest Coast	Spain	NA	500	Proposed
Sweden					
Lillgrund Bank	NA	Sweden	NA	48	Proposed
Utgrunden II	Kelmar	Sweden	NA	72	Proposed
Barsebank	NA	Sweden	NA	750	Proposed
United States					
Cape Wind	6.5 km off Cape Cod, MA	United States	130	Avg. 170; Max. 454	EIS stage
Long Island Offshore Wind Park (LIOWP)	5.8 km off Jones Beach, Long Island, NY	United States	40	140	EIS Stage
Texas Offshore Wind Project Research Plan	Padre Island, TX	United States	100 to 500	500	Lease let by State of Texas
Wales					
Rhyl Flats	8 km off Abergele	Wales	30	90	Approved
Scarweather Sands	5.5 km off Sker Point	Wales	30	99	Approved
Gwynt y Mor	Liverpool Bay (13 to 15 km offshore)	Wales	200	750	Submitted

NA = Not Available

The following paragraphs give detailed descriptions of the two proposed projects in the United States that are most advanced in the planning stage. The London Array project in the United Kingdom is also discussed to demonstrate the future size of offshore wind parks.

The **Cape Wind** project would be located approximately 6.5 km off Craigville Beach, Cape Cod, MA. The project, currently in the permitting stage, would consist of 130 wind turbines with a maximum design water depth of 15 m. The turbines would be placed in parallel lines in an array, with spacing 629 m along the line and 1 km between the lines. The tip diameter of the turbine rotors would be 104 m. Each turbine would have two flashing red lights 79 m above mean low water (Cape Wind Associates, 2007).

The turbines would be supported by towers installed on monopile foundations. Each foundation would be between 5 and 6.5 m across and weigh between 250 and 350 tons. Depending on the specific seabed conditions, the foundations would be driven approximately 25 m into the seabed (Cape Wind Associates, 2007). The wind park is expected to generate an average of 170 MW and a maximum of 454 MW. Power would be transmitted from each turbine through 33 kV cables to an energy service platform (ESP), then to shore through two 115 kV alternating current (AC) cables (Cape Wind Associates, 2007). The ESP would cover an area of 30.5 by 61 m and would be placed in approximately 8.5 m of water, extending 11.9 m above the water surface.

The **Long Island Offshore Wind Park** project would be located approximately 5.8 km southeast of Jones Beach State Park, NY, and southwest of Robert Moses State Park (LIOWP, 2007). The facility would consist of 40 wind turbines in a cluster design. When complete, the 21-km^2 wind park would be one of the largest alternative energy projects in New York State.

The LIOWP project would include 40 turbines rated at 3.6 MW each for a total of 140 MW. The facility would generate enough electricity for 44,000 homes. Each of the nacelles would be approximately 60 m high above water level, with blades approximately 55 m long. The optimal wind speed for these turbines would be 43 to 58 kilometers per hour (km/h), and they would be able to operate under wind speeds of 13 to 90 km/h (LIOWP, 2007).

The **London Array** project, planned for a location 20 km off the Kent and Essex coasts of England, would be the largest wind park constructed to date. The park would consist of 270 turbines over an area of 245 km^2 in water depths ranging up to 23 m. On average, the London Array would be a 1,000 kW project, generating enough energy to supply 750,000 homes. The London Array would be located within the Thames Estuary Strategic Environmental Assessment area defined by England's Department of Trade & Industry (DTI) and The Crown Estate in 2003 as one of the areas where applicants would be invited in the second round of United Kingdom offshore wind park developments (RPS, 2005).

3.1.5 Future Trends

In the future, development of technology and site choices for wind parks will have the following goals:

- Increase energy output and efficiency
- Address environmental impacts identified by monitoring results at operating sites
- Decrease impacts to use conflicts

- Allow economic feasibility for siting in deeper offshore waters

Larger turbines can produce more energy with the right wind conditions, and future technology trends probably will involve larger turbines to maximize energy production. Turbines at existing wind parks typically generate 2 to 3.8 MW each. A major corporation is testing a 5 MW turbine rated for higher winds; however, installation of larger turbines in deeper waters is limited by economics and technology. Selecting deeper water offshore sites for wind parks where wind resources are stronger and less erratic would increase energy output; however, wind parks farther offshore would require larger turbines to accommodate the higher offshore wind velocities. Present turbine technology and economic feasibility have prevented siting in waters deeper than 15 to 30 m; thus, future technology trends will focus on designing foundations for installation in deeper offshore waters. Prototypes for deeper installation are primarily floating foundations anchored to the seabottom.

In addition to increasing the size of individual turbines, future trends likely will include increasing the number of turbines in a given wind park. The 271 turbines proposed at the London Array project are an example of this trend. The number of turbines in that proposed project is three times larger than the largest existing wind park at Horns Rev, Denmark, which has 80 turbines.

The environmental impact assessments completed for the first permitted wind parks identified natural resources that could be affected; however, the actual impacts could not be defined until sizeable wind parks were operational for several years. Monitoring programs are ongoing at the operating European wind parks, and data from these programs (discussed later in this report) are expected to identify specific wind park infrastructure and design elements that affect natural resources. Future trends in engineering design of wind parks should be focused on diminishing these impacts.

Potential use conflicts can be identified before wind park operation begins, but the extent of the impact becomes clear only after operation begins. Monitoring is necessary to measure the exact impacts to the fishing industry, recreational uses, and navigation. That information should then be considered in the design of future wind park projects. For example, navigation issues, specifically the shadow effects on radar from a large wind park, are spurring research in the United Kingdom into radar technology that could overcome these effects (Hay, pers. comm., 2007).

3.2 Wave Technology

3.2.1 General Overview

Although no full-scale wave energy projects are operational, several offshore wave energy projects are in the permitting or demonstration phases in Oregon, Washington, and Hawaii. Internationally, wave energy projects are operating on a small scale or are in development in Japan, the United Kingdom, and Australia.

In the United States, areas with the greatest potential for wave energy development are Hawaii and the Pacific coast (Bedard et al., 2005). Offshore wave energy likely would be commercially introduced first in Hawaii and northern California because of the combination of strong wave climate and the relatively high cost of electricity in the regions (Thorpe, 1999). Oregon and

Washington also have strong wave resources; however, the demand for electricity in those states is lower because they already generate alternative power from hydro resources. Wave resources along the eastern coast of the United States likely are not suitable for development as an energy source.

Ocean wave energy technologies are being actively developed in the United States and Europe. In an effort to put Scotland at the forefront of technology on ocean wave energy, the government of Scotland recently launched a grant program for technology development. A research institute, the European Marine Energy Centre (EMEC) in the Orkney Islands north of Scotland, is serving as a test facility for wave energy and tidal energy technologies. EMEC maintains meteorological and oceanographic monitoring centers and several test berths to deploy technology experiments. The following paragraphs describe some of the technologies being tested at EMEC.

3.2.2 Description of Technology and Infrastructure

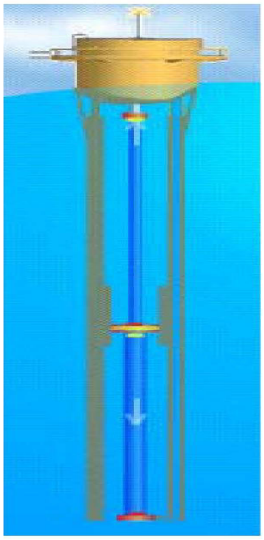
No full-scale wave energy projects are operational, but several technologies are in developmental stages. The technologies include three wave energy converter designs:

- Floating
- Oscillating water column
- Overtopping

Floating Wave Energy Converters

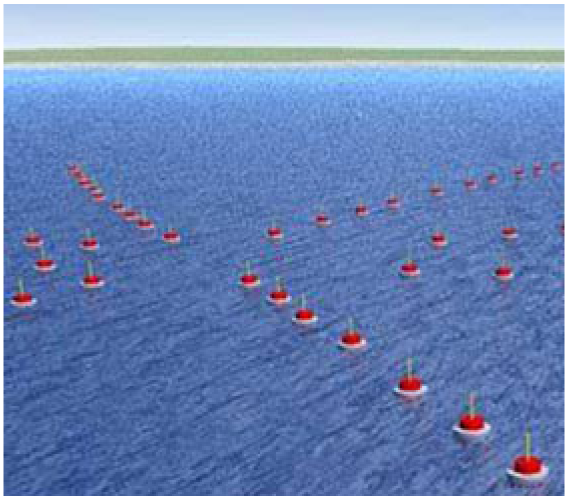
To convert wave kinetic energy movement to electricity, one technology uses floating buoys tethered by anchors to the seabed. Buoys are grouped in arrays to maximize efficient energy production. Figures 3-2 and 3-3 show a buoy design that is the basis of wave energy projects that are in permitting stages in Portugal and the United States (Finavera, 2006). The United States project, located in Makah Bay, WA, includes a 1-MW array power plant that would use four buoys 6 km offshore in water depths of 46 to 61 m (Finavera, 2006). The developer chose the location for several reasons: depth, proximity to shore, good wave climate, shoreline transmission line, electricity demand in coastal communities, participation of a publicly supported utility, and an interested landowner (the Makah Indian Nation) (Finavera, 2006).

Figure 3-4 shows the above-surface portion of another type of wave energy buoy. In this design, a piston-like structure inside the housing moves as the buoy bobs with the rise and fall of waves. This movement drives a generator on the ocean floor that produces electricity, which is sent to the shore by an underwater cable. The development company estimates that a 10-MW power station would occupy approximately 0.12 km^2 of ocean space (Ocean Power Technology, 2007). The technology was field-tested offshore of Atlantic City, NJ, in water 5 m deep. The 40-kW buoy used in the test project measured 4 m in diameter near the ocean surface, and it was 16 m long. Approximately 4 m of the system was above the ocean surface.



Source: Finavera homepage at www.finavera.com.

Figure 3-2: Schematic drawing of a buoy-type wave energy converter.



Source: Finavera, 2006.

Figure 3-3: Proposed grouping of ocean wave energy technology units.

Another type of floating wave energy converter is a semisubmerged, articulated structure comprising cylindrical sections linked by hinged joints. Figure 3-5 shows an example of the design, which is being tested at the EMEC research institute in the Orkney Islands. The units, held in position by a mooring system anchored in the seabed, can move around and face into oncoming waves. The 750-kW full-scale prototype is 120 m long and 3.5 m in diameter. In operation, it would contain three power conversion modules rated at 250 kW each. Ideally the structure would be moored in waters approximately 50 to 60 m in depth, which would allow access to the potential of larger swell waves (Ocean Power Delivery, 2007).

Source: Ocean Power Technologies, 2007.

Figure 3-4: An example of a buoy-type wave energy technology.

Oscillating Water Column Wave Energy Converters

Oscillating water column (OWC) technologies typically are used in nearshore tidal locations, often along the coastline. They are fixed structures that house hydropneumatic internal chambers where the wave action causes the internal water level in each chamber to rise and fall, forcing airflow over a turbine. Although these are typically shoreline devices, a shallow-water prototype developed and tested by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) potentially could be adapted for installation in deeper water as a floating unit (JAMSTEC, 1998). This prototype is illustrated in figure 3-6.

Overtopping Design Wave Energy Converters

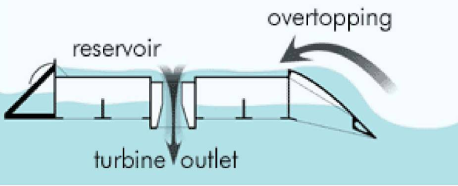
Figure 3-7 shows an artist's rendering of an overtopping, floating, slack-moored wave energy converter. Ocean waves overtop a ramp, elevating water to a reservoir higher than sea level. This creates a head of water, which is subsequently released through a number of turbines that convert the mechanical wave energy to electrical output. The water leaves the reservoir through hydro turbines. The only moving part of the device is the turbine itself (Wave Dragon, 2005). This prototype is being tested through grants from the European Union and the Danish government. Early prototypes are placed in water approximately 6 m deep, but designs are planned for placement in greater than 30 m of water (Wave Dragon, 2005).

Source: Ocean Power Delivery, 2007.

Figure 3-5: Articulated floating cylinders used to collect wave energy.

Source: JAMSTEC, 1998.

Figure 3-6: Photograph of an oscillating water column device.



Source: Wave Dragon, 2005.

Figure 3-7: Schematic of an overtopping design wave energy converter.

3.2.3 Future Trends in Ocean Wave Energy Conversion

Although no ocean wave energy conversion projects in the United States have yet been through a full permitting process, testing of ocean wave energy conversion technologies is very active. It is likely that a wave energy conversion project will be operational and connected to a grid within the next 5 to 10 years. Wave energy projects in the planning stages within the United States are listed by state in table 3-3.

Table 3-3: Wave energy projects in the planning stages in the United States.

State	Number of Permits Pending	Number of Permits Issued	Number of Licenses Pending
CA	4		
OR	2	3	
WA			1

FERC Hydropower - Industry Activities Web page:

http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp

The Scottish government has been relatively aggressive in establishing a wave energy project in Scottish waters. The government there has awarded 7.5 million dollars (13 million pounds) in several grants, and the list of technologies from those grants may be a good indicator of feasible designs. Table 3-4 lists companies slated to receive the Scottish grants. Most of these projects will install small arrays or single devices at the wave and tidal test facilities near the EMEC in Orkney. Devices are expected to be in the water in 2007, and full commissioning will be carried out during 2008.

3.3 Ocean Current Technology

3.3.1 General Overview

In the United States, no operating commercial systems using ocean current technology are connected to an electrical grid at this time (MMS, 2006). However, the technology to harness ocean current energy as an alternative energy source is in the developmental stage. Demonstration and pilot studies of different prototypes are taking place throughout the world.

Marine current velocities are lower than those of wind, but because water is 835 times denser than air, a 3-knot current has the kinetic energy of 161 km/h wind. The total potential energy contained in marine currents worldwide is estimated at approximately 5,000 GW (MMS, 2006). Available data indicate that current velocities between 2 and 5 meters per second (m/s) would be required to make ocean current energy technology economically viable at a particular site (MMS, 2006).

Table 3-4: Companies recently awarded grant money by the Scottish government for the development of ocean wave energy conversion technology.

CRE Energy Ltd, £4.141 million ($8.2 million) Ocean Power Delivery Pelamis units, each rated at 750 kW for a total output of 3 MW
AWS Ocean Energy, £2.128 million ($4.2 million) 500-kW Archimedes Wave Swing (AWS) wave energy converter at the European Wave Energy Centre
ScotRenewables, £1.796 million ($3.5 million) Floating tidal stream energy converter involving dual horizontal-axis rotors driving generators in subsurface nacelles
Open Hydro, £1.214 million ($2.4 million) 250-kW open-center turbine on the seabed at the EMEC tidal site (During 2006, OpenHydro was the first company to install a tidal turbine at EMEC)
Ocean Power Technologies, £0.598 million ($1.2 million) PowerBuoy® acting as a point absorber, which moves up and down a central spar as the wave passes by
Aquamarine, £0.275 million ($0.5 million) Oyster™ devices designed to exploit the wave resource in nearshore locations. (The nearshore environment is considered optimal for a device because the waves retain significant power compared to an offshore location and shallow water depth limits damaging extreme waves; and thus, capital and operating costs are reduced and economic efficiency maximized.)
CleanTechCom, £0.273 million ($0.5 million) 1-m diameter siphon pipes that pass through the No 1 Churchill Barrier on land at the northern tip of Lamb Holm island on Orkney
Wavegen, £0.149 million ($0.3 million) Advanced Wells turbine system, using an OWC system
Tidal Generation, £0.077 million ($0.2 million) Submerged tidal turbine

Source: Scottish Executive, 2007.

In the United States, the most promising sources of ocean current energy include specifically the Florida Current (which is part of the Gulf Stream) and the California Current (MMS, 2006). These ocean current resources are located relatively close to shore and near centers of high electricity demand, making ocean current energy an attractive resource. In addition, ocean currents tend to be significantly more constant than wind resources, which can fluctuate greatly over relatively short periods of time.

This report does not consider tidal energy because those projects would be installed near or inshore, rather than on the OCS; however, tidal energy technology shares some elements in common with ocean current energy technology. Tidal energy projects probably will be tested before full implementation of ocean current energy projects. A list of both tidal and current energy projects in the planning stages in the United States is provided in table 3-5.

Table 3-5: Ocean current and tidal energy project status in the United States.

State	Number of Permits Pending	Number of Permits Issued
AK	2	7
CA		1
FL		8
MA	1	1
ME	6	2
NH-ME		2
NY	3	3
OR		2
WA		9

FERC Hydropower - Industry Activities Web page:

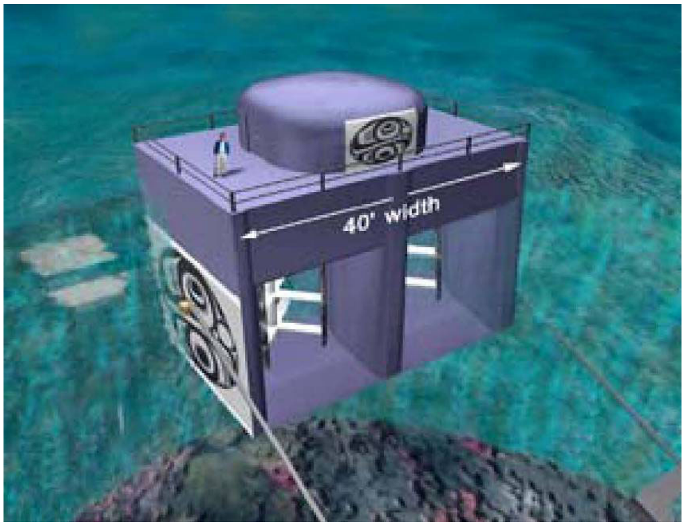
http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp

3.3.2 Description of Ocean Current Technology and Infrastructure

Ocean current technology is similar to wind technology, only underwater. Instead of wind, ocean current pushes turbine blades to transfer kinetic energy. Similar to wind turbines, the blades of the current turbines move at a very slow speed. For example, one type of design has vertical turbine rotors that rotate 10 to 30 revolutions per minute, which is approximately 10 times slower than ship propellers. Although the rotors move slowly, they produce a significant amount of energy because of the density of water moving them.

The technologies for marine current energy projects likely will be similar to those for tidal. The development of tidal energy technology is moving much quicker than the development of marine current technologies because tidal energy is located in shallow, nearshore waters, making it more accessible. Because there is little information on technologies being developed specifically for offshore ocean current energy, tidal technologies provide the best available information on potential ocean current technologies. It is probable that future ocean current technologies will be based on modified versions of the tidal energy technologies being developed today. Some of the tidal technologies are mounted on the seafloor and others are anchored or floating, which may be more applicable for offshore ocean current installation.

Several types of bottom-mounted rotor technologies are being developed for tidal energy projects. However, seafloor-mounted designs would have limited deeper water application because the strongest ocean currents are typically near the water surface. Also, the maintenance costs could be prohibitively high for a turbine situated near the OCS seafloor (Blue Energy, 2006). One such seafloor-mounted tidal energy technology is the Davis Turbine, which is a turbine mounted in concrete caissons directly on the seafloor, as shown in figure 3-8.



Source: http://www.bluenergy.com/davishydroturbine.html.

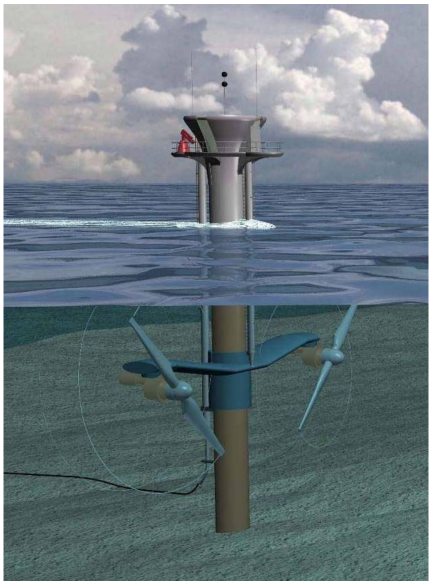
Figure 3-8: Schematic drawing of a seafloor-mounted Davis Turbine tidal energy converter.

Another type of design that may have better application to offshore marine current energy is the equivalent of an underwater wind turbine structure. These turbines can be grouped as “current parks.” For each turbine, a foundation is placed on the ocean bottom, and the turbine rotors are placed atop a tower that extends up through the water column. These designs have been through field testing, and they are planned for installation as a tidal energy technology (Hammerfest Strøm, 2007; Marine Current Turbines, 2002). Figure 3-9 shows an example of the submarine turbine technology.

Each turbine is capable of generating 500 to 1,000 kW of energy (IT Power, 2005; Triton Consultants Ltd., 2002). They are pitched so that they can be used for currents in both directions. The basic speed and depth requirements for cost-effective power generation from tidal currents using this technology are a mean spring peak velocity exceeding about 4.5 to 5 knots (2.25 to 2.5 m/s) in a water depth of 20 to 30 m (Marine Current Turbines, 2002).

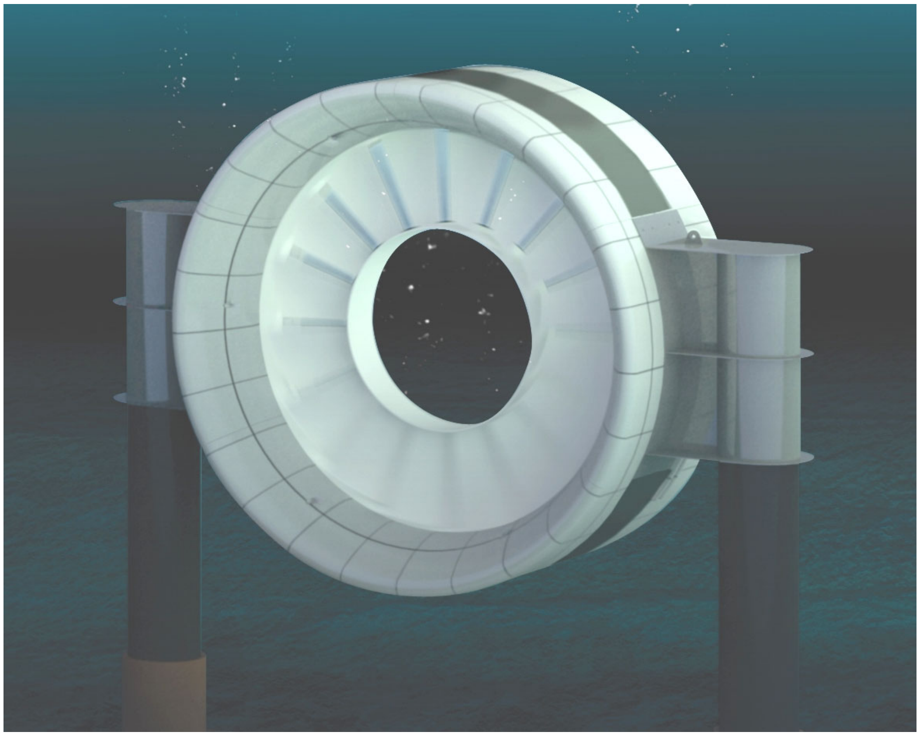
Another type of current technology is in the development phase for offshore deployment in the Florida Current. Florida Hydro is testing a disk-like design called the Open Center Turbine, as shown in figure 3-10. The moving parts of this technology are encased within the unit. Designed to produce 2.5 MW, the turbine was tested off Palm Beach, FL. The prototype is also being tested at the EMEC where it would be installed between two vertical pilings, as illustrated in figure 3-11 (Open Hydro Homepage, 2007).

Several other ocean current technologies are being developed. Those designs are tethered to the seabottom using anchors or on poles that extend from seabed foundations (ABP, 2004). These technologies are in the very early stages of development; however, they may be the most promising design for deeper, offshore applications on the OCS.



Source: http://www.marineturbines.com/technical.htm.

Figure 3-9: Artist's impression of a pile-mounted twin rotor tidal turbine.



Source: Open Hydro Group Limited.

Figure 3-10: Open center current/tidal turbine with encased moving parts.

Source: Open Hydro Group Limited.

Figure 3-11: Installation of an open center current/tidal turbine.

3.4 Solar Technology

3.4.1 General Overview

Solar energy technology has been producing useable energy from land-based, full-scale, grid-connected power plants for more than a decade, but use of solar energy technology on the OCS is very limited. Economically feasible installation of full-scale solar energy projects on the OCS will depend on producing significant amounts of transmittable energy. To provide an overview of what land-based technology could be applied to the OCS, this section focuses on descriptions of large onshore projects.

The possibilities for solar technology are not limited to large offshore solar plants; solar energy technology could be collocated with other alternative energy technologies. For example, solar collectors could be installed near the base of a wind turbine, and then used to augment energy output. Solar technology also could be installed as an alternative use for decommissioned oil and gas platforms on the OCS. Already some small, unmanned oil and gas platforms use solar panels for electricity needs. Solar panels are also used on buoys, platforms, and meteorological stations.

The potential for annual average solar power varies greatly by latitude and cloud cover; solar radiation is significantly greater in the lower latitudes. In the United States, solar radiation is greatest in southern parts of the country. A literature review yielded no information on solar radiation levels offshore and along the OCS (MMS, 2006). However, unpublished solar radiation data may exist as shipboard information collected during routine or research operations.

3.4.2 Description of Technology and Infrastructure

Solar energy is converted into useable energy through two basic technologies: thermal and photonic. Thermal technologies convert solar energy to heat. Photonic technologies absorb solar photons, which are then converted into electricity through photovoltaic (PV) cells. Technology is also in the early stages of development to store the photonic energy as hydrogen for later use, rather than convert it directly to electricity (MMS, 2006). Chemical storage and transportation technologies have not been developed, and this report does not address them.

Some solar technologies use concentrating mechanisms to focus heat or photonic solar energy into a collector. Technology and application of concentrated PV are not as advanced as concentrated thermal technology, but it is under development. Concentrated PV and thermal systems use mirrors or lenses configured to concentrate solar radiation on receiving panels. Figure 3-12 shows a picture of a concentrating thermal solar energy plant in the U.S. Mojave Desert.

Source: EERE, 2006.

Figure 3-12: Solar thermal plant built in the 1980s in the Mojave Desert, Kramer Junction, CA.

3.4.2.1 Thermal Solar Technology

Nine concentrated thermal solar plants, two of which have 80 MW output, have operated in the Mojave Desert for a decade (Broehl, 2006). These plants use acres of moveable troughs, power towers, or dish systems to track the sun and concentrate solar thermal energy (heat) on receiving tubes. Thermal energy is converted to steam energy, which then drives turbines. A newer project of similar, but updated concentrated thermal solar-and-steam technology is being built in the Nevada desert. The Nevada Solar One power plant will include 184,000 mirrors arranged in long parabolic arrays over 1.2 km^2 of desert (Kanellos, 2007). It will have the capacity to generate 64 MW for commercial use (Broehl, 2006).

Thermal solar plants work best in warm, dry climates such as deserts (Kanellos, 2007). Application of this technology on the OCS, where humidity is high, likely is not feasible with current technology.

3.4.2.2 Photovoltaic Solar Technology

Most photonic systems use PV cells to convert sunlight directly into electricity. A photovoltaic cell is made from a very thin slice of silicon crystal, similar to a semiconductor device. Sunlight activates electrons in the cell, thus creating current that flows out of the cell to produce electricity (PowerLight, 2006). Solar panels are solar cells electrically connected together and encapsulated in a weatherproof package.

Photovoltaic solar technology is being applied in increasingly larger onshore projects in Europe. One of the larger PV projects is located in a former military reserve in Pocking, Germany. The plant, which consists of 57,000 mono- and polycrystalline panels installed over 0.32 km^2, is rated at a total of 10 MW (Renewable Energy UK, 2007). Other, large-scale, grid-connected PV solar power plants are planned in Portugal, South Korea, Israel, and Germany.

3.4.3 Potential Solar Applications on the OCS

Current solar energy technology has limited application on the OCS. It is distributed only to power buoys, weather stations, and small, unmanned oil and gas platforms. A literature review revealed no solar energy projects on the OCS at any stage of planning or development. Any offshore solar energy project would need to be mounted onto some sort of large floating or fixed structure (MMS, 2006). The number of solar panels, and therefore, the size of the structure necessary to support an offshore commercial solar energy facility would vary depending on the solar radiation level at the location, the orientation of the panels, and weather conditions.

Thermal solar technologies require dry, warm locations, and thus, current technologies likely would not be feasible on the OCS where humidity is high. PV solar technology surface area requirements also limit their application at OCS locations, where a floating platform would be required. Approximately 8 to 12 square meters is required for each kilowatt of capacity, meaning 0.8 to 1.2 hectares (0.008 to 0.012 km^2) of PV cells would be required for each 1 MW of power output (MMS, 2006). Concentrated PV systems developed for thermal solar projects are in early development. Efficient concentrated PV technologies may increase the economic feasibility of OCS solar applications because PV is more effective in humid environments.

3.5 Hydrogen Technology

Hydrogen technology would be used on the OCS as a transport or storage mechanism for energy produced by one of the other alternative energy technologies (wind, wave, current or solar). No projects were identified at any stage of planning or implementation for this type of technology. The best source of information on the possibilities of using hydrogen technology for storage or transport of energy on the OCS is the MMS (2006) white paper. Since the application of hydrogen technology is so undefined at this stage, and because there are no current plans or prototypes for OCS application, the potential impacts are not included in the later sections of this report.

4. Social, Economic, and Cultural Concerns of Offshore Alternative Energy

Social, economic, and cultural concerns of offshore alternative energy installations were not the main focus of this synthesis study. However, information on some components of these concerns has been evaluated. Thus, this section discusses four aspects of social, economic, and cultural concerns. Experiences at existing and planned offshore wind parks have been reviewed to identify both successes and failures in public acceptance in Section 4.1. Potential space-use conflicts (Section 4.2) and aesthetic impacts (Section 4.3) are discussed, and the results of monitoring and assessment studies at existing offshore wind parks are presented, along with information needs that are applicable to all offshore alternative energy installations. All other additional areas of social, economic, and cultural concern are briefly summarized in Section 4.4.

4.1 Public Acceptance of Existing Projects—Successes and Failures

4.1.1 Overview of Operational Projects

Onshore wind turbines have been used for centuries. Offshore wind parks have been operating along the coastlines of the United Kingdom, Denmark, Holland, and Sweden since the mid-1990s. No offshore wind parks are operating offshore of the United States.

Opinion polls conducted in the United States and Europe clearly indicate that the public is supportive of developing alterative energy sources, specifically onshore and offshore wind energy (Coyle, 2007; Ladenburg, 2006; Dong et al., 2006; Market Research Wales Ltd., 2002; Firestone, Kempton, and Krueger, 2007).

The following sections provide examples of what factors contributed to gaining public acceptance for the wind parks operating in Europe. Projects in Denmark and the United Kingdom were chosen as examples, but the experiences are consistent with those of other European countries with successful offshore wind projects. A section is also included on U.S. experiences that are gaining public acceptance as the wind industry works through the permitting process to achieve operational offshore wind parks.

4.1.2 European Experience—Denmark and the United Kingdom

A review of the public acceptance experience in Denmark and the United Kingdom illustrates some fairly strong trends in public opinion:

- The public is in favor of offshore wind energy.
- The public is generally in favor of offshore wind park development in the region where they reside.
- Visual impacts appear to be the primary issue of public concern.
- Offshore wind park development appears to gain public approval as the community is exposed to operational projects.
- Early local input to the planning process is critical to gaining public acceptance.

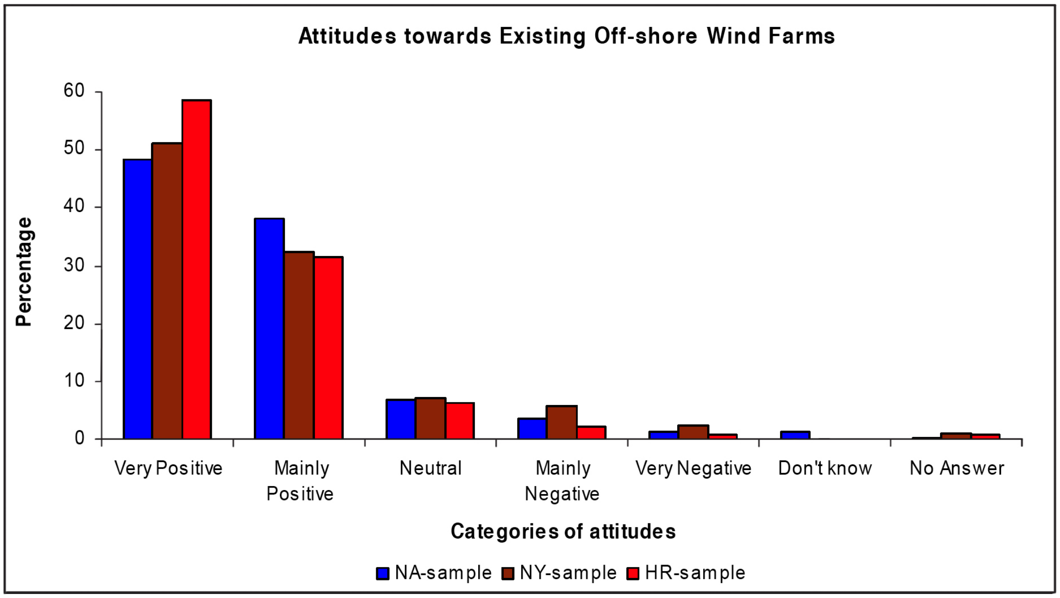
Several studies have been conducted in Europe to measure public attitudes toward offshore wind energy projects. There is a strong indication that the public in Denmark and the United Kingdom support offshore wind parks.

Scroby Sands is a 30-turbine wind park started in 2004 off the coast of England. A survey of local public opinion was taken during a public exhibition held two weeks before the permit application was submitted, preconstruction. Survey results showed the public was generally in favor of wind energy (149 to 2) and also in favor of the wind park at Scroby Sands (141 to 4) (Coyle, 2007).

Horns Rev and Nysted are two of the largest operating wind parks in the world. Located off Denmark, they have been operational since 2002 and 2004, respectively, with 80 and 72 turbines each. Kuehn (2005a, b) conducted a qualitative assessment of public attitudes of the wind parks at Horns Rev and Nysted on the basis of interviews with a few selected "social actors." Opposition existed in both communities because local citizens felt they had been ignored in the centralized decisionmaking process of site selection. At Horns Rev, opposition was based on a fear of declines in the tourist industry if the view of the ocean was changed; at Nysted, opposition was based on the feeling that the coastal landscape should be preserved because of its natural beauty (Kuehn, 2005a). A year after construction of the wind park at Horns Rev, there was more acceptance of the wind park because tourism suffered no change, visual impacts were not as bad as feared, and the voiced opinion that "It is possible to accept and endure living with a wind park since they are here to stay" (Kuehn, 2005a). A year after construction at Nysted, some negative attitudes still persisted. Some interviewees felt they had been intentionally mislead by the visualizations used in the environmental assessment because the visualizations did not include the transformer station and the navigational lights, which were very visible at night (Kuehn, 2005b).

A public opinion survey of three groups in Denmark—a national sample, a sample from the Nysted area, and a sample from the Horns Rev area—was conducted by Ladenburg (2006). In mail surveys sent to randomly selected households, there were 362 respondents from national lists and 140 to 170 respondents from people living in the two local areas of the wind park. The response rate was about 50 percent. Nearly 90 percent of the respondents expressed positive or neutral attitudes on both existing (figure 4-1) and future (figure 4-2) offshore wind parks. In the survey the following respondents expressed more negative attitudes:

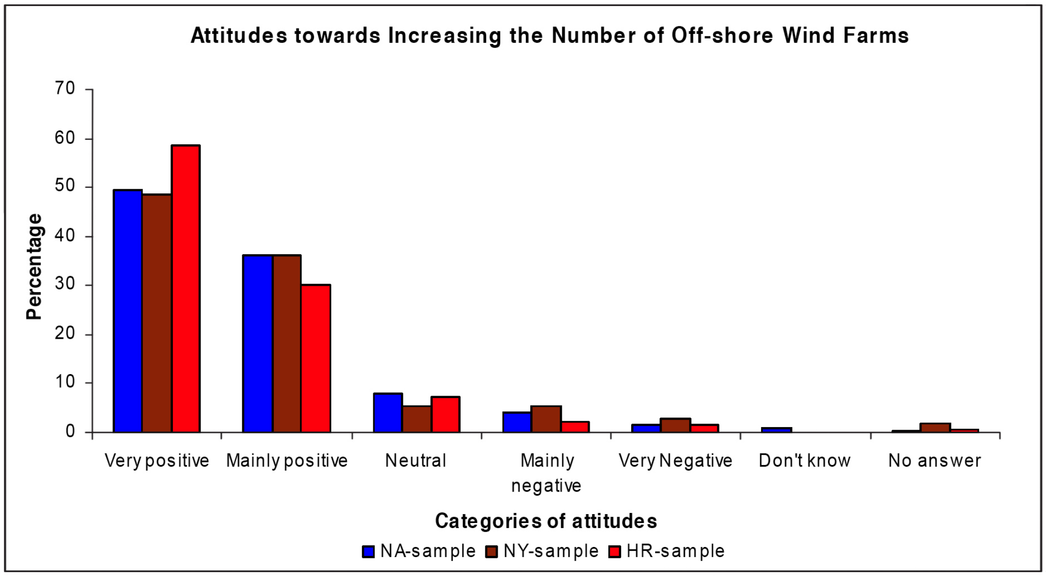
- People at Nysted, where the wind park had been operating a shorter time, and which is closer to shore at about 9 to 10 kilometers (km), than Horns Rev, which is 14 to 20 km offshore;
- Older respondents, both national and local;
- National respondents who were members of an outdoor organization;
- Local respondents who could see the offshore wind parks from their house and who visited the beach frequently; and
- Commercial fishers at Horns Rev.



Note: NA = national sample, NY = Nysted, HR = Horns Rev.

Source: Ladenburg, 2006.

Figure 4-1: Comparison of public attitudes in Denmark toward existing offshore wind parks.

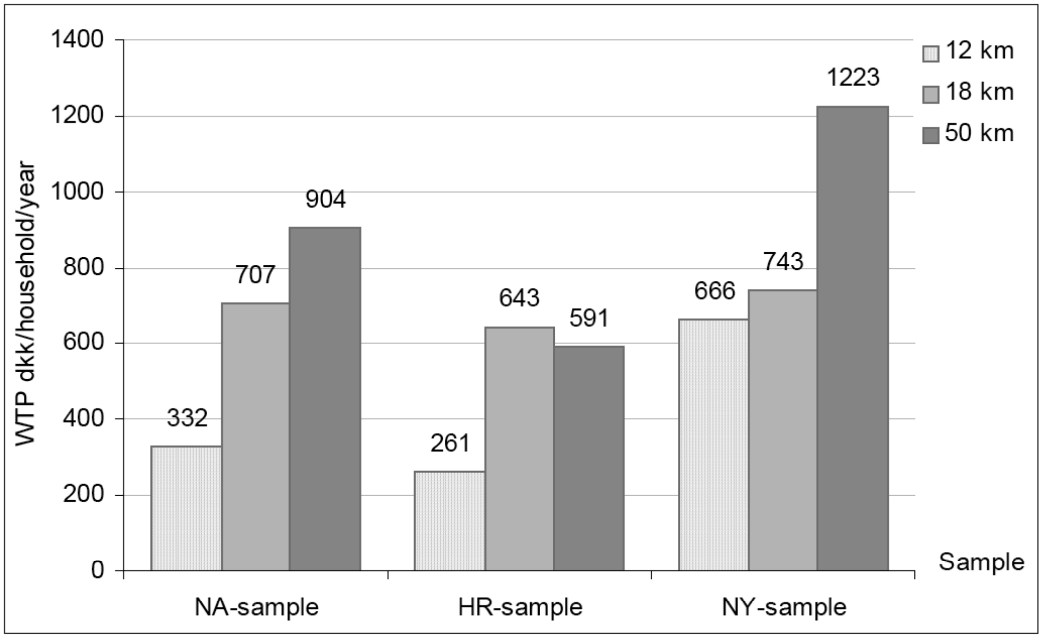


Note: NA = national sample, NY = Nysted, HR = Horns Rev.

Source: Ladenburg, 2006.

Figure 4-2: Comparison of public attitudes in Denmark toward future offshore wind parks.

Ladenburg et al. (2005) also conducted an economic valuation of the willingness to pay to move wind parks farther offshore using the choice estimation valuation method for both the national and local populations. The survey asked respondents to indicate their willingness to pay additional costs of electricity per household per year in four scenarios: increasing wind park distance from 8 to 12 km offshore, from 12 to 18 km offshore, from 18 to 50 km offshore, and greater than 50 km offshore. In all four choices, respondents from Nysted were willing to pay more money to increase wind park distances offshore than either the national respondents or the Horns Rev respondents, as shown in figure 4-3. Ladenburg et al. (2005) attributed this response to the fact that the wind park at Nysted is closer to shore (9 to 10 km), and because it has greater visual impact on the local community.



Note: NA = national sample, NY = Nysted, HR = Horns Rev.

Source: Ladenburg et al., 2005.

Figure 4-3: Willingness-to-pay (WTP) in terms of the additional costs of per household per year to increase the distance from the coast of offshore wind parks.

A report on public approval in Denmark prepared by Dong et al. (2006) cites very high public support (80 percent) for wind park expansion. Dong et al. notes that opposition at Horns Rev was greatest before construction, and opposition decreased to neutral during operation. After the public in Denmark has lived with offshore wind parks for a decade, public opinion is overall very much in support of expanding offshore wind energy projects, even in areas where the community currently lives with operational wind parks within 10 km of shore.

In 2002 in Wales, a telephone survey of 500 adults in five regions (Market Research Wales Ltd., 2002) asked if participants would prefer nuclear or offshore wind power production. The result was an 87-percent preference for the offshore wind alternative. Consistent with other studies, the greatest support for wind power came from younger respondents and the lowest support for offshore wind came from respondents over the age of 55 years. Lower socioeconomic groups also showed less support for offshore wind energy production.

4.1.3

4.1.4 Pathways to Gaining Public Acceptance

The ground work for gaining public acceptance of offshore wind projects in Europe was multipronged. The government was involved in early planning and site selection of wind park locations. Development of offshore wind resources was presented in the context of complying with Kyoto agreements and working toward achieving country-specific goals for alternative energy development. In both Denmark and the United Kingdom, development of offshore wind parks started with smaller, pilot-scale wind parks of 10 or fewer turbines. The following paragraphs describe some examples.

4.1.4.1 United Kingdom

Starting with small projects in historically industrialized areas allowed the public to become acquainted with wind parks. In the United Kingdom, the early Blyth Harbor project built in 1992 comprised only three turbines located within 1 km of the shoreline. The turbines were situated off a historically industrialized harbor rather than off the tourist and residential coastline on either side of the harbor. Between 2003 and 2006, projects at North Hoyle, Scroby Sands, Kentish Flats, and Barrow, each with 30 turbines, came online. The Crown Estate is currently overseeing United Kingdom Round 2 wind park development offshore, which has a potential for up to 15 projects capable of producing 7.2 gigawatts (GW) of energy.

The largest of the Round 2 projects is the London Array, which will include 270 turbines in the Thames Estuary. Permitting is moving forward on this project; however, there is a dispute with local residents in the village where the cable comes onshore and where the associated infrastructure would be built. This project provides a good example of the importance of working with local residents and public interest groups as early as possible in the process. The developer proponent is currently working with the local population to resolve this issue. The size of the London Array project and the speed of its progress indicate that public and government acceptance is supporting offshore wind development in the United Kingdom.

Outreach in the United Kingdom is facilitated by liaison groups formed by the Department of Trade and Industry (2007). Three groups focus on environmental, navigation, and fisheries issues and they provide input to the government's policy development. Members include representatives of nongovernment organizations, industry groups, and wind park developers who meet 3 or 4 times yearly to discuss issues associated with offshore alternative energy projects. For example, the Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW) gives the fishing industry a place to discuss specific projects or alternative energy development in general with wind park developers and regulators. FLOWW also establishes contact among stakeholders to allow development of agreements or engineering design changes that will facilitate a given project's progress.

One primary use-conflict issue associated with offshore development concerns the fishing industry. An outreach project was completed to seek views of the fishing industry in the three strategic areas of the proposed Round 2 wind parks (Mackinson et al., 2006). Despite outreach through mailings and industry organizations, participation by fishers was poor. Following are three suggested reasons:

- Face-to-face outreach and communication were much more effective than questionnaires.
- Fishers mistrusted the planning and permitting process.
- Fishers are extremely anxious about their economic futures.

Some major concerns of the fishing industry were navigability within wind parks, loss of fishing area, changes in fish behavior leading to reduced catches, and construction debris on the seabed interfering with fishing operations.

Following is a list of recommendations Mackinson et al. (2006) developed to gain the support of the fishing industry:

- Make available as soon as possible in the planning process monitoring study data from existing wind parks to address the fishing industry's concerns; note that issues and impacts will be very site-specific depending on the types of fisheries and fleets in a specific geographic area.
- Involve the fishing industry as early as possible in the planning process.
- Use face-to-face communication and outreach to improve trust.
- Develop marine spatial planning tools.

The British Wind Energy Association (BWEA) wrote a guide, "Best Practice Guidelines: Consultation for Offshore Wind Energy Developments" (BWEA, 2002), to underline the importance of early consultation to involve the local community in the planning process. BWEA provides several examples of how public input in the planning stage facilitated project completion:

- *Scroby Sands Wind Park:* Construction methods were adjusted to accommodate the needs of pupping seals and the breeding season for terns.
- *North Hoyle Wind Park:* The layout of the turbine array was adjusted to provide for navigation between turbines while still meeting the aesthetic needs of the Countryside Council of Wales.

The engineering design and methods also were modified for the London Array project to address issues identified during the planning process (RPS, 2005). Collaborating with the Royal Society for the Protection of Birds (RSPB), the developer decreased the number of turbines planned for the first phase of construction from 258 to 175 to accommodate a local population of diving birds. The RSPB supports the London Array project, and the group identified the developers' approach in working with the community to resolve environmental concerns as illustrative of RSPB's experience with renewables project developers (The Birdinsight, 2007). RSPB underlines the lesson from the London Array project to avoid designated sites from the outset, saying that doing so could save years of wrangling and enable renewable energy schemes to get off the ground far more quickly. By comparison, the RSPB strongly opposes the onshore Lewis wind project because it says development of the chosen site would harm large areas of peatland

and threaten a range of breeding and migrating birds (RSPB, 2007). Opposition from environmental groups has resulted in project delays.

The siting of the onshore substation for the London Array is facing strong public opposition from the local Graveny Rural Environmental Action Team. Opposition is based on the location of a substation in a greenfield area. Although the offshore portion of the project is moving through the permitting process, this local opposition has held up approvals for the onshore portion of the project, and additional public meetings are being planned (GREAT, 2007). The Kent Wildlife Trust originally also opposed the onshore substation; however, following a review of the ecological survey, discussions with the developer, and development of planning conditions, the Trust has lifted its objections to the onshore portion of the project (Kent Wildlife Trust, 2007).

These examples illustrate a very important concept—possible mitigation methods to reduce impacts on resources are extremely site specific. An example of site-specific issues is the significant environmental impact associated with migration and breeding, which requires site-specific information and species-specific knowledge. Identifying types of species in the area and noting the times and locations of migration routes are key to keeping environmental impacts to a minimum and gaining public confidence that these issues are addressed.

4.1.4.2 Denmark

As in the United Kingdom, Denmark started with construction of smaller wind parks and is moving to larger parks. In the report, “Offshore Wind Power: Danish Experiences and Solutions” (Hagemann and Jensen, 2005), the Danish Energy Authority outlines its policy framework for offshore alternative energy development. Early policy goals focused on ensuring that projects were supported at a local level, in some cases supported by shareholder ownership of the project. Until the mid-1990s the main offshore alternative energy project ownership was shareholding.

In Denmark, approximately 150,000 families are involved in wind energy projects. The Middelgrunden project is a good example of a locally owned cooperative (Larsen et al., 2005). This 20-turbine project is larger than the first United Kingdom wind parks.

Following are some of the policy objectives identified by the Danish Energy Authority:

- Ensure that the electricity system can handle the expected large new quantities of wind energy.
- Identify viable locations; Danish Energy Authority is tasked with an overview of potential locations.
- Tap into the global market and translate it into economic activity for Demark.
- Foster a focused initiative in research, development, demonstration, and training; the Advisory Council for Energy Research and the Danish Energy Authority have proposed drafting an all-encompassing, cross-disciplinary approach to energy research strategy.

The Danish Energy Authority, the Forestry and Nature Agency, and electricity companies jointly developed an Action Plan on Offshore Wind Power for Denmark in 1997. This working group looked at economics, site selection, and operational monitoring requirements and, based on their review, recommended four potential sites for wind park siting. As a result, Horns Rev and

Nysted were constructed. As discussed in the previous section, the Nysted and Horns Rev wind parks have received increased public acceptance during their operational lifetimes. The success at Horns Rev and Nysted laid the groundwork for the second round of Danish projects, and a competitive tender issued for Horns Rev II was won by Energi E2 in 2004. The tender for Rødsand II followed.

Before issuing the tenders, the government evaluated potential sites for use-conflict issues and consulted with the general public and authorities on environmental, navigational, and landscape-related issues. Results of this screening were integrated into project requirements for the environmental impact assessment, and these requirements were included in the tender issued by the government.

The European Policy Seminar on Offshore Wind Power Issues addressed potential impediments to the progress of offshore alternative energy projects. The seminar was held in Copenhagen in 2005 as a follow-up to the European Union (EU) Workshop on Development of Wind Energy held in 2004 (Danish Energy Authority, 2005). The meeting focused on solutions, approaches, and structural cooperation among parties to address identified obstacles to development of offshore wind. The recommendations of the seminar recognized the importance of site selection and public awareness, and included the following topics:

- Establishment and use of marine spatial planning instruments to support optimal site selection.
- Development of a modeling tool to assess cumulative impacts.
- Recognition of the need for enhanced public awareness of the eventual environmental benefits and technological possibilities of offshore wind power (e.g., increasing transparency of existing knowledge on affiliated benefits and possibilities for co-ownership).

In line with the recommendations listed above, the EU, European Wind Energy Association, various nature conservation non-governmental organizations, and state representatives have established an ad hoc working group to streamline implementation of environmental impact assessments by clearly defining environmental priority issues (Danish Energy Authority, 2005).

4.1.5 Experience in the United States

Currently there are no wind parks offshore of the United States, although several offshore wind park projects are at varying stages of development and planning.

4.1.5.1 U.S. Project Overview

The Cape Wind project, proposed for the OCS off Cape Cod, MA, is furthest along in the permitting process. Cape Wind developers submitted an Environmental Notification Form to the Commonwealth of Massachusetts in 2001 under the Massachusetts Environmental Protection Act (MEPA). They submitted an Environmental Impact Report (EIR) in compliance with state requirements. The MEPA office issued an approval in March 2007. MMS is currently reviewing the Draft Environmental Impact Statement (DEIS) for the project and will coordinate the National Environmental Protection Act (NEPA) review.

Several challenges have slowed the progress of permitting for the Cape Wind project:

- No offshore wind park has been permitted or constructed in the United States.
- Federal jurisdiction over permitting was not clear, and Cape Wind originally filed with the U.S. Army Corps of Engineers.
- The Energy Bill of 2005 authorized DOI as the lead department with jurisdiction over permitting of offshore wind farms; Cape Wind subsequently filed with MMS.
- The Cape Wind project faces well-organized local opposition.
- Several powerful politicians at the federal and state levels oppose the Cape Wind project.

The Cape Wind project does not share elements that helped make the first offshore wind projects in Europe successful. The Cape Wind project is relatively large, with 180 proposed wind turbines compared to the first European offshore wind parks that had fewer than 10 turbines, and the early full-scale projects that comprised fewer than 100 turbines. Thus, the presence of wind parks in United States waters is unfamiliar to local communities. Also, early European projects were supported financially and with initial site selection and screening to varying extents by the respective governments; the Cape Wind project is funded and developed solely by the developer.

According to the Cape Wind developer, project proponents held more than 450 public meetings to facilitate stakeholder involvement in the project development, which has been critical in gaining public acceptance (Olmstead, 2007). Visual impacts are reportedly the public's primary concern. MMS is preparing a Draft EIS that will consider all issues identified by the public.

Another recently proposed offshore wind park project follows more closely the model of European offshore wind development. The Hull Offshore Wind Project is a small four-turbine project planned for 1.6 km offshore of Hull, MA, just outside Boston Harbor (Manwell, 2007). The Hull project resembles the development of early European offshore wind parks in the following ways:

- It is locally sponsored by the Municipal Light Plant.
- It is partially subsidized by the Massachusetts Technology Collaborative.
- It is a small project.

The City of Hull has been generating electricity from onshore turbines since the 1980s, and the residents' familiarity with living near wind turbines has led to broad acceptance (Renewable Energy Research Laboratory, 2007). At the first public meeting to discuss the planned offshore wind project, no opposition to the project was voiced (Watson, 2007), even though the wind turbines would be placed only 1.6 km from the shoreline where many of the town's residences are located.

4.1.5.2 Public Opinion Poll Results in the United States

A public opinion poll conducted for Cape Wind Associates near the start of the project planning and permitting process indicated that more than 50 percent of the 400 people sampled on Cape Cod and the nearby islands were in favor of the Cape Wind project (Opinion Dynamics Corporation, 2002). Another survey of 600 Massachusetts residents throughout the state was conducted under sponsorship of the Civil Society Institute in 2006 after considerable media coverage and public information outreach between 2002 and 2006. The results showed that 90 percent of the respondents thought that Massachusetts should move ahead to develop offshore wind power and alternative energy on a large scale (Opinion Research Corporation, 2006). That survey also reported that 81 percent of the Massachusetts residents polled, and 61 percent of the Cape Cod residents polled, supported the Cape Wind project specifically (Opinion Research Corporation, 2006).

Additional public opinion surveys have been completed in states along the U.S. east coast. A survey of 4,026 tourists and residents conducted at four locations along the New Jersey Shore indicated that 47 percent of respondents were in favor of wind park development offshore of New Jersey (Lieberman Research Group, 2006). The respondents were shown simulation pictures of what the wind park would look like at four different distances from shore (5, 10, 20, and 32 km). Table 4-1 shows that the distance from shore was a key variable, with significant increase in approvals as distance from the shoreline increased.

Table 4-1: Distance as a variable in public approval of wind parks offshore New Jersey.

Distance from Shore	5 km (%)	10 km (%)	20 km (%)	32 km (%)
Percentage of Respondents Favoring Wind Park Development	38	42	51	57

Another survey of public attitudes toward wind energy in eastern North Carolina showed that 68 percent of the respondents believed that offshore wind parks should be allowed (Grady and Cousino, 2004). Support for development of wind parks in the ocean sounds was somewhat lower, with 50 to 64 percent approving nearshore areas, depending on whether the turbines were clustered or not.

A survey was also recently conducted to gauge public opinion on offshore wind development in Delaware (Firestone, Kempton, and Krueger, 2007). Preliminary results indicate that more than 90 percent of those polled want the state of Delaware to encourage, promote or allow development of wind farms in the open ocean off Delaware. Strong support for wind farm development in Delaware Bay was also indicated, although 31.6 percent of those polled indicated that they would prefer development in the open ocean rather than the bay (Firestone, Kempton, and Krueger, 2007)

4.1.5.3 Outlook for U.S. OCS Wind Projects

The results of the opinion polls discussed above indicate that the public supports wind energy development on the OCS of the United States. As in Europe, early outreach to and involvement of local communities are recognized as the most important component in gaining local support for projects. Because the United States is behind Europe in developing offshore wind parks, it is likely that the first projects in the United States will be on a considerably larger scale in turbine size and number than the first European projects, which makes local public acceptance more difficult to obtain. However, if the United States follows the European model, subsequent offshore wind projects following the first may gain public acceptance more readily.

Environmental impacts tend to rise to the top of public concern based on site-specific issues, as illustrated by the strong opposition to the Cape Wind project based on environmental impacts. In Europe proposed sites go through an initial screening for sensitive environmental receptors as part of the European Union's Strategic Environmental Assessment (SEA) process. The SEA is completed earlier than an environmental impact assessment, and it is used as a site-screening tool (UN, 2005).

The governments in the United Kingdom and Denmark have taken an active part in completing SEAs as part of their strategic plans to develop offshore alternative energy projects. In comparison, the U.S. government is not involved in initial site selection and screening, and there has been no high-level screening comparable to the European SEA. In the United States, developers select sites without the benefit of government support for site screening, and environmental impact issues are brought up later in the permitting process than in Europe. This has proven problematic in siting the first wind park in the United States. MMS prepared a draft Programmatic EIS (released March 16, 2007). This EIS is being prepared at a high level for the East, West, and Gulf coasts. MMS will also require site-specific EISs for specific projects and may prepare regional documents that would consider regional siting issues.

4.2 Space-Use Conflicts

4.2.1 Potential Space-Use Conflicts

Potential space-use conflicts common to all types of offshore alternative energy facilities in the United States include commercial fisheries; subsistence fishing; marine recreational activities such as boating, fishing, scuba diving, and surfing; sand and gravel extraction; oil and gas infrastructure; navigation; aquaculture; and other alternative energy facilities. Wave energy installations have several additional potential impacts: 1) reduced wave energy in the lee of the installation that could affect recreational surfing; 2) a higher potential for a formal exclusion zone around the installation; and 3) a potential to affect kelp harvesting. Ocean current installations may also have a higher potential for a formal exclusion zone because the devices have moving parts that could pose hazards to fishing gear and the public. There likely would be a safety buffer around individual units; depending on the layout of the array, the entire marine current facility could become an exclusion zone.

Generally, conflicts with existing navigation, oil and gas infrastructure, aquaculture, and sand and gravel extraction sites are avoided during the siting phase. Designated conservation areas also are avoided to the extent practical. Because commercial fishing, subsistence fishing, and recreational use can occur in most marine coastal areas, these activities cannot be avoided, and thus, they can pose significant space-use conflicts for offshore alternative energy installations.

The magnitude and duration of these potential space-conflicts vary during construction and operational phases. Temporary vessel exclusion zones may exist in work areas during construction. For example, there may be exclusion safety zones around each turbine during wind park construction or around the vessel laying the cable to shore, exclusions that are similar to the 500-m safety zone used in the United Kingdom around any manned position.

After an offshore energy facility is operational, various restrictions may be imposed to limit public access. Denmark imposes a no-trawling buffer of 200 m around buried cables, both between units and to shore. Egmond aan Zee wind park in the Netherlands has a 500-m safety zone that excludes all vessel traffic in the area of the 36 turbines. Some wind park installations in the United Kingdom have a 50 m safety zone around each turbine. There may be temporary safety zones around work sites during major maintenance periods. Some wind parks have no restrictions on access.

Exclusion zones around wave energy installations may be established for safety purposes because the devices have mooring systems that pose hazards to navigation and fishing. Also, the devices can move in response to waves and wind, depending on the design, making them unsafe for public access. Use of an exclusion zone varies by wave energy project. During operations, recreational use (fishing, boating, and diving) will not be restricted at the six-buoy demonstration project in Hawai'i (Department of the Navy, 2003). However, there will be a fishing and navigation exclusion zone around the four-device demonstration project in Makah Bay that will affect tribal crab and long-line commercial fishing and recreational fishing (AquaEnergy Ltd., 2006). In Europe and the United Kingdom, there are expectations that safety zones (up to 500 m), into which no vessel can enter without permission, will be established around wave energy installations (WaveNet, 2003). The proposed Wave Hub project off southwest England includes a request for a 500 m safety zone (Halcrow Group Ltd., 2006). The potential impacts to the local commercial fisheries (including both trawl and pot fisheries) was estimated at "moderate negative" for the proposed Wave Hub project site off south west England. (Halcrow Group Ltd., 2006). Impacts included increased pressure in adjacent areas and loss of areas where static gear fishermen can fish without fear of having their gear damaged or destroyed by trawlers.

Exclusion zones around ocean current installations may be established for safety because the devices have moving parts that could pose hazards to fishing gear and the public. There likely would be a safety buffer around individual units; depending on the layout of the array, the entire marine current facility could become an exclusion zone.

Even without declared exclusion zones, wind and wave installation can pose significant navigational hazards. This is particularly true for trawlers that were used to operating in the area before construction. Those areas of traditional use can become de facto exclusion areas for certain sizes of vessels and types of fishing gear. Particular navigational concerns arise for trawling and long lining in wind parks when the turbines are not aligned with tidal currents. Trawlers may need to haul in their nets early or maneuver in alternate courses when operating in the vicinity of a wind park, thus reducing their fishing efficiency. Trawling in the vicinity of buried cables poses risks of hang ups if the cables become exposed. Where transmission cables cannot be buried because of rock outcrops on the seafloor, there may be a trawling exclusion zone along the cable route to shore, depending on the site conditions. There will be a trawling exclusion zone along the cable at Makah Bay, Washington (AquaEnergy Ltd., 2006). There will be no exclusion zones along the cable route for the Wave Hub project in England, where the plan is to ensure that fishermen are aware of the cable location and the risk of snagging, as well as using proper installation methods to reduce the potential for the cable to span above irregularities in the seafloor (Halcrow Group Ltd., 2006).

The Oregon Fishermen's Cable Committee (2007) and the telecommunications industry have established procedures for trawling in the vicinity of submarine cables. This program is intended to protect submarine cables from being damaged by contact with trawl gear. Trawling over cables is not encouraged, and the procedures address how fishing vessels should operate when "near" cables to avoid contact. Fishermen who sign agreements with companies maintaining submarine cables can be protected from liability for damaging the cables by complying with these procedures. Also, compliance will facilitate compensation for trawl gear sacrificed to avoid damage to a submarine cable (http://www.ofcc.com/procedures.htm). These protocols could be a model where a cable crosses important trawl fisheries areas and cannot be buried.

The introduced hard substrates of wind park foundations and scour protections function as artificial reefs, thus attracting both fishes and fishers. Static gear fishers who operate pot fisheries could readily fish within a wind park, and they might benefit from the creation of hard-substrate habitat around the turbines. However, cables that become exposed could present a potential hazard for snagging pots and anchors.

Newly created hard-substrate habitat could attract both commercial fisheries and recreational fishers, and thereby potentially cause conflicts. For example, at the Burbo offshore wind park in the United Kingdom, crab and lobster fishers thought that new fishing opportunities could be created for pot fisheries because the wind park created an area effectively protected from trawling. The crab and lobster fishers were opposed to an exclusion zone for potters, although they would not object to trawlers being excluded (AMEC, 2002).

Where exclusion zones are implemented, an argument is often made of the benefits of no-take and no-trawl zones to the fishery resource in the vicinity of the installation. At the Wave Hub project site, the "benefit" of a no-take zone was used to offset the moderate negative impact to fisheries, and no mitigation was proposed at this site (Halcrow Group Ltd., 2006). Wave energy installations would likely have much less introduced hard surfaces, compared to wind parks, and the marine fouling communities may be regularly removed. Thus, wave energy systems may function more as fish attracting devices without the ecological value of increased fish production.

Wave energy installations are more likely to be located along the Pacific coast and in areas where kelp beds are commercially harvested (mainly California). Most types of wave energy devices would likely be located seaward of kelp because the kelp attenuates wave energy, reducing the power production (Hagerman and Bedard, 2004). Alternatively, kelp beds seaward of the installation would have to be cut. Buffer zones would likely be established around installations near harvested kelp beds to assure that the harvesting vessels do not damage the devices under adverse conditions such as loss of power or rough seas.

Site-specific studies will be needed to determine the actual extent and degree of wave height reductions, depending on the configuration and type of devices. Impact assessment will also be highly site-specific and should seek stakeholder involvement. For example, in the United Kingdom, surfing organizations have been invited as part of the consultation process for two offshore wave energy demonstration projects where they were involved in the design and review of modeling studies and agreed that there would be no impact on surf quality for the Wave Hub project (Halcrow Group Ltd., 2006).

4.2.2 Space-Use Conflicts at Existing Offshore Wind Facilities

Studies of space-use conflicts at existing offshore wind parks are few; mostly they address impacts to commercial fisheries. No studies were identified on impacts to recreational users.

During construction of the four Round 1 wind parks in the United Kingdom, advisory safety notices were issued to warn mariners and fishermen of the potential danger and advise them to avoid the specified areas. No serious accidents were reported (Department of Trade and Industry, 2006).

As part of its environmental assessment efforts for Round 2 wind parks in the United Kingdom, the Department for Environment, Food, and Rural Affairs sponsored a study, *The Perceptions of the Fishing Industry into the Potential Socioeconomic Impacts of Offshore Wind Energy Developments on Their Work Patterns and Income* (Mackinson et al., 2006), based on experiences with the Round 1 wind parks. In that study, fishers were reported to indicate that the "Turbines were considered a major hazard to navigation and fishing activities, with some fishers expressing the opinion that they would avoid wind farms even though they are allowed to fish within them." Also, because of the lack of licenses, investment costs, and the effort required to learn new methods, fishers were not inclined to change fishing methods. On the other hand, recreational fishers described the expected overall economic change as beneficial.

In the United Kingdom, few requests were filed for safety zones around the Round 1 installations, which had no more than 30 turbines; however, the larger Round 2 installations (the London Array will be up to 271 turbines) will pose greater navigational risks. Thus, in November 2006, the United Kingdom published a consultation document requesting public comment on a process whereby an applicant or the government could request a safety zone around offshore renewable energy installations as required by the Energy Act 2004 (Department of Trade and Industry, 2006). Two types of safety zones were considered reasonable for the purposes of the consultation: 500 m around any installation during construction and decommissioning, and 50 m around any installation to keep vessels navigating in the area from making contact with the structure. The Department of Trade and Industry also asked for comments on what categories of exemptions should be included under the regulations, and specifically what types of fishing activity that could safely continue to be undertaken in wind parks. The Department of Trade and Industry also asked for ideas on how existing activities might be adapted to make their safe continuation possible (Department of Trade and Industry, 2006). It was noted that safety zones would be established only on the basis of sound risk assessment and evidence of need. Thus, a safety zone would be considered only if requested by the applicant or when the government thought it was appropriate, even if the applicant did not request it.

Interestingly, the Department of Trade and Industry (2006) also reported that "A draft report by the Sea Fish Industry Authority (SEAFISH) commissioned by DTI on behalf of the Fishing Liaison with Wind and Wet Renewables (FLOWW) stakeholder group, recommends that commercial fishing of any kind should not be permitted anywhere within wind parks and that 500-m safety zones, the largest permitted under international law, should be established around each turbine." Considering that 2,500 offshore turbines are planned for United Kingdom waters, more than 1,660 km^2 would be off limits to any vessel activity, which was considered to be excessive (Department of Trade and Industry, 2006).

A study of the offshore wind power project outside Nogersund, Sweden, showed that, although there was no negative impact on fishes from the 220-kilowatt turbine, fishers caught less fish when the turbine was in operation (Larsson, 2000, cited in WaveNet, 2003); however, fishers still caught more fish in the vicinity of the wind turbine compared to other areas.

In summary, conflicts with stationary uses such as designated navigational channels, oil and gas infrastructure, and sand extraction sites usually are avoided during the siting phase. However, offshore alternative energy installations can pose significant space-use conflicts with the more mobile uses of a site because of actual or de facto exclusion of vessel traffic within the wind or wave array and trawling buffers along cable routes, if designated. There are no consistent guidelines on when safety exclusion zones should be established around offshore alternative energy installations or the size of safety buffers. The United Kingdom is evaluating the need for safety zones and assessing consequences of doing so or not doing so. It will be important to learn from their experiences.

4.2.3 Current Models Used to Evaluate Space-Use Conflicts

Extensive desktop data collection activities are part of the siting and permitting phases of offshore alternative projects. These data collection activities usually include stakeholder outreach efforts to identify and avoid, where possible, significant space-use conflicts. Data collections include information such as identity of areas important for fishing and recreational uses and sand and gravel extraction areas. During environmental assessments of individual sites, it often has been difficult to obtain quantitative data for evaluation of the potential impact on fisheries. The most successful projects used early and open communications with stakeholders. Gray, Haggatt, and Bell (2005) conducted a very important analysis of the interaction among the fishing industry, the wind energy park industry, and regulators. The researchers showed how critical a comprehensive and early stakeholder process is for management of development. For example, the fishing industry can influence site choice by identifying areas that were least valuable, thus minimizing the loss of what they consider to be the most profitable areas. The value of areas varies by fishery (vessel and gear type); avoiding one valuable area may increase the conflict with a different type of fishery. Identifying sites with no use conflicts is difficult, and thus, it is important to consider all potential use conflicts and minimize them to the extent practicable.

The potential impacts on fisheries are assessed by evaluating catch data, vessel numbers and types, and temporal fishing patterns in the project area, and then by determining the impacts of full or partial (by gear) loss of fishing access. The use of landings data is problematic because there are no reporting requirements for recreational fisheries and the recreational survey data are seriously deficient in quality and quantity. The documentation to determine where the fishes are captured by the commercial fishery is not specific. The problem for commercial fisheries is that their reporting requirements for location are deliberately very broad to protect the fishermen. Specific data on recreational fishing are very difficult to assess because reporting requirements are voluntary. In the Gulf of Mexico and along the Atlantic coast, highly migratory species (swordfish, tunas, billfish) are managed under a plan administered by the Secretary of the Department of Commerce (NOAA, 2006). On the Pacific Coast, highly migratory species are managed by regional fishery management councils, an arrangement that complicates policy development. Short-term impacts during construction normally are not considered significant. Long-term impacts resulting from permanent loss of access to fishing grounds through actual or de facto exclusion zones can be significant for displaced fishers, especially if no alternative sites or types of fisheries exist because of regulations limiting catches of other species or limited issuance of entry permits. Most fishers are not willing or able to change fishing methods because they have invested much time to learn how to successfully fish specific areas (Department of Trade and Industry, 2006). In the United Kingdom, impacts on fishers are often considered insignificant for wind parks without exclusion zones. For wind parks with exclusion zones, some sort of compensation is negotiated with affected fishers.

4.2.4 Space-Use Conflict Mitigation Used at Existing Offshore Wind Parks

Significant space-use conflicts for wind park projects are avoided through good siting practices; such avoidance is the dominant mitigation method used. Mackinson et al. (2006) reported fishers offer few—and sometimes conflicting—mitigation recommendations such as the following examples:

- Restore seabed to preconstruction state and remove debris postconstruction so that damage to fishing gear is reduced.
- Space wind turbines as close together as is safely possible to reduce the overall area of the wind park, and therefore, decrease the area of exclusion.
- Consider increasing the distance between turbines to 1,500 m to allow long liners to set and retrieve lines between the turbines.

Many existing offshore wind parks have no formal exclusion areas; therefore, the only limitations on postconstruction are individual decisions about what activities can be safely conducted within the footprint of individual turbines and the entire wind park. As noted above, this likely will change in the United Kingdom where safety zones around each turbine are under consideration.

During construction activities, fishers are given advance notification of all work likely to affect commercial fisheries. This advance notification allows fishers to remove equipment such as pots and lines before the exclusion zone is put in place. Many wind park operators offer to hire fishing vessels for support during construction. The timing of construction activities can be scheduled to avoid the most sensitive periods for both fishes and fishers. Often postconstruction trawl sweeps are conducted to flatten any anchor mounds and identify any discharged debris. Cables between turbines and to shore are buried 1 to 3 m to reduce the risk of snags.

Part of the consenting process in the United Kingdom is to determine if granting permission for an offshore development will disrupt fishing and if mitigation measures should be taken to avoid disruption. In situations where conflicts with the fishing industry are unavoidable, developers have negotiated compensation agreements with fishers who have lost access to a particular traditional fishing area. Generally, fishers must demonstrate a loss of income that can be documented from their landings records. The United Kingdom Department of Trade and Industry established the FLOWW renewables group to encourage open dialogue between the fishing industry and the alternative energy sector and to foster closer relations between them. The purpose of FLOWW is to provide guidelines for companies involved in offshore energy development when dealing with fishing and fisheries. The goal is that offshore wind, wave, and tidal energy installations and fisheries should coexist to the advantage of both parties. One of the first FLOWW projects was the development of guidelines by the British Wind Energy Association (BWEA, 2002) for offshore wind developers when dealing with the fishing industry and a process for resolving issues.

4.2.5 Information Needs—Space-Use Conflicts

The largest impact on fisheries is embodied in the area of socioeconomic-political conflicts. The interaction of issues among fishing interests, which depend on fishery resources, is profound and controversial. A review of the files on the actions of the Mid-Atlantic Fishery Management Council (www.mafmc.net) on the fish locally known as "fluke" (the proper common name is summer flounder [*Paralichthys dentatus*]) clearly shows the complex nature of the environmental and socioeconomic issues regarding the habitat and production of this fish and how contentious the decisionmaking process is for the allocation of the resource between recreational and commercial sectors. No sector will consider giving up what it perceives to be its fish to the other competing interests. Thus, if no commercial fishing access is permitted or possible because of an offshore energy installation, then the commercial interests are reluctant to permit recreational fishing; and likewise, the recreational fishers are reluctant to permit commercial fishing. If an area is not open to trawling or recreational fishing (as environmental interests might prefer), the area can become a marine protected area, especially for benthic dwelling species. However, that action might be rejected by the fishing interests. These discussions can be very time consuming. A site selection process that involves competing fishery and environmental interests has been developed by the South Atlantic Fishery Management Council. In 2006, the Council started the process to establish marine protected areas for fishery habitat protection, and it has a voluminous record and documentation of the process and issues (SAFMC, 2007c). Studies on the policy, social, and economic consequences of declared or de facto fisheries exclusion zones at offshore alternative energy installations would provide the basis for developing a uniform and fair approach.

The selection of a specific site with its own potential impact to fisheries dictates the need for mitigation measures. In the United Kingdom, a FLOWW renewables group provides guidelines for operators to work with the fishing industry before construction and after operations begin. Regional fisheries management councils have advisory panels that can possibly fulfill the role.

Offshore wind parks, in particular, can function as artificial reefs, creating a need for a management strategy. The strategy could be as simple as no management. Somewhat more complex would be a management plan on a continuum based on allocation of limited access to user groups. A complex strategy could include complete exclusion in numerous categories (open access, recreational and commercial fishing for all gear types, all recreational gear only, surface trolling gear for recreational only, closed to all for periods of time, diving only, closed to all). Habitat alteration from oil production has resulted in extensive research activities such as the rigs-to-reefs programs. When oil and gas platforms are decommissioned in the Gulf of Mexico, an established process allows companies to remove the superstructure and sink it to the bottom to serve as an artificial reef. Recreational and commercial fishing sectors consider this an advantage, and the practice provides a significant cost saving for production companies (NTIS, 1987;Wilson, Pierce, and Miller, 2003; Patterson, Cowan, and Shipp, 2004; McKay, Nides, and Vigil, 2004; Wilson, 2006). If wind parks do provide local value as artificial reefs, studies will be needed to determine the ecological benefits during the life of the wind park and the consequences of its eventual removal.

4.3 Aesthetics

4.3.1 Potential Aesthetics Impacts

Experience with offshore wind park developments has demonstrated that aesthetic impacts, which are a combination of seascape and visual issues, are often the most prominent reason for public objection. These issues are so important that several organizations have developed guidance documents on how to address seascape and visual impacts during environmental assessments, and those documents address public concerns for both onshore and offshore wind parks (Department of Trade and Industry, 2005; Hill et al., 2001; University of Newcastle, 2002). Department of Trade and Industry (2005) defined *seascape* as "a discrete area within which there is shared inter-visibility between land and sea (a single visual envelope)" and *visual effects* as "results from changes in the landscape or seascape and are defined as changes in the appearance of the landscape or seascape, and the effects of those changes on people." Noise is another type of aesthetic concern.

The construction phase (usually completed within 1 year) has periods of concentrated vessel activity between shore-based construction depots and the offshore site. Construction activities visible from land and sea include service vessel travel, barge traffic, night lighting, jack-up rig operation, crane activity, tower construction, foundation installation, rotor blade placement, and cable-laying ship activity, among others.

The loudest sounds generated during construction activities at wind parks are associated with pile driving (Nedwell and Howell, 2004). Installation of other types of foundations or scour protection is expected to generate lower sound levels.

Visible above-water structures during wind park operations include turbine foundations and rotating blades, as well as the substation and any meteorological masts. The visibility of these structures varies depending on distance, viewpoint characteristics, meteorological conditions, and size and layout of the wind park.

Any type of offshore installation will require navigational aids, such as buoys, lights, radar reflectors, and contrasting day marker painting. All above-water devices will be visible to boaters, as will the navigational aids that, by U.S. Coast Guard standards, have to be visible within 1 nautical mile. Very large wave arrays on the OCS with a large waterplane area are likely to be visible from shore under certain conditions. The degree of visual impacts will vary by location and size of the installation. There has been little concern about visual impacts for the small pilot wave energy installations deployed to date. Halcrow Group Ltd. (2006a) conducted a landscape and visual impact assessment using the largest device likely to be used at the Wave Hub site, namely a multiple point-absorber system with a number of floating buoys attached to a light and stable floating platform. The assessment results showed no significant impacts for the site, which is 15 km from shore.

Most of the existing wave energy technologies have a low profile that does not extend much above the water level. The exceptions are the oscillating water column designs; the freeboard of the Energetech device is about 10 m and the Mighty Whale is about 4 m. The number of devices and spacing of likely arrays of full-scale installations have not been determined.

Aesthetic concerns likely will be negligible for ocean current devices that do not extend above the water surface. If navigation aids are required to identify exclusion or safety zones, the lights might be visible from shore at night. It is conceivable there could also be concerns based on knowledge that there were artificial energy extraction devices under the sea, a habitat that the public has traditionally considered natural and protected. Array configurations—the number of turbines and their spacing—for full-scale installations have not been determined, so it is difficult to envision the size of commercial projects.

The operation of the turbines generates noise, although well designed and operating turbines are generally quiet. Sound may be a concern for the oscillating water column designs for wave energy devices. According to Hagerman and Bedard (2004), the sound from a single prototype operating off India was measured at 70-90 dB adjacent to the device and 60 dB at the shoreline 650 m away. The sound in the village was reported to be similar to a small, single-engine airplane flying overhead. The sound increases with wave energy, although the sound can be reduced, or eliminated, by careful design and/or acoustic muffling (Hagerman and Bedard, 2004). Obviously, more measurements are needed under the typical range of operating conditions before a full assessment can be conducted.

4.3.2 Aesthetics Impacts at Existing Offshore Wind Facilities

Studies on public attitudes towards existing offshore wind parks are described in Section 4.1.2. On the basis of these studies, visual impacts can be a significant factor to local communities, particularly in communities that want to preserve local seascapes for their natural beauty. The studies indicate that these impacts can be reduced by moving wind parks farther offshore.

In the United Kingdom, little postconstruction monitoring of public perceptions has been conducted at existing offshore wind parks. This lack has been noted as a deficiency in the current environmental impact assessment practice (Department of Trade and Industry, 2005).

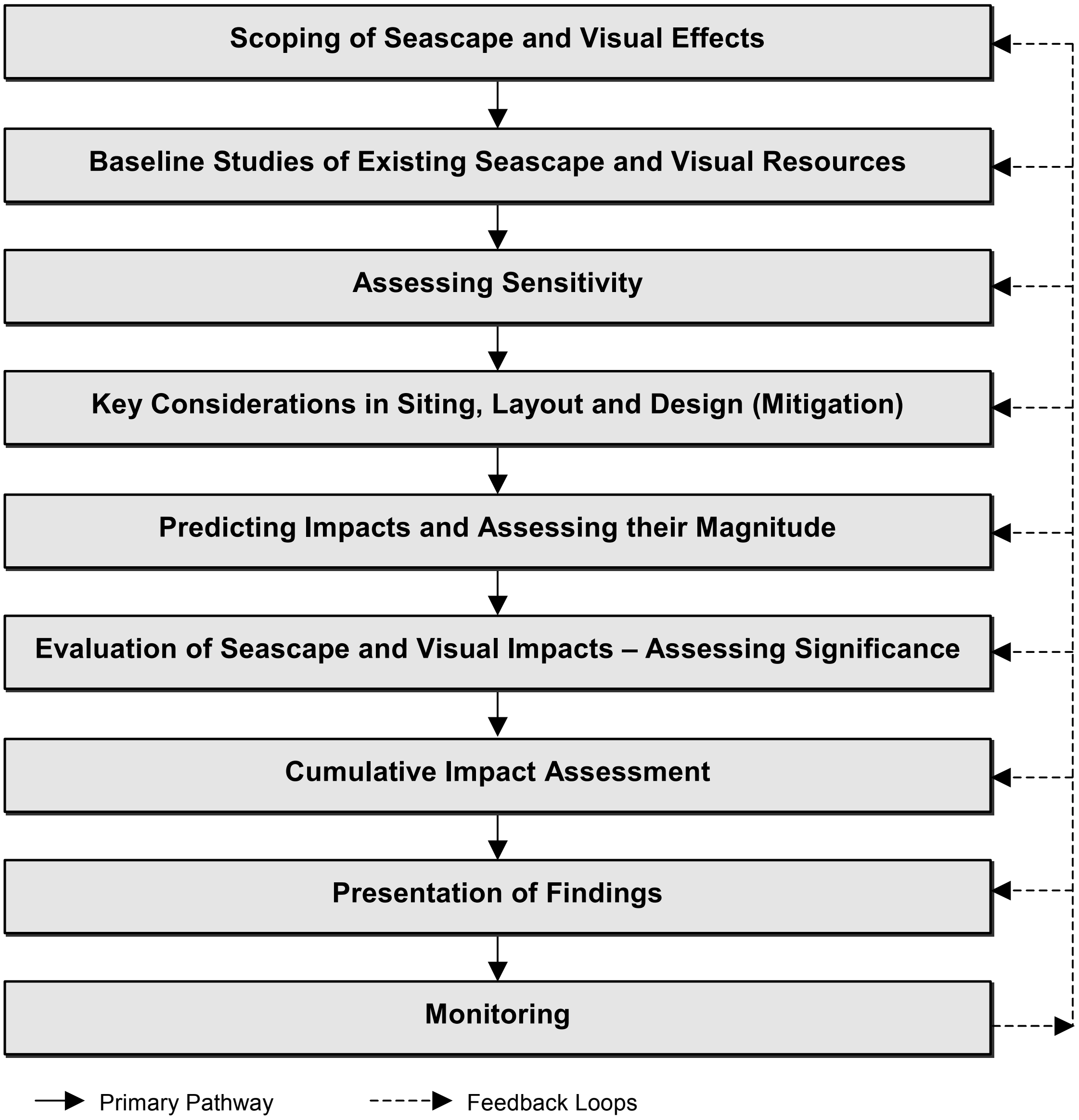
4.3.3 Current Models Used to Evaluate Aesthetics Impacts

4.3.3.1 Visual Impacts

The current practice at offshore wind parks is to conduct a visual impact assessment, which is a formal process that describes the impacts of the development on views of the landscape and seascape through intrusion, obstruction, or changing the content and focus of views, the reactions (attitudes and behaviors) of the viewers who may be affected, and the overall change in visual amenity. The United Kingdom has published guidelines for conducting visual assessments of offshore wind parks and other coastal developments (Department of Trade and Industry, 2005; Hill et al., 2001).

The Department of Trade and Industry (2005) has developed a detailed process specifically for assessment of seascape and visual impacts, as shown in figure 4-4. The Department of Trade and Industry assessment process includes the following activities:

- Extensive collection of existing information
- Spatial analysis using specialized software to predict the potential visibility from representative and particularly sensitive viewpoints

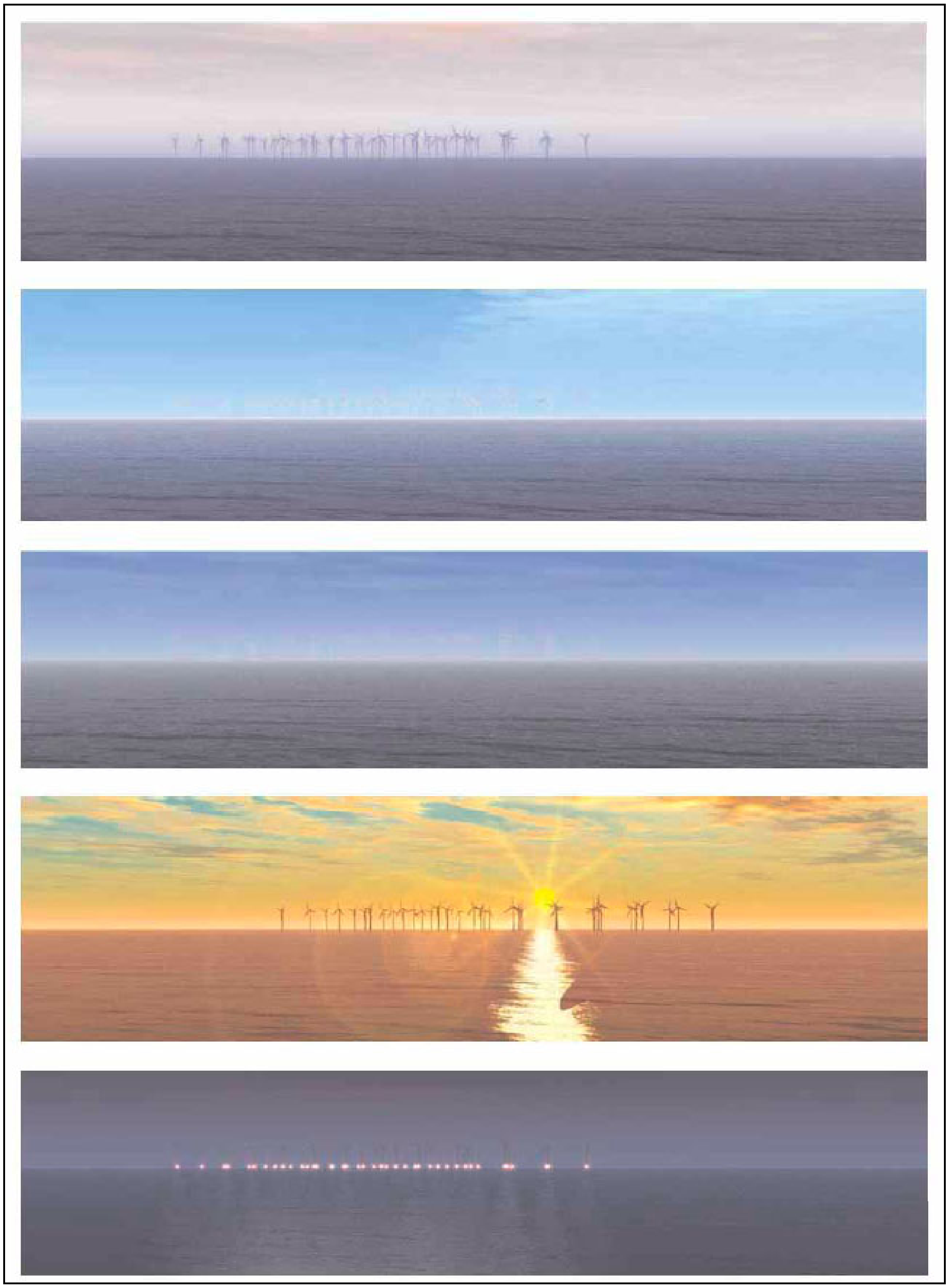


Source: Department of Trade and Industry, 2005.

Figure 4-4: Stages in the process for conducting seascape and visual impact assessments in the United Kingdom.

- Field surveys to collect information on seascape quality, sensitivity, value, and capacity to accommodate change of these viewpoints
- Computer-generated visibility analysis and use of photomontages to illustrate potential impacts
- Use of descriptive matrices to describe the magnitude and significance of the impacts, including cumulative impacts
- Presentation techniques to communicate the results of the seascape and visual impacts assessment

Figure 4-5 shows an example of how a computer-generated visibility analysis can use a photomontage to illustrate different lighting conditions.



Source: Department of Trade and Industry, 2005.

Figure 4-5: Example photomontage showing the effects of lighting conditions on an offshore wind park that is 6 km from the coast.

The Middelgrunden wind park, located 3.5 km outside of the harbor at Copenhagen, Denmark, consists of 20 turbines. The wind park is an example of how public involvement in project planning can influence attitude. In 2000 the wind park achieved a high degree of public acceptance because early in the planning process the local community was involved (Larsen et al., 2005). The turbine numbers and layout were revised based on public response to the visualization assessments. In addition, a local cooperative with more than 8,500 members half-owns the wind park. Three years after construction, the local newspaper stated, "Here, the windmills are seen as a graceful gateway to a historic harbor and a proud symbol for an environmentally conscious country that has put itself at the cutting edge of one of Europe's fastest growing energy sectors: wind power" (Larsen et al., 2005).

For the Cape Wind project, visual impact assessments were conducted for selected viewpoints that included historic properties and onshore recreational sites (mostly beaches) and offshore sites (Cape Wind Associates, 2007). Computer-generated simulations of how the wind park would appear under different conditions were created using day and nighttime photographs for each viewpoint. It was determined that the wind park would have adverse visual effects on 2 of 3 National Historic Landmarks, 4 of 5 historic districts, and 10 of 12 individual historic properties included in the assessment (Cape Wind Associates, 2007). Adverse impact was defined as "introduction of visual, atmospheric, or audible elements that diminish the integrity of a property's significant features that qualify the property for inclusion in the National Register" (36 CFR 800.5(1)) (Cape Wind Associates, 2007).

WaveNet (2003) made the following recommendations to reduce public opposition to offshore wave energy installations, based on lessons learned in Europe and the United Kingdom from existing offshore wind parks:

- The devices should in general be placed as far away from the coast as possible, and in particular proximity to recreational areas and/or areas of great scenic value should be avoided.
- The planning process must be very open and careful, and if the site is visible from land, the effect on the environment and economy (e.g., tourism) of the coastal area should be assessed.
- Layout, number, and size of wave energy converters and cumulative effects should be thoroughly and openly analyzed and discussed before a decision is taken.
- Early local involvement in the planning phase is essential, and community involvement in ownership of the wave park will be beneficial when the technology has been proven.

4.3.3.2 Sound Impacts

Wind turbines produce two sources of sound: mechanical sound produced by the gearbox, generator, and other parts of the drive train; and aerodynamic sound produced by the passage of the blades through the air. In the United Kingdom, *The Assessment and Rating of Noise from Wind Farms* (ETSU for Department of Trade and Industry, 1996) has been adopted as the standard methodology for determining operational sound impacts from wind parks. This method describes a framework for assessing wind park sound, and it suggests sound limits of 5 dB above day and night background conditions at the nearest noise-sensitive location. Table 4-2 lists various sound sources for comparison with onshore wind parks (The Scottish Office, 1994).

Noise from offshore wind turbines is unlikely to reach levels above background conditions for onshore locations; however, other sources of noise such as foghorns required for navigational safety can be associated with offshore wind parks and cause concern.

Sound during pile driving can be predicted using hemispherical spreading models. Researchers at the Kentish Flats wind park determined that pile driving sound, under the worst-case scenario of nighttime and onshore wind conditions, when allowing for a partially open window, would reach the nearest houses (8.5 km away) at below the sleep disturbance criteria defined by the World Health Organization (Emu Ltd., 2002).

Table 4-2: Sound sources for comparison with wind park sounds.

Source/Activity	Indicative sound level in decibels
Threshold of hearing	0
Rural night-time background	20 to 40
Quiet bedroom	35
Wind park at 350 m	35 to 45
Car at 40 mph at 100 m	55
Busy general office	60
Truck at 30 mph at 100 m	65
Pneumatic drill at 7 m	95
Jet aircraft at 250 m	105
Threshold of pain	140

Source: The Scottish Office, 1994.

4.3.3.3 Aesthetics Impact Mitigation Used at Existing Offshore Wind Parks

The most effective measure offshore wind park developers can take to mitigate aesthetic impacts is proper site selection. Department of Trade and Industry (2005) recommends the following siting and layout guidelines as principals of good practice:

- Consider locating developments in lower-sensitivity seascapes with higher capacities to accommodate change.
- Consider locating developments as far away from the coastline as possible. In the United Kingdom, Round 2 offshore projects are located at distances of between 8 km to 25 km offshore, making them indiscernible in certain weather and light conditions, although these distances specifically apply to the locations of the Round 2 projects, meaning they cannot be used for other areas (BMT Cordah Ltd., 2003).
- Consider locating developments particularly away from coastal landscape designations.
- Consider using headlands and development siting to minimize visibility.
- Consider locating developments in already industrialized and developed seascapes.
- Minimize horizon spread from key views, which is often one of the dominant factors in determining the magnitude of change in the view.
- Consider the siting relationship with other existing offshore and onshore wind parks.

Following is a list of other mitigation measures that have been used or proposed on other projects:

- Paint visible structures a marine grey color to minimize contrast with the surrounding sea and sky.
- Use tubular towers that are simple, clean-lined structures.
- Use the lowest intensity daytime and nighttime lighting considered safe.
- Monitor above-ground sound levels at key points of concern during pile driving to assure that sound levels comply with permit requirements.
- Use state-of-the-art, very low-noise turbines to minimize operational sound effects.
- Install kiosks at selected locations to provide information about the development.

It is difficult to modify the layout of an offshore alternative energy installation to provide the best view from different viewpoints because of competing considerations; however, developers can use visualization simulations to present the results of different layouts from different viewpoints.

4.3.3.4 Information Needs—Aesthetics

Offshore wind parks located in the OCS in the United States will be located at distances of 5.5 to 16.5 km (3 to 9 nautical miles) from the coast, depending on state definitions of territorial seas. Various studies have shown that offshore wind parks would be visible at distances of 12 to 25 km; however, site-specific visualization studies would provide the basis for assessment of seascape and visual impacts for individual projects. Experience in Denmark, the United Kingdom, and the Cape Wind Project in the United States has shown that aesthetic impacts are often the most prominent reason for public objection. Detailed guidelines have been developed for seascape and visual impact assessments of offshore wind parks in the United Kingdom (Department of Trade and Industry, 2005). Similar guidelines should be developed for assessment of offshore wind parks in the United States to make assessments consistent among projects. In particular, there is a need for consistency in how seascape and visual impacts are defined because they are highly qualitative in nature. The tools for creating visualizations of the changes to the seascape and views are well developed; however, the evaluation methods tend to be subjective and qualitative.

Studies to determine the thresholds of visual impact for offshore wind parks would make them useful in visual impact studies. Such studies would provide better data to predict levels of visual impact at different distances. In the United Kingdom, levels of visual impact have been based on common consensus from previous experience based on distances largely derived from land-based wind park studies (Department of Trade and Industry, 2005). Monitoring studies of public response to offshore wind parks postconstruction would provide much needed data to improve the assessment process.

4.4 Additional Areas of Social, Cultural, and Economic Interest

There is a wide range of other areas of social, cultural, and economic interests to be considered in environmental assessments of offshore alternative energy installations. Because these areas have not been addressed in detail during this literature synthesis, they are briefly described below.

- *Land use and infrastructure*: Developers must have an interconnection (to a grid for example) or they cannot bring energy onshore. Offshore installations require onshore development close to shore, such as substations, grid connections, and transmission lines. In addition, there must be adequate industrial sites and port facilities for construction, operations, and decommissioning. Existing facilities and roadways often must be modified or expanded to accommodate specialized equipment and the large components (e.g., monopiles, turbines). In some cases, a project may require dredging or modifications of waterways to accommodate construction vessels. All of these types of impacts will need to be addressed during in the environmental assessment of specific projects.
- *Economic impacts*: The number of jobs created from any development is one of the first things a state or county will ask. MMS uses IMPLAN® (Professional Social Accounting and Impact Analysis Software) to estimate total job creation including multiplier impacts of the project at different scales.
- *Sociocultural/subistence*: Many locations have historic ties to the ocean in the form of cultural uses. These uses can be ceremonial or related to nutrition such as subsistence hunting and fishing. Environmental assessments would be conducted to determine if the proposed action would affect sociocultural heritage of coastal communities and subsistence use. Many coastal communities are experiencing significant pressures from uncontrolled growth, and thus cumulative impacts may be of concern.
- *Environmental Justice*: Under Executive Order 12898 all federal agencies are required to determine if their actions will cause disproportionately high and adverse human health or environmental impacts to low-income, minority, or tribal communities. Such impacts can derive from physical or natural resource impacts that result in disproportionate social, cultural, or economic effects on these communities. Examples include visual changes in seascapes, construction impacts such as noise and dust, and construction of onshore facilities in areas that would mostly affect low-income or minority populations. If there are significant impacts, then mitigation must be applied.
- *Recreation and Tourism*: Direct impacts to recreation within the footprint of an offshore alternative energy installation are discussed in Section 4.2 on Space-Use Conflicts. However, there can be indirect impacts to recreation associated with both the construction and operation of offshore facilities. These impacts can be negative, such as increased vessel traffic and exclusion areas, and positive, such as enhanced fishing opportunities for certain species that are attracted by the introduction of hard substrates. Tourism can be a major economic force for coastal communities, and any negative changes in tourism will be of major concern. As discussed in Section 4.3, the fear of loss of tourism revenues was a major reason for public opposition to offshore wind parks in Denmark. According to the Cape Wind EIR (Cape Wind Associates, 2007), the most significant potential for adverse effects on both tourism and recreational areas is from visual affects of the project. Thus, the visualization impact analysis will be an important component of the environmental assessment.

- *Navigation and Transportation*: Studies must be conducted to assess if areas selected for development impact existing air and water navigation or transportation routes. For water navigation, impacts to commercial and recreational boating would be addressed through a navigational risk assessment, often coordinated with the U.S. Coast Guard. All projects must comply with U.S. Coast Guard requirements for navigation lighting. For air navigation, the developers must coordinate with the Federal Aviation Administration (FAA) in the review of potential impacts to air navigation for structures greater than 200 ft (61 m) in height above ground or sea level that might affect any protected areas or airspace around airports.
- *Communications*: There is a potential for certain types of projects (mostly wind) to interfere with telecommunications, FAA radar systems, and marine communications (VHF [very high frequency] radio and radar). Telecommunication systems such as radio and microwave operate on a line-of-sight basis; therefore, structures could obstruct these signals if they are in line-of-sight between a transmitter and a receiver. Developers need to coordinate with the Federal Communications Commission to determine if the project could interfere with existing and proposed telecommunications towers. They also need to coordinate with the FAA to determine if the project could interfere with aviation radar systems. A study by Elsam Engineering (2004) at the Horns Rev wind park in Denmark found that the turbines did not have any significant effect on VHF communications or shadows on radars from the rotating blades.

5. Potential Direct, Indirect, and Cumulative Impacts of Offshore Energy Technologies

This section explores the potential direct, indirect, and cumulative impacts of offshore energy technologies based on existing literature that addresses both the baseline information on resources of concern and known potential impacts. The most information is available for offshore wind technologies because they are the most mature. Limited information is available for pilot and demonstration projects for wave technologies. Only very limited data are available for ocean current technologies. Where applicable to offshore settings, the text discusses some data from tidal current technologies.

5.1 Wind Technologies

5.1.1 Potential Impacts Summary

Several excellent reviews are available on the potential impacts of offshore wind parks on marine resources; most are based on environmental impact assessments and monitoring programs of existing offshore wind parks in Europe and the United Kingdom. These reports range from material sponsored by the proponents of a particular project and include their original background material and preliminary studies through operational monitoring (Dong Energy and Vattenfall, 2006), to studies from academia (Gill, 2005). Gill's paper on Offshore Renewable Energy Development (ORED) highlights several important findings on the ecological implications of this issue:

- "Ecological factors are not being considered properly and are underrepresented in any discussion of the costs and benefits of adopting offshore renewable resources."
- "Removal of long established ORED will immediately reduce habitat heterogeneity and take out a large component of the benthic community."
- "It is important to establish whether the type, frequency and intensity of sounds associated with ORED will have any implication (such as reaction or habituation) for the species that inhabit or migrate through the coastal environment."

Gill (2005) also addressed the role of electromagnetic fields (EMF): "Research into the effects of ORED-related electric fields (E-fields) on sensitive species, particularly benthic ones, is required, especially when assessing the ORED environmental impact at important local feeding or breeding grounds or nursery areas." The artificial reef effect has been described as a beneficial response by providing habitat for adults, spawning sites, and habitat for juvenile fish. That might be so, but Gill (2005) argued that there is little evidence to support the "local ecosystem connectivity, population (and possibly metapopulation) dynamics and food web interactions." This will require very comprehensive and well-designed studies at different temporal and spatial scales. Finally, Gill (2005) emphasized that "As the number of ORED increases in the coastal zone, cumulative impact assessments are required to provide spatial and temporal assessment of the environmental impacts by taking account of the proximity of existing and planned future developments (Carryer and Deeming, 1998)."

The following subsections in this section address potential impacts from OCS wind parks separately for physical processes (currents and tides, waves, and sediment transport), benthic resources, fishery resources, marine mammals, sea turtles, flying animals (birds, bats, and flying insects), space-use conflicts, and aesthetics. These resources and issues are likely to be of greatest concern during the siting and environmental assessment of offshore wind parks in the United States. It is also important to acknowledge that there are key ecological linkages among resource concerns. For example, changes to physical processes that affect sediment characteristics can affect benthic communities and fish habitat. Changes to benthic communities can affect energy flow to fishery resources. Changes to fishery resources can affect predator-prey relationships for marine birds and marine mammals. These ecological relationships are outlined by concept in figure 5-1 for the construction phase and figure 5-2 for the operational phase of offshore wind parks, modified after Hiscock, Tyler-Walters, and Jones (2002). The magnitude, extent, duration, and significance of these potential impacts depend greatly on site-specific conditions. It is the goal of environmental assessment studies to evaluate these potential impacts considering the ecological interrelationships.

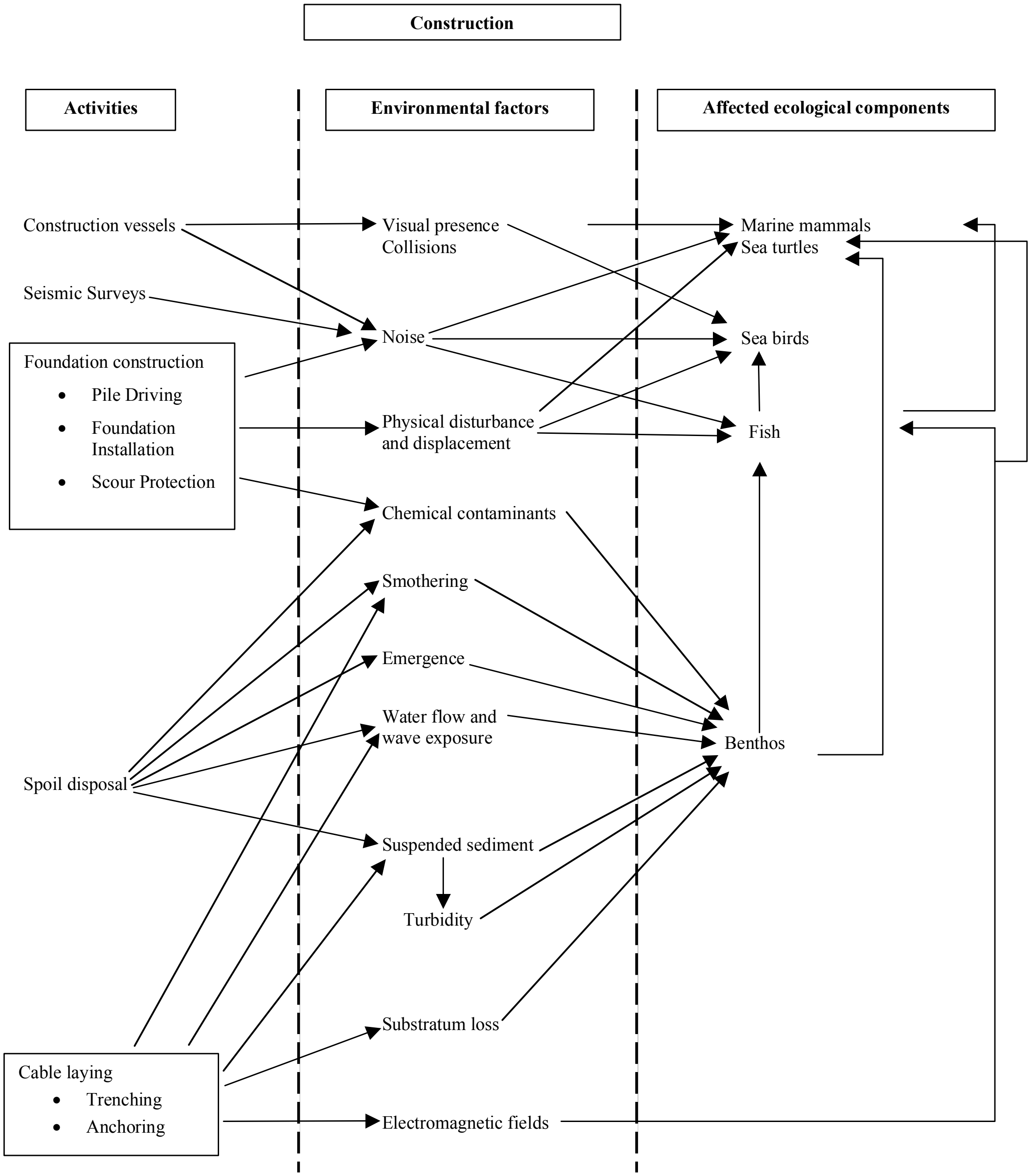
5.1.2 Physical Processes

5.1.2.1 Potential Impacts of Wind Technologies—Physical Processes

This analysis addresses potential impacts resulting from physical processes during construction and operation of alternative energy facilities used to harness wind power along the Outer Continental Shelf (OCS). Physical processes associated with wind technology include currents and tides, waves, and sediment transport. Table 5-1 lists potential impacts for each process. The following sections summarize existing information and identify where information is needed. Several paragraphs at the end of this section list research needs in all the physical processes to fill in information gaps.

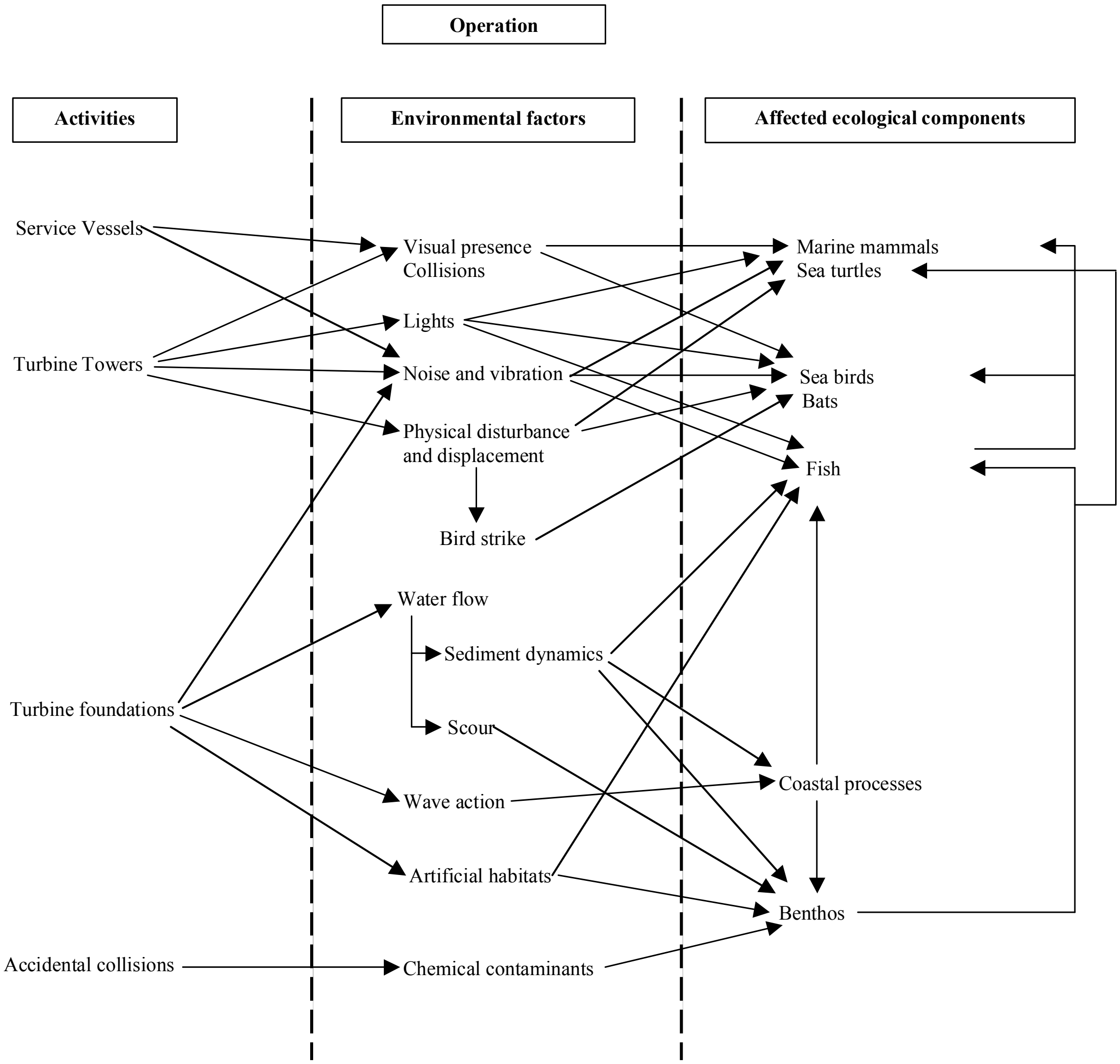
Potential Impacts to Currents and Tides

Wind turbine foundations have the potential to affect current flow velocity and direction and increase turbulence. These current changes can result in modified near- and farfield sediment transport regimes. These changes to sediment transport in the farfield could result in erosion or accretion hotspots on adjacent shorelines. Modified currents also could change the local area mixing capabilities, possibly affecting the distribution of salinity, nutrients, effluents, river outflows, and thermal stratification. These modified physical parameters may impact the benthic habitat/resources, and fish habitat (discussed in separate sections). In neighboring areas beyond or within the OCS, current modification could change the capability to generate power using power systems that transfer energy from currents. Additional impacts, discussed in a later section, could influence wave climate through wave-current interaction. While the blocking effect of wind power structures can lead to a lag in surface elevation variations near the structure, the primary potential tidal influence in the OCS area is to produce or modify a current. Currents are subject to the same impacts as main ocean currents themselves. Changes to major ocean currents such as the Gulf Stream are farfield and extreme farfield impacts, and they can reach well beyond the continental United States, affecting the climate of North America as well as other continents.



Source: Modified after Hiscock, Tyler-Walters, and Jones, 2002.

Figure 5-1: Conceptual diagram of the interrelationships among types of activities associated with construction of offshore wind parks and the environmental factors and resource groups that are potentially affected.



Source: Modified after Hiscock, Tyler-Walters, and Jones, 2002.

Figure 5-2: Conceptual diagram of the interrelationships among types of activities associated with operation of offshore wind parks and the environmental factors and resource groups that are potentially affected.

Table 5-1: Potential impacts of wind technology on OCS physical processes.

Construction Phase	**Potential Impact—Physical Processes**
Foundation Installation	
Construction Vessels	Initiation of scour around jack-up legs if jack-up rig is used
Pile Driving	Sediment suspension and redistribution during pile driving Initiation of scour processes, scour around jack-up legs, and sediment suspension and redistribution during pile driving
Foundation Installation	Sediment suspension and redistribution during seabed excavation and leveling for gravity foundations Initiation of scour processes, sediment suspension and redistribution during seabed excavation and leveling for gravity foundations
Scour Protection	Sediment suspension and redistribution during scour protection placement, modified hydrodynamics due to reduced depth
Dredged Materials Disposal	Hydraulic stability of dredge material at disposal site, modified hydrodynamics due to reduced depth at disposal site, sediment suspension and grain size changes
Cable Laying	
Trenching	Sediment suspension and redistribution, wave focusing and shoaling due to presence of trench in nearshore areas
Anchoring	Sediment suspension resulting from positioning, anchoring, and movement of cable-laying vessels
Operations Phase	**Potential Impact—Physical Processes**
Turbine Towers	Currents and tides: No direct impacts Waves: Reduced wind-wave generation capacity in lee of wind park Sediment transport: Indirect impacts from potentially modified wave climate
Turbine Foundations	Currents and tides: Change in flow velocity and direction, increased turbulence, modified mixing capabilities, reduced capacity to current-extraction approaches in downstream areas, modified wave-current interactions Waves: Reduced wave heights, modified wave-structure interactions, modified wave-current interactions, reduced capacity to wave-extraction approaches in lee of wind park Sediment transport: Local scour, global scour, changes to seabed topography, changes to littoral zone limits or longshore sediment transport rates or both
Cables	Currents, tides, and waves: Wave focusing and shoaling and increased tidal currents in nearshore areas if trench not backfilled Sediment transport: Local scour
Accidental Collisions	None

Potential Impacts to Waves

Waves are driven by meteorological events, thus they vary seasonally and between years. Events are based on storminess and other global climate factors such as El Niño and more extreme solitary events such as hurricanes, tsunamis, and freak waves. The potential for impacts to waves also can vary in the same relative time scale.

Offshore wind turbine foundations on the OCS could affect waves in several different ways:

- Direct wave-structure interactions such as reflection, diffraction, breaking, and sheltering
- Wave-current interactions caused by modified current climate
- Reduced capacity for local wave generation through a modified wind profile and increased turbulence (relevant only to the lee of wind parks)

Farfield effects of a modified wave climate include impacts to coastal zone hydrodynamics and sediment transport, altered recreational capabilities such as surfing, and limits on the capability of neighboring areas to generate power using wave energy conversion facilities. Nearfield effects of a modified wave climate include changes in navigational conditions, wave loads on adjacent structures, and sediment transport under waves.

Potential Impacts to Sediment Transport

Changes to flow conditions affect sediment transport. Two nearfield impacts can result from a modified sediment transport regime—local scour and global scour. A submerged foundation structure can increase turbulence and, in some cases, disrupt coherent flow structures (vortices). These changes near a structure often lead to increased bed shear stress, potentially causing local erosion known as “local scour.” Local scour is significant to structures because it often represents erosion of supporting sediments. Erosion of bottom sediments in areas between multiple structures is known as “global scour.” Global scour, which results from the presence of wind park structures, can cause changes to flow conditions. Global scour differs from local scour because it involves a multistructure group influence and modified bed shear stress.

Potential farfield sediment transport impacts are changes to seabed topographic features and changes to littoral zone limits or transport rates. These farfield impacts could result in sediment erosion and deposition in areas where the process did not occur previously. This impact can affect intakes and outfalls, beaches and other recreational areas, navigation channels, and shoreline vegetation. Further concerns include loss of habitat, exposure and resuspension of contaminated sediments where they exist, damage to archaeological sites, and damage to existing infrastructure installed on the seabed or below it.

The first locations for these projects likely will be in the ridges and shoals of the OCS to take advantage of the high topographic features, and thus, decreased foundation costs. OCS ridges and shoals are often sand or gravel and areas where sediment transport is a significant issue.

While there is a relationship between the relative magnitude of the impacts to the waves and currents and the magnitude of impacts to sediment transport, potentially a modified sediment transport regime could be significantly greater. An example is where a structure or group of structures changes the net longshore sediment transport direction.

5.1.2.2 Results of Monitoring at Existing Wind Facilities—Physical Processes

Historically, impacts on physical processes have been quantified and addressed in environmental impact assessments and design phases. In general, conditions of physical processes at existing offshore wind facilities postconstruction have not been monitored. The United Kingdom has two exceptions—Scroby Sands and Kentish Flats.

Data from postconstruction in situ monitoring of currents at the Scroby Sands wind park were used to estimate modified bed shear stress (CEFAS, 2006) and to help calibrate further numerical modeling. That modeling is not complete.

Wave data at the Scroby Sands offshore wind park were collected only preconstruction. To help understand the effect of the project on waves and to verify numerical models, postconstruction data are needed; however, to date data have not been collected.

The Scroby Sands coastal processes monitoring report (CEFAS, 2006) has documented some evidence of global scour. In general, the findings show that global scour that occurred after the foundations were installed was not significant to the total volume of change on the bank. A year postconstruction at the Kentish Flats project, no seabed change was observed some distance away from the turbine foundations (Emu Ltd., 2005) or in the vicinity of the cabling (Emu Ltd., 2006). The expected local scour (Emu Ltd., 2002) was observed at both Scroby Sands and Kentish Flats. As anticipated at Kentish Flats, observations at three of four inspected foundations showed local scour pits 1.8 to 2.3 m deep and extending 5 to 10 m from the foundation (Emu Ltd. 2005). Observation in 2005 showed that near installation vessel jack-up legs local scour pits varying between 0.5 and 2.0 m deep had started backfilling by as much as 1.8 m (Emu Ltd., 2005); however, 6 months later, the backfilling process had slowed or stopped with an average of 0.2 m having been deposited (Emu Ltd., 2006).

5.1.2.3 Current Models Used to Determine Impacts—Physical Processes

Currents and Tides

As is typical with offshore alternative energy projects, detecting impacts to currents and tides requires site-specific reviews. Historically assessments for impacts to currents and tides have been done in the nearfield (all areas within the extents of the project site), with notable examples at offshore wind parks at Scroby Sands (CEFAS, 2006), Horns Rev (DHI Water and Environment, 1999), and Nysted (ENERGI E2 A/S and Elsam Engineering A/S, 2004). The results of these nearfield site-specific reviews generally have indicated a reduction of a few percentage points in current velocities. The Horns Rev study showed 2 percent reduction; the Nysted study found 3 to 4 percent reduction. A combination of desktop and numerical models usually is used to complete nearfield studies. Typically the models use nested finite difference grids, with the finest grids used to model the area of interest. Current velocity data were collected in situ at the Scroby Sands project using a current profiler to aid with future modeling calibrations and development; however, this modeling is not completed. Assessments for impacts in the farfield (the regional area beyond the extents of the project site) generally have not been reported. In some cases, the small impacts predicted in a preconstruction nearfield assessment have been used to justify not pursuing farfield modeling and monitoring, which was the case with the Horns Rev project. There are two exceptions to the farfield example—the theoretical numerical modeling completed for a 2002 assessment, “Potential Effects of Offshore Wind

Developments on Coastal Processes" (Cooper and Beiboer, 2002), and an analysis of the morphological stability of the Rødsand barrier located near the Nysted wind park. That study found farfield changes to tidal current velocities on the magnitude of 0.7 percent (close to the accuracy of the applied model). The nested numerical models in the Nysted project were capable of predicting changes to currents, tides, and waves (ENERGI E2 A/S and Elsam Engineering A/S, 2004); however, the accuracy of the predictions was not presented.

Waves

At existing offshore wind projects, wave data to assess the wave height reductions that will occur have been collected during environmental impact assessments or design phases. The assessments use various numerical models. For example, a simplified desktop approach predicted a 3 percent wave height drop in the nearfield of the Horns Rev project (DHI Water and Environment, 1999). To date no data have been collected in the postconstruction period.

A 2002 report, "Potential Effects of Offshore Wind Developments on Coastal Processes (Cooper and Beiboer, 2002), presented results from a theoretical project site in both the near- and farfield. That study found farfield changes for monopiles to be less than 0.5 percent and nearfield changes for monopiles approximately 5 percent, and up to 15 percent for larger gravity-based structures. Nysted project farfield impacts on waves at a specific location (Rødsand barrier) were calculated using nested finite-difference models. The results were reported on the stability and development of the barrier reef; however, the impact on wave heights was not presented.

Sediment Transport

Because local scour is important to supporting sediments, extensive study has focused on local scour around objects, particularly around cylinders. Scour around other objects such as gravity-based structures and caissons also have been studied thoroughly.

Two primary factors govern local scour around a cylinder. The primary one is the presence of a horseshoe vortex; the secondary one is the presence of lee-wake vortices and vortex shedding (Sumer and Fredsøe, 2002). Currents are generally of greater concern than waves for developing scour pits; the relative importance of waves relative to currents is governed by the relationship between the current velocity, the stroke of the wave, and the diameter of the pile (Sumer and Fredsøe, 2002); in shallow water the influence of waves on scour is greater than in deeper water, where large wave-induced bed velocities are unlikely to occur. Extensive numerical and physical modeling has been completed for scour around offshore wind turbine monopile foundations. Results generally have found scour depths in the range of the pile diameter (Høgedal and Hald, 2005; Offshore Center Danmark, 2006). Furthermore, recent research discovered that the effect of breaking waves is not as significant as numerous researchers originally thought, and that the scour depths do not exceed conditions found in extreme currents (Offshore Center Danmark, 2006).

Although local scour is not as significant for larger, gravity-based structures as it is around monopiles, some research has been done in the area. Bos and Verheij (2002) presented results of physical modeling and scour protection for gravity structures including fully submerged structures. Research at the Borkum Riff offshore wind park project (Aalborg University, 2004) showed results for gravity-based and tripod structures. The design of scour protection, traditionally accomplished using stones, has been extensively researched. Sumer and Fredsøe (2002), Annandale (2006), and Whitehouse (1998) presented findings on standard approaches.

Because it has been assumed that the separation distance required between offshore wind turbines will limit the effect of global scouring on supporting soils as compared to the effect of local scour, significantly less research has been undertaken on global scour in offshore environments when compared to research done on local scour.

On the basis of an assumption that driving forces in the farfield are minor, it also has been assumed that the effect sediment transport has on adjacent shorelines is negligible (as was the case at Horns Rev). However, when satellite and aerial photography were used at the Nysted project in conjunction with bathymetric surveys to monitor the morphological change on a specific site (Rødsand barrier) scientists calibrated a nested numerical model and came up with an estimate that the Rødsand barrier will move 12 m per year with the sheltering of the wind park rather than an estimated 15 m per year without the wind park (ENERGI E2 A/S and Elsam Engineering A/S, 2004).

5.1.2.4 Proposed Mitigation Measures—Physical Processes

Traditionally mitigation measures have not been used to reduce changes to the physical processes offshore; it is very difficult to effectively mitigate the impacts. Furthermore, most past environmental impact assessments for physical processes at offshore wind park projects concluded that there were no significant impacts, and thus, there was no need for mitigation.

The most effective preconstruction mitigation approach to reduce impacts to the physical processes offshore is to properly site the project. If the project is properly sited, modified currents and tides, waves, and sediment transport have a minimum influence on conditions such as neighboring shorelines, bank stability, and navigation. Part of the siting process is to identify areas sensitive to a modified metocean climate.

Mitigation approaches used during construction include monitoring of suspended sediments and the onset of scour. Construction can be timed seasonally so that increased suspended sediment would have a minimal effect on marine species (Emu Ltd., 2002). Sediment control barriers can be installed where the impact is significant. Furthermore, spill-control equipment should be available on site for spills from an installation vessel (Cape Wind Associates, 2007). Accidental dropping of construction materials or installation equipment can cause scour; the scour may be mitigated by requiring contractors to remove debris from the sea floor (Emu Ltd., 2002).

In projects located near waterways that convey water, compensation dredging has been used to mitigate current changes; however, this mitigation technique would not apply on the OCS. The most effective approach for reducing the impacts to waves and currents (for a fixed location) likely would require modifying structure foundation footprints and submerged geometries.

During preconstruction phases, planners and developers should anticipate impacts resulting from a reduced wave climate in the lee of a wind park; during the postconstruction phase, scientists and engineers should monitor reduced wave impacts. For the proposed United Kingdom Wave Hub project (Halcrow Group Ltd., 2006), planners, developers, and project proponents have discussed potential modified wave climate with local surfing groups to determine the degree of the impact and possible mitigation approaches (siting). In addition, scientists have numerically modeled the wave climate to assess changes to nearshore morphology. At the Nysted site, satellite and aerial photography proved a reasonable monitoring technique to assess the impacts of a modified wave and current climate on a specific geographic feature, the Rødsand barrier (ENERGI E2 A/S and Elsam Engineering A/S, 2004).

A possible mitigation technique to assess impacts to sediment transport is strategic sediment nourishment, although typically this has not been done in existing offshore wind energy projects. Local scour typically is mitigated through adequate planning and design, as well as with the installation of scour protection when necessary. Postconstruction bathymetric surveys as part of a morphological monitoring program provide a start to mitigation. Examples are the completed seabed monitoring programs at Scroby Sands (CEFAS, 2006) and Kentish Flats (Emu Ltd. 2005, 2006), and in the farfield at a sand feature in the lee of Nysted (ENERGI E2 A/S and Elsam Engineering A/S, 2004).

Reducing impacts to the physical processes also could be achieved through defining acceptable limits for development densities and acceptable thresholds on the magnitude of the impacts. So far these measures have not been taken.

5.1.2.5 Information Needs—Physical Processes

Currents and Tides

The currents and tides around North America have been studied extensively on both coarse and fine scales; data are available from various sources. In the United States, data are recorded and distributed by the National Oceanic & Atmospheric Administration (NOAA). The raw science behind tides, currents, and their interactions are well understood and clearly described in the Handbook of Coastal and Ocean Engineering (Partheniades, 1991). Furthermore, the influence of submerged structures on currents is relatively well understood. Locally, the primary physical changes to currents are the presence of a horseshoe vortex, lee-wave vortices, and vortex shedding (Sumer and Fredsøe, 1997). These phenomena will result in increased vertical mixing, hence less stratification of nutrients and modified theromoclines in the near-field are expected.

The MMS Marine Minerals Program has undertaken site-specific studies on the existing offshore sand mining and dredging conditions for the Atlantic and Gulf of Mexico, although the subject is not specific to alternative energy projects. Analyses of the coastal processes in these studies may be of particular relevance to alternative energy projects being developed within the limits or nearby the individual sites.

The regional and global impacts of ocean currents on climate are significant, and conceptually they are well understood. Scientists believe that changes to ocean currents can instigate abrupt climate change (NRC, 2002), which likely would result in severe hardships on economies and societies around the world (Arnell et al., 2005). These changes may be caused by natural fluctuations, or they may be accelerated through influences such as global warming (Broecker, 1997). While the importance of ocean currents is well understood, the impact of offshore wind development in the OCS on global ocean currents has not been researched. The energy conversion approaches most likely to disrupt the ocean currents would be current technologies (and to a lesser extent wave technologies) because these structures have the most significant below-water cross-section.

Perhaps the most significant information need is that alternative energy projects have not yet been constructed on a commercial scale in a tidal or current climate similar to that found on the OCS near the United States. Existing alternative energy projects all have been built in the relatively sheltered Baltic Sea, or in the North Sea, which experiences a much different metocean climate. Certainly, many of the existing experiences (particularly in the nearfield) are relevant; however, in the farfield, little data are available from existing sites. In the farfield, modeling structural resistance in tides and currents is challenging. Numerical modeling has been done previously using increased seabed-resistance elements (Cooper and Beiboer, 2002). Ultimately, an improved approach is required to properly assess the magnitude of the farfield impact and to mimic accurately the changes to flow regime. In the nearfield, it is possible to use numerical computational fluid dynamics models or physical modeling, or both, to assess the impacts for a specific project.

For specific nearfield impacts, only the monopile foundation case has been studied exhaustively. It is likely that geometries of different foundation approaches will continue to receive treatment with individual projects as they are considered.

Waves

The wave climate around the United States varies from region to region, and in most areas site-specific wave climates would be developed using various approaches. Coarse, existing wave data for the United States are available from the wave information study (WIS) program published online by the U.S. Army Corps of Engineers Field Research Facility (http://frf.usace.army.mil/); measured data are published by NOAA through its National Data Buoy Center program (http://www.ndbc.noaa.gov).

Generally the physics of waves and transformational behavior are well understood, and they have been researched extensively. Goda (1985) and Sarpkaya and Isaacson (1981) reported wave response to the presence of structures. Sumer and Fredsøe (1997) describe the localized effects of waves around monopiles or other surface-piercing cylinders.

As in the case with the impacts of tides and currents, assessing how waves are impacted by alternative energy development on the OCS is made more challenging because of the lack of existing developments in comparable wave conditions. The wave-structure interactions generally are relevant, and results may be transferred across to future projects; however, beyond the immediate local effects of wave-structure interaction, relatively little is known about the nearfield wave climate between the structures. Studies completed so far have been either simple desktop analyses using wave energies (DHI Water and Environment, 1999) or numerical analyses using seabed-resistance elements (Cooper and Beiboer, 2002). As in the nearfield, a real gap exists in available data in the farfield. The gap includes a lack of information from existing projects, as well as in general cases. A recommendation to undertake wave monitoring at the Scroby Sands offshore wind park in the United Kingdom has not been started (CEFAS, 2006).

A further need is to understand how a modified wave climate may affect global scour and bank stability of the shoals where they are installed, and how the modified wave climates may affect sediment transport rates in the lee of the wind parks, which is discussed further in the next section. In the farfield, the potential impact of offshore wind installations on local wave generation (as a result of the modified wind profile) is unknown; local wave generation could impact wave heights in the lee of wind parks.

Research Needs for Tides, Currents, and Waves

Research on the impact of waves on alternative energy development has not addressed currents and tides so far. Because the processes are simultaneously present and they influence each other, the discussion here includes research information needed for tides, currents, and waves.

Studies on how a wind park could deform incident waves as they move through the area would provide the basis for impact assessment. The resulting information will help to assess the impact of a field of cylindrical elements (the relationship of diameter, spacing, and number of monopiles) on wave transformation in the area and downwind of the wind park. The studies should make use of numerical modeling, physical modeling, and field measurements.

Numerical Modeling**.** Farfield numerical modeling is restricted because the grid spacing is so coarse that the structural elements themselves become difficult to represent. Resolving this issue is complex, and success is not guaranteed. A possible approach is to complete the modeling in two separate parts, and then compare the results and reapply the results from one into the other. The first approach applies a nested fine grid within a coarser grid in a finite difference model. The second possible approach applies a finite element model. Both approaches allow for trying various representations such as representing structures as artificial islands, inverted jets, or permeable breakwaters. The results from one model could be used as boundary conditions in another model.

Assessment of a modified wind profile and its impacts to wave heights and directions in the lee of a wind park should include a literature review and assessment, measurement of lee wakes at existing sites, and application of appropriate computational aerodynamic models to generate more accurate results of the wind field.

Physical Modeling. A physical modeling program could be set up to model various conditions and configurations. A combined testing program could look into the impacts in the nearfield on waves and currents at various depths and conditions. The nearfield results could then be used as inputs to farfield numerical models.

The physical modeling plan would require the setup of appropriate generalized bathymetry and development of appropriate conceptual structures of variable sizes configured with various spacing, which essentially creates a dimensionless parameter representing the grid or array density. Wave and current measuring devices would be installed inside and outside the grid or array. The waves or currents or both should be applied at multiple directions and with different wave, current, or water-level conditions including breaking waves. If potential sites are sensitive in terms of impacts to vertical mixing of the water column, a three-dimensional hydrodynamic model would be required, at least in the nearfield.

Field Measurements. In situ monitoring of existing sites could provide valuable information. The monitoring would involve project site selection, literature review of existing data and studies, analysis of conditions for instrument siting, instrument deployment, retrieval, and analysis of the data. If baseline studies do not exist, it also would be necessary to install instrumentation at a nearby nondeveloped site to act as baseline or reference data.

The selection of an appropriate site would involve reviewing existing wave and current data, as well as seafloor topography to find a site with conditions that are the most applicable to the OCS near the United States. The selection of an appropriate site also should include an analysis to ensure that baseline data are available or that a suitable site exists to set up a simultaneous baseline study. A literature review about an existing site and site conditions would be required to obtain existing information for baseline data. A literature review also would help with positioning proposed instruments. As a minimum requirement, one instrument would be placed inside the development, one instrument would be placed inshore of the development, and another instrument would be placed offshore of the developed area. All of the instruments should be in place for 4 to 6 months. Wave data may be collected using directional wave buoys; however, to obtain current data simultaneously with a minimum number of instruments, bottom-mounted acoustic devices could be used.

Sediment Transport

The topic of sediment transport is relatively well understood. Textbooks by Fredsøe and Deigaard (1992), Van Rijn (1993), and Soulsby (1997) provide very good background into the physics behind sediment transport. However, little relevant research has been completed for offshore sediment transport impacts beyond local scour cases. Typically the impacts to sediment transport process are discussed during environmental impact assessment and design phases, but the results are rarely quantified with the exception of local scour. Research on a regional scale has been completed for the Scroby Sands wind park in the United Kingdom (CEFAS, 2006; Halcrow Group Ltd., 2001), the Kentish Flats wind park in the United Kingdom (Emu Ltd., 2005 and 2006), and the Nysted project in Denmark (ENERGI E2 A/S and Elsam Engineering A/S, 2004). Somewhat less research has been completed for the Horns Rev project in Denmark (DHI Water and Environment, 1999, 2006).

Seabed geologic conditions and properties for portions of the Atlantic and Gulf of Mexico OCS have been defined as part of site-specific studies completed by the MMS Marine Minerals Program. Regional and nearshore data are available through the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers, and various local state agencies. Examples of specific studies include the Schwab et al. (2000) report on seafloor sediments off southern Long Island and the Santa Monica Bay Mapping Project (Kvitek et al., 2003). On a national scale, the USGS National Seafloor Mapping and Benthic Habitat Studies objectives are to map the ocean floor around the United States and collect geological information (U.S. Geological Survey, 2006). A good compilation of available resources is a USGS summary bibliography of U.S. marine mineral sources (Williams and Manheim, 2003).

One impact resulting from changes to waves and currents is a subsequent change in sediment transport in the near- and farfield. Local scour requires little that needs to be done. Global scour and bank or shoal stability needs further information. Where global scouring is present, reports of existing data do not represent locations that are typical for the OCS of the United States. A significant concern on the OCS is the stability of the shoals; many options may be founded on unstable shoals. Modified currents and waves could result in destabilization of shoals within the OCS, which could cause them to undergo considerable change in shape and position. Conditions that would lead to destabilization are site specific.

Very little information is available on how impacts to sediment transport affect neighboring shorelines. Even a slight change to wave direction in the lee of generation parks could lead to significant shoreline changes. This phenomenon was observed and modeled off the coast of Florida, where offshore borrow pits caused very minor changes to the magnitude and direction of waves and currents. In turn, the minor changes to waves and currents resulted in significant changes to local longshore sediment transport and the development of an erosion hot-spot (Benedet et al., 2006). While Benedet et al. have studied borrow pits up to 1 km offshore, a modified wave/current climate in the nearshore area would have similar effects regardless of what has caused the impacts. Benedet et al. also presents a numerical modeling approach that could be applied to assess impacts to the sediment transport process at existing and future project sites.

To address the information needs discussed above, studies should be conducted to develop an improved understanding of the impact of wave-field deformation caused by wind parks on the sediment transport process and morphologic change. A key concern is wind park-associated global scour and its influence on the morphologic integrity of seafloor topographic features such as ridges and shoals. Ridges and shoals are preferred locations for wind park foundations because of reduced water depths, and therefore, reduced foundation costs.

Because waves and currents are the driving forces behind the sediment transport process, changes to waves and currents should be researched before a study of potential impacts resulting from sediment transport begins. Numerical modeling generally is the best tool to assess the levels of impacts caused by sediment transport such as global scour, shoal and bank stability, and effects to nearby longshore sediment transport. Physical modeling presents problems with scale issues.

Various approaches to setting up a numerical modeling program are feasible, but the project likely would be undertaken in five steps:

- Selection of several representative locations
- Selection of an appropriate numerical model
- Application of existing hydrodynamics to form a baseline
- Application of modified hydrodynamics to see the resultant change
- Analysis of the changes to the sediment transport at the chosen site and in the adjacent areas or regions

The selection of several different representative locations should include a range of possible configurations so that results can be used as relevant literature for as much of the OCS as possible. It would be useful to have existing data in the vicinity of the selected representative sites. Case modeling and data collection do not eliminate the need for site-specific studies, but they would provide data and methods useful for evaluating the viability of potential sites, as well as testing the validity of site-specific results.

Matching the scale requirements of selected representative areas with existing technology likely would require a two-dimensional or three-dimensional hydrodynamic model. Existing waves and currents would be applied to the model to establish baseline information. If existing information is unavailable at representative sites, data collection could be undertaken using a combination of directional wave buoys and bottom-mounted acoustic devices.

Potential changes to the hydrodynamic climate will probably have been determined previously, and these modified waves and currents would be applied in the hydrodynamic model. The resulting change to local sediment transport patterns and conditions (both longshore and cross-shore) on nearby shorelines could then be determined.

On the basis of the studies described above and other previously published studies, guidelines need to be developed to set acceptable limits of impacts resulting from wind parks. An important step in the guidelines is to define a process that can be used to determine acceptable limits for impacts. The measure of impacts needs to focus more on the effects of the modified processes rather than on impacts on the processes themselves. Examples include an increase in the erosion rate at adjacent shorelines, increased dredging requirements in navigation channels, and reduced mixing capabilities for outfalls and water intakes in the lee of the farm. Ultimately, the limits must be evaluated on a site-specific basis; however, general guidance on these issues should be provided. Such information generally is not available at this time. Developing a plan of study should include stakeholder analyses, expert identification, and a literature review to assess the manner used to define impacts (and cumulative impacts). The study should identify how to proceed on a site-specific basis.

5.1.3 Benthic Resources

5.1.3.1 Potential Impacts – Benthic Resources

Benthic resources include the animals and plants that live on the seafloor surface (epifauna) and within the sediments (infauna). Table 5-2 lists the potential impacts to benthic resources resulting from the construction and operations phases of offshore wind parks. The potential magnitude and significance of these impacts vary significantly, both generically and specifically for a site. Some impacts are temporary, others are permanent.

Impacts from construction vessels include sediment suspension in shallow waters from vessel movements, as well as bottom disturbances from anchors and the sweep of anchor lines along the bottom. Disturbing areas with contaminated sediments could cause the release of contaminants to the water column, which would increase biological exposures and uptakes. There is also risk from potential releases of oil and construction materials from vessels.

The potential impacts of foundation installation depend on the site conditions. Monopile installation can suspend sediments, generate drill cuttings that can be very different in sediment composition than the surface sediments, and create vibrations and very loud noises during pile driving. Vella et al. (2001) noted that few marine invertebrates possess sensory organs that can perceive sound pressure, although they do have mechanoreceptors and statocyst organs that can perceive sound waves. The few available studies on impacts of sound on marine invertebrates deal almost exclusively with potential impacts to squid from air guns used during seismic surveys. The researchers reported that the "general consensus is that there are generally few effects, behavioral or physiological, unless the organisms are very close (within a few metres) of a powerful noise source."

Table 5-2: Potential impacts to benthic resources from offshore wind parks.

Construction Phase	Potential Impacts—Benthic Resources
Construction Vessels	Physical disturbance of the seabed caused by positioning, anchoring, and movement of construction vessels including jack-up rigs, dredges, and barges; accidental spillage of contaminants or debris from construction vessels
Foundation Installation	
Pile Driving	Sediment suspension and redistribution during pile driving of monopiles; release of seabed contaminants during sediment suspension; noise and vibration during pile driving; habitat loss in foundation footprint
Foundation Installation	Sediment suspension and redistribution during seabed excavation and leveling for gravity foundations; release of seabed contaminants during sediment suspension; release of contaminants from grouting and other construction materials; noise and vibration during installation; habitat loss in foundation footprint
Scour Protection	Sediment suspension and redistribution during placement of scour protection; release of seabed contaminants during sediment suspension; noise and vibration during installation; habitat loss in scour protection footprint
Dredged Materials Disposal	Smothering, burial, grain size changes from disposal of dredged materials from excavation of foundations and drilling for monopiles
Cable Laying	
Trenching	Habitat disturbance during cable laying
Anchoring	Physical disturbance of the seabed resulting from positioning, anchoring, and movement of cable-laying vessels
Operation Phase	**Potential Impacts—Benthic Resources**
Turbine Foundations and Scour Protection	Habitat loss in foundation footprint; introduction of artificial hard substrate and fouling communities; changes in sediment grain size from changes in physical processes and sediment transport resulting from local scour and within and near the wind park; indirect changes from reductions and increases in predation and reduced fishing pressure
Cables	Electromagnetic field (EMF) impacts to sensitive infauna and epibenthos
Service Vessels	Accidental release of contaminants; physical disturbance of the seabed

Installation of gravity foundations involves sediment excavation and leveling of the seafloor, both of which can suspend sediments and destroy habitat in an area covering up to 30 meters (m) in diameter. Placement of stones in foundations or as scour protection is accomplished by dumping them from a barge, which can disturb the adjacent sediments. Scour protection also can be accomplished by placing artificial mats with fronds designed to trap local sediments.

Drilling in hard substrate to install monopiles and excavating for gravity foundation installation can generate dredged materials, which are usually disposed of offsite in approved disposal areas.

Cables between the individual turbines and from the wind park to land generally are buried 1 to 3 m in soft sediments using either a mechanical or jet plow. A backhoe may be used to excavate harder clays. The total length of buried cable depends on the number of turbines and distance of the wind park offshore. Existing wind parks have required up to 58 km of cable for the array between turbines and connection to shore. Jet plowing requires carving a localized trench in the seabed by injecting water into the bottom. The cable is placed in the trench, and the sediments settle back into the trench. The surface disturbed by the trenching is generally 0.3 to 3 m wide; each of the skids can be 0.5 to 1 m wide. The trenching process can physically disturb the sediments, the grain size can change because of loss of the finer fractions, and the seabed along the cable trace can lower, which occurred along the cable trace to shore at the Nysted wind park in Denmark (Birklund, 2006b). In environmental assessments of other cable laying projects, which usually consist of a single trench from point A to point B, it is usually assumed that the disturbances to benthic habitats and communities will be in a small area and short in duration, although no studies are cited. For example, the environmental assessment for a 19.5 km cable across Stellwagen Bank National Marine Sanctuary stated that benthic resources disturbed during cable laying (with a mechanical plow) would recover in weeks to months with only some species taking as long as the next spawning season (Tetra Tech, Inc., 2000). Studies of dredging impacts, which are much more intrusive because the top meter or so of the surface sediments are removed, have shown rapid recovery (within 1 to 3 years) in sandy and muddy habitats (Blake, Doyle, and Culter, 1996; Newell, Seiderer, and Hitchcock, 1998; Van Dolah et al., 1992).

Potential impacts from wind park operations include the noise and vibration generated by the turbines. There are concerns that the sediment characteristics within and adjacent to the wind park will change because of modification of wind, wave, and currents, which could alter sediment transport processes. Changes in sediment characteristics can indirectly affect the benthic community. The depth of local scour around foundations can be in the range of the pile diameter, potentially creating depressions up to 4 to 6 m, thus creating the need for scour protection at many sites.

Buried cables will generate both electric and magnetic fields. In a modeling study CMACS (2003) found “cable with perfect shielding, i.e., where conductor sheathes are grounded, does not generate an electric field (E-field) directly. However, a magnetic field (B-field) is generated in the local environment by the alternating current in the cable. This in turn, generates induced E-fields close to the cable within the range detectable by electro-sensitive fish species. Simulations with non-perfect shielding, i.e., where there is poor grounding of sheathes, showed that there is a leakage E-field, but it is smaller than the induced E-fields and unlikely to be additive.” CMACS (2003) also determined that the magnetic fields are unaffected by burial in sediment. Although the magnetic field strengths can be estimated, few studies exist to help determine which marine benthic invertebrates might be affected by magnetic fields and the levels of any effect. Therefore, most environmental impact assessments (EIA) state that the impacts to benthic communities are unknown, but they are likely to be low because of the very low magnetic fields the cables generate.

Perhaps the greatest potential impact results from the introduction of artificial hard substrate and the associated fouling communities on both foundations and scour protection in areas dominated by sediments. Studies of oil and gas platforms such as those by Gallaway and Lewbel (1982), Carney (2005), and Dokken et al. (2000) in the Gulf of Mexico, and Page, Dugan, and Bram (2005) and Continental Shelf Associates (2005) in southern California have shown that vertical structures are rapidly colonized by fouling communities that are very different than native, soft-sediment communities. The stones used for foundation stabilization and scour protection at wind parks can provide a different kind of artificial habitat that provides both hard surfaces for epifauna and crevices and structural complexity that can attract a wide range of fishes and invertebrates, much like artificial reefs. Biomass increases can be very large; however, very little is known about the factors affecting rates and patterns of succession and equilibrium, the overall ecological impacts in a region, and the risks of introduction of invasive species (Carney, 2005).

Potential indirect changes to benthos can result from reductions or increases in predation. For example, reductions would come from seaducks who avoid feeding within the wind park; increases would come from benthic feeders attracted to the new hard substrate around the foundations. Indirect changes to benthos can result from reduced fishing pressure, particularly trawling, which would increase populations and individual sizes and reduce habitat disturbances by bottom fishing gear. Although fishing in wind parks generally is not prohibited (except in Denmark where trawling is prohibited within 200 m of a cable trace), most trawl fishers have indicated they would not trawl inside the wind parks because of safety concerns.

Cumulative impacts could occur from adjacent alternative energy facilities and other activities such as sand and gravel dredging.

As discussed in the following section on monitoring studies at existing sites, some data are being generated to assist in better assessment of these potential impacts.

5.1.3.2 Results of Monitoring at Existing Offshore Wind Parks—Benthic Resources

Monitoring of benthic resources at existing offshore wind facilities often includes infauna collected using sediment cores or grabs, benthic epifauna using benthic trawls or photoquadrats, and fouling epibenthos on the foundations using photoquadrats, scrapings, and qualitative descriptions. Studies of benthic resources conducted at existing wind parks in Europe and the United Kingdom are summarized in table 5-3.

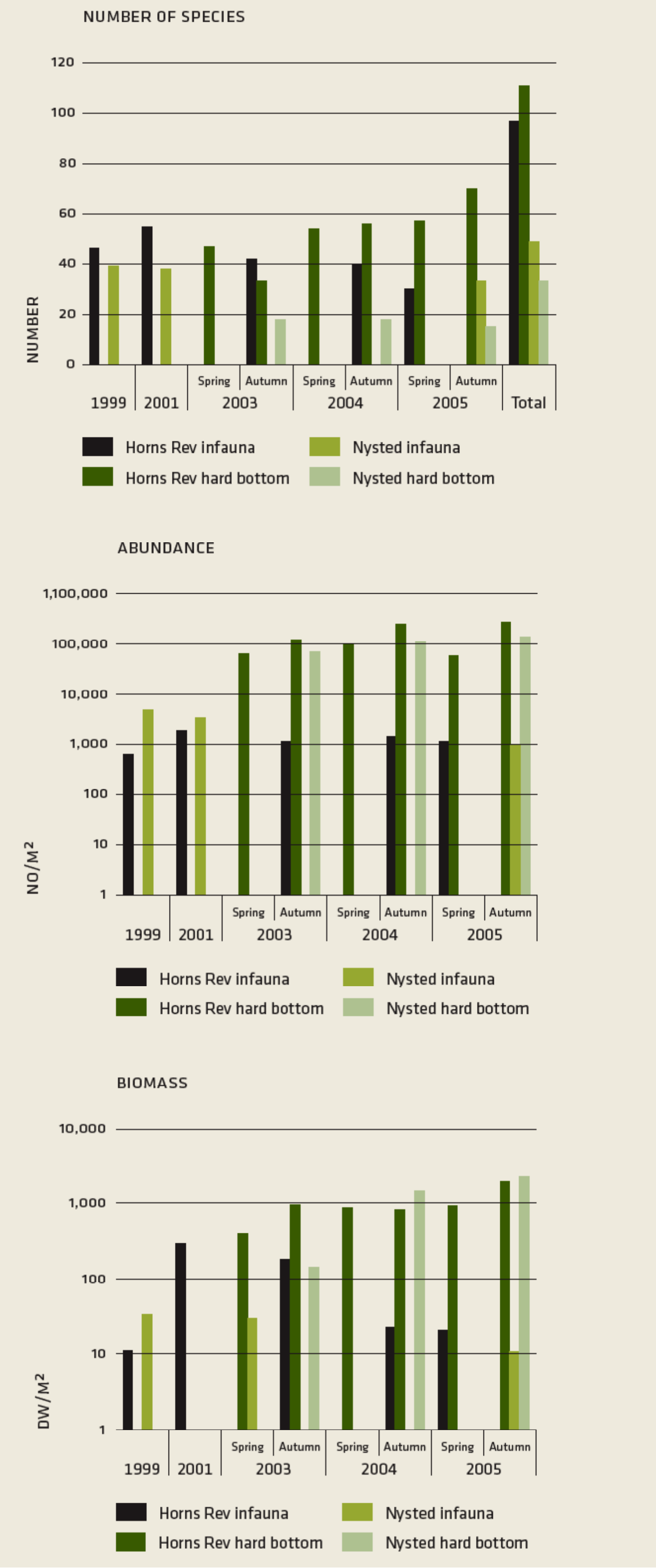
The longest postconstruction studies have been conducted at Horns Rev, Denmark, with 2 years of preconstruction and 3 years of operational data (table 5-3) for benthic infauna, hard bottom substrate, sand eels, and clams. The turbine foundations are 4-m diameter monopile structures with a raised gravel mattress or armor for scour protection that is 1.3 m high and 27 m in diameter. Figure 5-3 shows a summary of the benthic monitoring studies at the two large wind parks in Denmark, Horns Rev, and Nysted, from Dong et al. (2006).

Benthic infauna and sediments were studied at six stations in the wind park and six reference stations (Bech et al., 2005; Leonhard and Pedersen, 2006). Sediment grain size in the wind park increased between 2001 and 2005, but sediment grain size increased proportionally in the reference areas as well. Leonhard and Pedersen (2006) summarized the results of the benthic monitoring studies. Infauna showed great spatial and temporal variability; however, no statistically significant changes were found in abundance and biomass distributions from 1999 to 2005 for most of the designated indicator organisms (see figure 5-3). The Danish government convened an International Advisory Panel of Experts on Marine Ecology (IAPEME) to provide an independent review of the monitoring programs at Horns Rev and Nysted. In its review of the benthic monitoring program at Horns Rev, IAPEME (2006) noted that because of the limitations in the survey design only major changes in the infaunal community will show in data analysis. No investigations were made on the direct impacts to the benthic communities resulting from pile driving or cable laying activities.

Table 5-3: Benthic monitoring programs at five offshore wind parks in Europe and the United Kingdom.

Wind Park	Survey Years/ Citation	Benthic Infauna/Epifauna	Fouling Communities
Horns Rev, Denmark; 80 turbines; online since 2002	1999–2005 Bech et al., 2005; Leonhard and Pedersen, 2005, 2006; Jensen, Kristensen, and Hoffmann, 2004; Dong et al., 2006	Infauna: 3 sites along 6 transects in park area, 6 reference sites, diver collected 2 cores/site; Sand eels: 10 sites in park area, 5 reference sites, 4 to 5 replicate 10-minute tows with sand eel dredge	6 transects of 3 stations each on foundation stones; 3 monopiles at 5 different depths; 0.04 m^2 scraps (n=3), visual estimates of frequency
Nysted, Denmark: 72 turbines; online since 2004	1999–2005; Birklund, 2005, 2006a,b; Dong et al., 2006	Infauna: duplicate 2 m^2 photoquadrats at 133 sites in park, 110 sites along 10 km cable, 68 reference sites; grab sampler 0.1 m^2 at 71 sites in park and 17 reference sites; Mussels collected at 12 sites in park and 7 reference sites (n=5)	8 turbines with 0.24 m^2 photoquads, 5–10 on the shaft and 20 on the stones on foundation and scour protection; scraping of 4 turbines, 0.0225 m^2 on shaft, 0.0625 m^2 on stones
North Hoyle, U.K.; 30 turbines; online since 2004	2001–2005 Npower Renewables, 2005a, b	Infauna: 4 sites in park area, 3 along cable, 10 reference, 0.1 m^2 Day grab, 3 replicates/site; Epibenthos: 4 sites in park area; 2 along cable, 16 reference sites, 2-m beam trawl, 4-mm mesh, 300-m tow	Descriptive information for 2 turbines, brief zonation surveys of 4 turbines; 0.01 m^2 scraps on 2 turbines Underwater video
Scroby Sands, U.K; 30 turbines; online since Dec. 2004	E.ON UK, 2005	Grab samples	N/A
Kentish Flats, U.K.; 30 turbines; online since 2005	Emu Ltd., 2006	Infauna: 5 stations in park area, 3 close to turbines, 8 in 1 tidal excursion, 3 along cable, 4 reference, n=3 Hamon grab, 0.1 m^2 ; Epifauna: 3 transects in park, 2 along cable, 5 reference 2-m bean trawl, 5-mm mesh, 500-1,000 m tow	N/A

When cataloging indirect effects, Leonhard and Pedersen (2006) proposed that the increases in bivalves and bristle worms inside the park compared to adjacent reference sites were related to reduced predation by the numerous common scoters who avoided feeding in the wind park area. The researchers also suggested that increased predation by scoters on American razor clams in areas adjacent to the park was the reason this species was lower in both the park and a more distant reference area. The researchers did not detect any changes that after 3 years could be attributable to reduced fishing pressure inside the wind park; however, they did suggest that over



Source: Dong et al., 2006.

Figure 5-3: Summary of the pre- and postconstruction monitoring of benthos at the Horns Rev and Nysted offshore wind parks in Denmark.

time the cumulative effect of multiple wind parks in the area would be increased benthic biodiversity because of reduced fishing pressure inside the wind parks. (By law in Denmark trawling is prohibited within 200 m of a cable trace, thus trawling is prohibited within the park and along the cable route.) Fouling species such as the crustaceans *Jassa marmorata* and *Caprella linearis* typically associated with hard substrate habitats were found on the seabed outside the wind turbine sites, indicating their introduction by drift from the foundations.

Sand eels were studied at Nysted as a bioindicator for changes in sediment characteristics (Jensen, Kristensen, and Hoffmann, 2004). Densities at both the wind park and reference sites were low compared to other North Sea areas. Stations in the wind park showed an average increase in sand eel density of 300 percent between 2002 and 2004. Most of the increase was in sand eels measuring less than 8 cm. In contrast, the sand eel population at the reference stations decreased about 20 percent (Jensen, Kristensen, and Hoffmann, 2004). The species composition changed over time at both the wind park and reference stations, as well as for the whole North Sea. Effects from the wind park on sand eel density likely would result from changes in grain size (increase in fines) or change in predator densities, or both (Jensen, Kristensen, and Hoffmann, 2003). There were no significant changes in grain size in the wind park area. There was discussion on the possible effect of changes in sand eel predation, but no data were collected to document this effect. Also, the authors could not determine if changes in fishery patterns around the wind park (which was not a highly fished area) were a factor.

Leonhard and Pedersen (2005, 2006) monitored the fouling communities on hard bottom substrate at Horns Rev on both the stone foundations and monopiles for 3 years after construction in March and September 2003–2005. Colonization of the hard structures was rapid—within 1 year, 16 vegetation species and 65 invertebrate species were observed; after 3 years, 26 vegetation and 111 invertebrate species were observed. From 2003 to 2005 total abundance increased by 225 percent, and biomass increased by 200 percent. The edible crab *Cancer pagurus* was using the foundation stones as nursery habitat, with three class sizes of juveniles in September 2005. There was considerable vertical zonation on the monopiles, with the splash zone dominated entirely by the giant midge *Telmatogeton japonicus*, the upper subtidal zone dominated by the mussel *Mytilus edulis* and green and brown algae, and the lower subtidal zone with a more mixed community of lower abundances. The small crustacean *Jassa marmorata* was the dominant species on hard bottom substrates, although over time there were increases in sea anemones and soft corals. The spatial and temporal patterns in species distribution and abundance reflected known patterns of succession with replacement of early colonizers with more stable communities, evidence of predation (particularly by the sea star *Asterias rubens*), competition for space, and increasing number of species. According to IAPEME (2002), it should take about 5 years for new hard substrate communities in temperate areas of Europe to reach a state similar to mature communities on natural rock. The data from the monitoring at Horns Rev support this assessment.

Leonhard and Pedersen (2006) found hydrodynamic effects on the fouling community with up/down current directions on the foundations only close to the base of the monopile. Also, the researchers inferred that operational noise and vibration did not affect mobile species such as crabs and fishes because of the large numbers that were attracted to the hard substrates and the similarity of species attracted to shipwrecks.

The second large wind park in Denmark is at Nysted, in the Baltic Sea, where the salinities are brackish and the substrate is mostly medium sand with scattered gravel. The turbines are set in concrete foundations that are hexagon shaped, divided into six cells that are filled with stones, extended 1 to 2 m above the seafloor, and have a total diameter of 25 m that includes additional stones for scour protection.

Birklund (2006a) monitored the fouling community for 3 years after construction at Nysted. Common mussels, barnacles, and filamentous red algae were the dominant species, with mussels accounting for up to 99 percent of the biomass on the shaft and stones in 2005. As the community evolved to an almost monoculture of mussels, macroalgae decreased in species diversity and biomass on both the shafts and stones. After 3 years, the species richness on the foundations (n=15) was similar to a nearby natural rock habitat (n=17). The low salinities limit the number of species and exclude the sea star as a key predator that normally would reduce mussel dominance. The biomass and abundance were lower on the scour protection stones when compared to those in the foundation chambers because they are exposed to more sand scour and sedimentation than the stones in the raised foundation chambers. At one site, the scour protection stones had become buried in sand; at four others, there was evidence of sand and silt accumulation. The fouling community was uniform in different directions around the foundations.

Benthic infauna monitoring at Nysted included studies at the wind park, cable trace to shore, and appropriate controls from 1999 (baseline), 2001, and 2005 using a large number of photoquads and fewer cores (Birklund, 2006b). The results comparing the wind park and reference area over time can be summarized as follows: organic content of the sediments increased in the park when compared to the reference sites; species richness was consistent at both areas; abundance, biomass, and mussel coverage decreased at both areas; mussel condition increased at both areas; and mussel biomass decreased at the park sites but not at the reference sites. Birklund (2006b) concluded that the observed spatial variation and temporal changes were a result of natural variations and the wind park had no effect on benthic communities.

The Nysted cable trench from the transformer station to shore was 1.3 m wide, 1.3 m deep, and 10.3 km long. A backhoe was used to excavate the trench in the hard, clayey substrate, and the excavated sediments were placed alongside the trench, to be used for backfilling. Trenching started in September 2002, backfilling did not start until early 2003, and it was completed in February 2003. Furthermore, a replacement optical cable was deployed by a jet plow in June 2003. Based on studies conducted in 2003 and 2004, Birklund (2005) reported visibly disturbed sediments in a band up to 10 m along the trench caused by the sediment spill and spreading and formation of a depression that was filled with detached macroalgae. There were immediate impacts to eelgrass buried by sediments and shaded by increased suspended sediments, but recovery was documented in 2004. There was no eelgrass recovery in the trench itself because of the accumulation of detached algae. Attached macroalgae declined along the trench because of the sediment spill that smothered the gravel to which the algae attaches. Benthic epifauna also decreased and were slow to recover. These studies point to the importance of rapid backfilling of the trench.

In their review of the results as of 2003, IAPEME authors (2006) identified the need for more integration of benthic community studies with fish and bird studies to be able to assess effects of increased prey base on predator attraction. Their comments at the end of the chapter on benthic impacts in Dong et al. (2006) included the following points:

> The new hard substrate introduced new habitat and species into the areas; and thus, there was a need for "long-term monitoring of both wind parks to provide an appreciation of how the communities will develop and contribute to the ecology of the area, so providing a long-term dataset against which other wind farm developments can be judged." The authors were particularly concerned about the cumulative effects of introduction of hard scour protection structures with future expansions that may increase populations of mobile species attracted to these habitats. There could be both positive effects in terms of increases in commercial species and negative effects from a feeding halo around the foundations.
>
> "Data collected show that whilst some changes in infaunal biology and sediment characteristics have taken place, these do not seem to be focused within either wind farm area."

There are benthic monitoring data from three offshore wind parks in England—North Hoyle, Scroby Sands, and Kentish Flats. Impacts to benthic communities during construction were monitored at the North Hoyle site (Npower Renewables, 2005a). The bottom sediments were fine-medium sand with some areas of sand and gravel, with high variability over short distances. Benthic grab samples showed an overall reduction in the number of species and individuals during construction in 2003 compared to 2001–2002 preconstruction surveys. Dominant species in 2002 were an anemone, polychaete, and amphipod; dominant species in 2003 were donax and two annelid worms. These reductions occurred at all stations and were attributed to interannual variations. The sediment grain size showed both increases and decreases, and grain size strongly influenced the infauna. Epibenthos sampled using beam trawls showed a reduction in invertebrates but an increase in demersal fishes. The reductions in numbers of species and individuals continued in 2004, again at all stations (Npower Renewables, 2005b). There were only four stations within the wind park and three along the cable route. These studies demonstrate the need for more stations and multiple preconstruction surveys for better understanding of the natural spatial and temporal variations in benthic communities so that anthropogenic impacts can be identified.

Fouling communities were monitored on two turbines one year postconstruction (Npower Renewables, 2005a). Each foundation was estimated to have 1,000 to 1,300 kilograms (kg) of attached biota, all common species for the area. The dominant species was a barnacle, and there were large numbers of amphipods on the surface of the barnacles. Large shoals of juvenile whiting appeared to be feeding on the amphipods. The operations plan for North Hoyle includes periodic removal of encrusting organisms from the turbines to reduce hydrodynamic drag and minimize additional weight exerted on the monopile foundation.

Copies of the benthic monitoring reports for the Scroby Sands park in the United Kingdom were not available as of mid-February 2007; however, there has been extensive scour, as described in section 5.1.2.

Postconstruction studies of benthic communities at the Kentish Flats wind park were compared against 2002 baseline conditions within the wind park, along the cable route, and within one tidal excursion distance (8 km) from the wind park (Emu Ltd., 2006). The wind park is located 8.5 km offshore the Thames Estuary on a shallow (2 to 9 m) sand flat that showed high spatial and temporal variability in both grain size and benthic communities from both sediment grabs and epibenthic trawls. High levels of variability were recorded for replicate samples from the same sampling stations for all areas; thus, no significant temporal differences were detected. The faunal composition was similar in 2005 compared to 2002, although differences in the abundance were significant, particularly with respect to those sites characterized by mobile sand and few species of invertebrates.

Oysters at three transects along the cable route at Kentish Flats and one reference area were collected before and after cable laying to determine changes in tissue levels of selected metals, pesticides, and polychlorinated biphenyls (Emu Ltd., 2005). Most contaminants either decreased at both the cable route and reference site or increased less along the cable route compared to the reference site. Lead and chromium showed significant increases postconstruction; however, no effect could be related to construction activities because of increases in the reference site as well.

Following is a summary of the results of benthic monitoring programs at four existing offshore wind parks in Europe and the United Kingdom for up to 3 years after construction:

The most significant direct impacts were the loss of pre-existing habitats dominated by infauna in sandy sediments and the introduction of fouling communities on the introduced hard substrates.

Impacts during construction can be minimized by following good practices. At Nysted, where the trench for the cable to shore was excavated by backhoe and the sediments were piled adjacent to the trench for months before backfilling, the impacts to benthic habitats were much larger (10 times greater) than the footprint of the excavation. None of the other studies documented significant changes to the benthic habitats during construction.

The sites studied are in sandy, relatively high-energy locations, and the sediments and infauna are subjected to regular reworking, which can result in large temporal variations. Thus, although there were temporal and spatial variations pre- and postconstruction in sediment characteristics and benthic communities, these changes occurred in both the wind park and reference sites, and the spatial differences were not statistically significant.

New benthic species can be introduced postconstruction by drift or spreading from the new hard-bottom habitat.

The species diversity and structure of the fouling communities on the turbine foundations and scour protection appeared to be controlled by natural patterns in recruitment, predation, and succession.

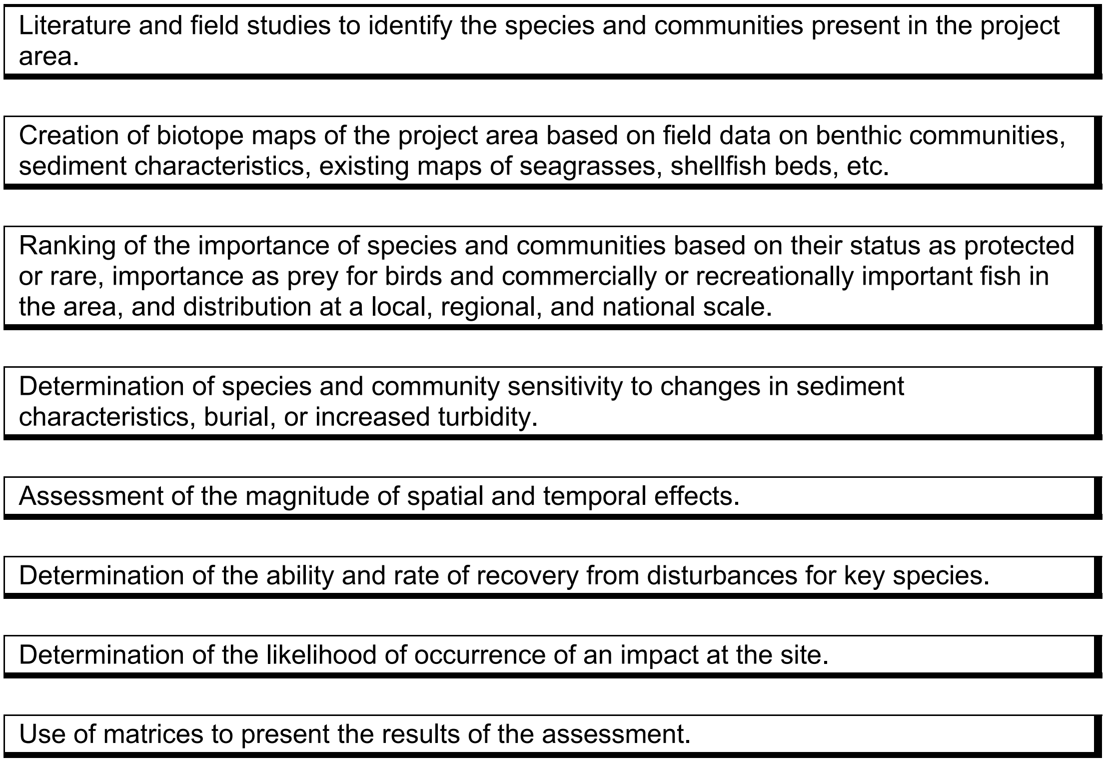
Indirect effects were suggested only at Horns Rev where the most common bivalves and bristle worms were greater in number in the wind park compared to reference areas, perhaps because of reduced predation by seaducks, which were observed to avoid feeding in the wind park.

5.1.3.3 Current Models Used to Determine Impacts—Benthic Resources

Potential impacts to benthic resources during the environmental assessment phase of an offshore wind park project are evaluated in both Europe and the United Kingdom as of 2006 using the general approach shown in figure 5-4.

The magnitude of the spatial and temporal effects is determined using various methods including literature reviews (e.g., studies on species sensitivity to noise), models to predict worst-case turbidity concentrations and thickness/areal extent of sediment deposition during dredging and trenching, and calculations of the percentage of habitat lost by construction of foundations. CEFAS (2004) recommends use of the maximum tidal excursion from the site boundaries as an initial basis for determining the minimum sphere of likely impact arising from the short-term redistribution of fines disturbed as a result of wind park developments. The researchers consider this to be a crucial consideration in the placement of baseline and monitoring stations.

Examples of this impact assessment approach include the Lynn offshore wind environmental impact statement (EIS) by AMEC (2002), the AMEC Aberdeen Scoping Opinion (2005), and the Horns Rev 2 benthic resources impact assessment (Leonhard, 2006). Table 5-4 is an example matrix from the EIA for benthic resources at the second wind park proposed for construction at Horns Rev (Leonhard, 2006). Thus, it reflects the most current approach used in Denmark where researchers have the most extensive experience. As shown in table 5-4, the significance of the impacts to benthic resources was determined to be either negligible or minor, which is often the conclusion of EIAs for offshore wind parks in Europe and the United Kingdom.



Literature and field studies to identify the species and communities present in the project area.

Creation of biotope maps of the project area based on field data on benthic communities, sediment characteristics, existing maps of seagrasses, shellfish beds, etc.

Ranking of the importance of species and communities based on their status as protected or rare, importance as prey for birds and commercially or recreationally important fish in the area, and distribution at a local, regional, and national scale.

Determination of species and community sensitivity to changes in sediment characteristics, burial, or increased turbidity.

Assessment of the magnitude of spatial and temporal effects.

Determination of the ability and rate of recovery from disturbances for key species.

Determination of the likelihood of occurrence of an impact at the site.

Use of matrices to present the results of the assessment.

Source: Leonard, 2006.

Figure 5-4: Flow chart of the process for environmental assessment of potential impacts to benthic resources used in Europe.

Table 5-4: Summary of potential impacts on benthic communities from construction and operation activities for the Horns Rev 2 offshore wind park.

Impact	Criteria	Preconstruction	Construction	Operation	Decommission
Noise & vibrations	Importance	Local	Local	Local	Local
	Magnitude	Minor	Minor	Minor	Minor
	Persistence	Temporary	Temporary	Temporary	Temporary
	Likelihood	High	High	High	High
	Other	Direct	Direct		Direct
	Significance	Negligible	Negligible	No impact	Negligible
Suspension & redistribution of sediments	Importance	N/A	Local	N/A	Local
	Magnitude		Minor		Minor
	Persistence		Temporary		Temporary
	Likelihood		Low-high		High
	Other		Direct		Direct
	Significance		Negligible		Negligible
Change in substrate type	Importance	N/A	Local	Local	Local
	Magnitude		Minor	Minor	Minor
	Persistence		Permanent	Permanent	Permanent
	Likelihood		High	High	High
	Other		Direct	Direct	Direct
	Significance		Minor	Minor	Minor
Loss of seabed area	Importance	N/A	Local	Local	N/A
	Magnitude		Minor	Minor	
	Persistence		Permanent	Permanent	
	Likelihood		High	High	
	Other		Direct	Direct	
	Significance		Minor	Minor	
Electromagnetic fields	Importance	N/A	N/A	Local	N/A
	Magnitude			Minor	
	Persistence			Permanent	
	Likelihood			Unknown	
	Other			Direct	
	Significance			Negligible	
Introduction of hard substrate	Importance	N/A	N/A	Local	Local
	Magnitude			Minor	Minor
	Persistence			Permanent	Permanent
	Likelihood			High	High
	Other			Direct	Direct
	Significance			Minor	Minor
Changes in hydrodynamic regimes	Importance	N/A	N/A	Local	N/A
	Magnitude			Minor	
	Persistence			Permanent	
	Likelihood			High	
	Other			Direct	
	Significance			Minor	
Cumulative effects	Importance	Local	Local	Local-regional	Local
	Magnitude	Minor	Minor	Minor	Minor
	Persistence	Temporary	Temporary	Permanent	Temporary
	Likelihood	Low	Low	Uncertain	Low
	Other				
	Significance	No impact	No impact	Unknown	No impact

Source: Leonard, 2006.

The permanent changes, such as habitat loss and introduction of species associated with construction of the foundations and scour protection, are considered local because of the very small area of the impacted footprint (usually less than 1 percent of the area of the wind park). Most of the existing sites are located in areas of mobile, sandy sediments where the benthic communities have been shown from previous studies of dredging or other disturbances to quickly recolonize disturbed areas. Impacts from monopile and cable installations are considered temporary and localized. When discussing indirect impacts such as changes in predation or reduced fishing pressure, it is noted that little or no data exist on which to quantify these impacts and, in most cases, it is assumed that they will have positive effects.

5.1.3.4 Mitigation Measures Used at Existing Offshore Wind Parks

Because most past environmental assessments of impacts to benthic resources from offshore wind parks concluded that there were no significant impacts, few mitigation measures have been proposed, and most of those proposed can be considered best management practices for the industry. Following are examples of mitigation measures used at existing wind parks:

Siting

- Avoid sensitive benthic habitats during siting.

Construction Vessel

- Use midline buoys on anchor lines to reduce the amount of anchor-line sweep disturbance.
- Use dynamically positioned vessels to minimize anchor effects.

Foundation/Scour Protection

- Select grout formation to maximize the use of chemicals with low environmental toxicity, high biodegradability, and low bioaccumulation potential.
- Dispose of dredged sediments in approved offsite disposal sites.
- Document any sediment spills during construction.
- Adopt good working practices to prevent accidental spillages and loss of solid objects.
- Use scour protection where needed to reduce foundation scour that could change the elevation or grain size of seabed sediments, or both.
- Use scour mats with fronds (biologically neutral) to trap local sediment rather than stones that introduce artificial hard substrates.
- Conduct postconstruction surveys to identify potential debris locations. At the Kentish Flats, U.K. park, 10 potential targets that were identified by side-scan sonar were inspected by divers and surveyed using a magnetometer, confirming that there was no construction debris present (Quest Underwater Services Ltd., 2006).
- Drag construction areas to remove construction debris.

Cable Laying

- Use jet plowing for trenching and cable laying to disturb less sediment than mechanical or other dredging methods cause.
- Use horizontal directional drilling to install the cable in intertidal habitats to prevent habitat damage.
- Follow proper cable design and shielding and bury cable 1 to 3 m deep to reduce potential EMF and temperature effects.

Restoration/Monitoring

- Reseed shellfish beds disturbed during trenching.
- Replant eelgrass beds disturbed during trenching operations.
- Conduct monitoring studies during construction and operation to detect impacts.

5.1.3.5 Information Needs Analysis

Baseline Studies

The benthic communities in the OCS have been described in studies, mostly funded by Minerals Management Service (MMS) along the Atlantic (Wigley and Theroux, 1981), western and central Gulf of Mexico [summarized in the Final EIS for the 2007–2012 Outer Continental Shelf Oil and Gas Leasing Program (MMS, 2007)], and the Pacific (Lie and Kelly, 1970; Carey, 1972; SAIC, 1989; Dailey, Reish, and Anderson, 1990). The benthic communities of the eastern Gulf of Mexico OCS are not as well characterized. Rabalais and Boesch (1987) used much of these data to identify the dominant features, processes, and benthic assemblages for each OCS region.

Benthic communities have been characterized as part of the site-specific studies on the existing conditions for the Atlantic and Gulf Coast states undertaken by the MMS Marine Minerals Program with respect to offshore sand mining and dredging. (Most of these studies are available at http://www.mms.gov/sandandgravel.) Analyses of the benthic characterizations completed in these studies may be of particular relevance to alternative energy projects being developed on or nearby these sites.

The U.S. Geological Survey (USGS) has compiled extant sea floor sediment character and textural data as well as other geologic information for the three coasts of the United States into the usSEABED data system—Atlantic (Reid et al., 2005); Gulf of Mexico and Caribbean (Buczkowski et al., 2006); and Pacific (Reid et al., 2006)—with data available at http://walrus.wr.usgs.gov/usseabed. The USGS has also synthesized these data into regional geographic information system (GIS) summaries such as for the New York and New Jersey bight (Williams et al., 2006) and southern California (Cochrane et al., 2005). Such geological data are often used for generation of habitat maps; however, significant effort is needed to create true benthic habitat maps.

Benthic habitat maps showing spatially recognizable areas where the physical, chemical, and biological environment is distinctly different from surrounding environments are important data for regional assessments of potential areas for development of offshore alternative energy technologies, site-specific assessments, and determination of potential cumulative impacts. Habitat maps would help in the design of surveys to ensure that wind park operators address all of the habitat types in the area, use the proper methodology to characterize the resources, and reference baseline conditions for a monitoring program.

The USGS Coastal and Marine Geology Program has been coordinating among Department of the Interior, National Oceanic and Atmospheric Administration, the regional Fishery Management Councils, and States on the National Benthic Habitat Mapping Program to develop regional benthic habitat classification protocols and start work on pilot areas. (See project descriptions at http://walrus.wr.usgs.gov/research/projects/nearshorehab.html for the Pacific region, http://woodshole.er.usgs.gov/project-pages/stellwagen/ for the Atlantic region, and http://coastal.er.usgs.gov/flash/ for the Florida Shelf Habitat Map, or FlaSH.) Areas targeted for offshore alternative energy facilities should be mapped as part of these regional programs.

Impact Assessment Studies

Based on up to three years of studies of existing offshore wind parks in shallow and sandy substrates in Denmark and the United Kingdom, it appears that the direct impacts of construction and operation on existing benthic communities are small. Clearly, there are major changes associated with the introduction of hard substrates; however, the ecological consequences are not well understood. Often the increased number of species and biomass, both attached and attracted to the hard substrates, are considered to be beneficial. Of great uncertainty are indirect and cumulative impacts.

Several documents were helpful in identifying information needs in impact assessment studies for benthic resources. In the United Kingdom, the Government's Research Advisory Group (RAG) produced a fourth revision of the RAG list of issues raised and research needs for offshore renewable energy (RAG and COWRIE, 2006). The European Commission sponsored the Concerted Action for Offshore Wind Energy Deployment, which summarized environmental issues in a report by SenterNovem (2005) that identified information needs and problem areas. The IAPEME comments in the report on key environmental issues learned from the benthic resources monitoring of the Danish offshore wind parks (Dong et al., 2006, pp. 62–63) pointed out the strengths and weaknesses of the monitoring programs and made suggestions where further research was needed.

The following information needs in impact assessment for benthic resources are noted:

Loss of soft substrate habitat. Direct loss of existing soft substrate habitat from construction of foundations and scour protection can be quantified; however, there is no agreement on how to evaluate such impacts. It is usually reported as a very small percentage of the wind park area, and thus, it is assumed to be negligible, even for cumulative impacts, unless unique habitats are affected. Such habitats are usually avoided during siting studies. There are no guidelines for how much of a change should be considered other than negligible.

Introduction of hard substrates in soft sediments. The introduction of hard substrates and the associated fouling community in otherwise soft sediments is clearly a very pronounced direct effect, but there is no agreement on how to evaluate the positive or negative values of this effect. Existing studies describe the fouling community in terms of species abundance and biomass and assume a positive effect. In the United States, studies of oil and gas platforms have documented similar types of fouling communities. Studies by Page, Dugan, and Bram (2005) and Continental Shelf Associates (2005) in southern California, and Carney (2005), Dokken et al. (2000), and the synthesis of Gallaway and Lewbel (1982) in the Gulf of Mexico can be used to predict the rate and pattern of succession for different environmental settings. No studies have looked at the new habitats in terms of their sustainability, energy flows, species interactions, and an understanding of scale, that is, how individual foundations interact with each other and with the surrounding natural community (Petersen and Malm, 2006).

Effects caused by scour, sediment change, noise, vibration, predation, and trawling. Data are insufficient to assess both direct and indirect effects on benthic communities from local scour, changes in sediment characteristics, noise, vibration, changes in predation, and changes in disturbances from trawling, compared with natural variations. None of the monitoring studies of existing offshore wind parks could attribute any changes to these potential impacts because of the rates of high natural variation. The current monitoring programs have a low ability to detect anthropogenic causes of changes despite the requirement to monitor benthic communities at a significant expense.

Standardized protocols and monitoring studies. Because monitoring of benthic habitats likely will be conducted at each United States site, it would be appropriate to have standard approaches and protocols, similar to the guidance by CEFAS (2004) for EIAs in the United Kingdom. Monitoring studies need to be well designed so they will provide meaningful results with appropriate levels of confidence. There are many direct and indirect effects to be quantified by monitoring, including (1) changes in original benthic habitats and communities from changes in physical processes, new species by drift from introduced habitats, reduced predation by seaducks, increased local predation by introduced species, and reduced disturbance by trawl fisheries; and (2) the artificial reef effect of the introduction of hard substrates. Studies at representative sites in different zoogeographic regions of the Atlantic and Gulf of Mexico, where offshore wind parks are likely to be proposed, would provide the basis for impact assessment. A more holistic approach is needed to better understand the positive and negative effects to benthic communities, which can be gained only from monitoring representative sites and using an ecosystems approach to interpretation of the results. Thus, benthic resource studies should be integrated with fish and bird studies.

Effects of magnetic fields. Magnetic fields may affect those species that use the earth's natural magnetic field to navigate. It is uncertain as to whether benthic invertebrates use this mechanism to navigate, and no known data exist in this respect. It is generally assumed to be low or unknown, thus it is generally ignored in EIAs. In a recent study, Bochert and Zettler (2004) used static magnetic fields to simulate potential impacts to shrimp, isopod, crab, mussel, and juvenile flounder from subsea cables using high voltage direct current. The researchers found no differences in survival or fitness after an exposure of 28–90 days; however, they noted that the exposures used were not comparable with time-varying fields from alternate current power transmission. Thus, well-designed laboratory studies on the possible effects of long-term exposure to the type and intensity of magnetic fields generated by the cables from offshore wind parks for key benthic species would provide the basis for more informed impact assessments. A definitive study should be able to answer whether EMF from cables from offshore alternative energy facilities (not just wind parks) directly affects benthic communities.

Possible reductions in predation. Magnetic fields may have indirect impacts to benthic communities because of a reduction in predation by masking the natural bioelectric fields of prey species or by repelling fish predators. Studies on magnetic field impacts on fish should determine if and how magnetic fields affect predator feeding of benthic prey.

Effectiveness of cable burial trenching methods. Most EIAs indicate that burial of cables to depths of 1 to 3 m and use of specific trenching methodologies are mitigation measures to reduce potential impacts to benthic resources from EMF, temperature, and physical disturbances during trenching; however, existing information is not adequate to assess the benefit of these measures. Specific studies could quantify the benefits of mitigation measures such as cable type, cable shielding, cable voltage strength, trenching methods, and burial depth in different sediment types applicable to U.S. project designs and settings.

Effects of noise and vibration. It is generally assumed that noise and vibration effects on benthic communities during operation are localized and low, or unknown, because of the general presence of fouling communities and fishes similar to wreck sites. Well-designed studies during operation of offshore wind parks would provide actual data on which to base impact assessment.

Cumulative effects of other variables. There are insufficient data and approaches to assess cumulative effects on benthic communities. Of particular concern is the potential spread of invasive species through the use of offshore facilities as stepping stones to cross previous barriers. It will be important to monitor the results of studies in Denmark and the United Kingdom where the next round of proposed offshore wind parks includes sites within a few kilometers of existing sites.

5.1.4 Fishery Resources

5.1.4.1 Potential Impacts—Fishery Resources

Fishery resources include the following groups of fishes and invertebrates:

- Pelagic forms that swim at or near the water surface such as mackerels and bluefish;
- Midwater species that occupy the midranges of the water column such as butterfish and squid;
- Demersal species that live on or next to the seafloor surface such as flatfishes and reef fishes;
- Infauna burrowing fish species that reside in sediments, such as the speckled worm eel in the United States and sand eels in Europe.

This section focuses on the characteristics of fishes and invertebrates rather than on fisheries. Benthic invertebrates that constitute commercial and recreational fishery resources such as crab, lobster, clam, and scallop are addressed in the section on benthic resources.

Benthic-pelagic coupling is the flow of energy between benthic organisms, zooplankton, and higher trophic levels of fishery resources; it is an intimate relationship (Bray, Miller, and Geesay, 1981). Perturbations of benthic communities can result in significant impacts on fish community structure and biomass. The impacts can be biological such as a change in the biota from the elimination or enhancement of a food source or physical such as modification of the sediment type and distribution that can altar spawning habitat or current flows, which in turn can affect sediments and fish distribution. Impacts on benthos have both direct and indirect effects on fishery resources.

Following is a list of potential impacts to fishery resources resulting from construction and operation of offshore wind parks:

- Disturbances from noise, sound, and vibration (Gisiner, 1998; Heathershaw, Ware, and David, 2001; Wahlberg and Westerberg, 2005; Nedwell and Howell, 2004; Hastings and Popper, 2005; Thomsen et al., 2006)
- Losses of and changes to habitat caused mainly by the introduction of hard substrates (Gallaway and Lewbel, 1982; Dokken et al., 2000)
- Exposure to electromagnetic fields (EMF) (Gill et al., 2005)
- Changes in fishing activities by commercial and recreational sectors both in and out of wind parks (Kaiser, Spence, and Hart, 2000; Kaiser and Jennings, 2002; FLOWW, 2006, 2007)

The potential magnitude and significance of these impacts vary significantly both spatially and temporally (table 5-5). The following sections contain more detailed discussions of these four main potential impacts of offshore wind parks on fishery resources.

Table 5-5: Potential impact to fishery resources from offshore wind parks.

Construction Phase	Potential Impacts—Fishery Resources
Construction Vessels	Noise from seismic surveys and vessel traffic; physical disturbance of the seabed caused by positioning, anchoring, and movement of construction vessels including jack-up rigs, dredges, and barges; accidental spillage of contaminants from construction vessels
Foundation Installation	
Pile Driving	Noise and vibration during pile driving can kill fishes in close proximity and drive others away; release of seabed contaminants during sediment suspension
Foundation Installation	Sediment suspension and redistribution during seabed excavation and leveling for gravity foundations; release of seabed contaminants during sediment suspension; noise and vibration during installation; change in habitat from introduction of hard substrates; indirect impacts due to impacts to benthic habitat and prey
Scour Protection	Sediment suspension and redistribution during placement of scour protection; release of seabed contaminants during sediment suspension; noise and vibration during installation; change in habitat from introduction of hard substrates; indirect impacts due to impacts to benthic habitat and prey
Dredged Materials Disposal	Reduction in spawning habitat due to smothering and grain size changes; smothering of eggs and larvae
Cable Laying	
Trenching	Habitat disturbance during cable laying
Anchoring	Physical disturbance of the seabed resulting from positioning, anchoring, and movement of cable-laying vessels
Operations Phase	**Potential Impacts—Fishery Resources**
Turbine Towers	Noise and vibration transmitted through the water and seafloor; startle and alarm at turbine start up; avoidance during operation

Table 5-5: Potential impact to fishery resources from offshore wind parks.

Operations Phase	Potential Impacts—Fishery Resources
Turbine Foundations and Scour Protection	Habitat loss in foundation footprint; changes in sediment grain size from changes in physical processes and sediment transport resulting from local scour and within and near the wind park; introduction of artificial hard substrate and fouling communities; impacts from changes in predator/prey relationships and reduced fishing pressure
Cables	Electromagnetic field (EMF) avoidance or attraction by sensitive species, especially elasmobranches (sharks, skates and rays), resulting in alteration of feeding or migratory behavior
Service Vessels	Accidental release of contaminants; physical disturbance of the seabed

Impact of Sound on Fishery Resources

Hastings and Popper (2005) have conducted the most complete analysis of the response of fishes to sound in water to date. Although the objective of their report for the California Department of Transportation (2005) was specifically a consideration of the impact of pile driving, their review of the relationships between sound and fishes has the most scope and depth to date and the review of the literature and glossary is comprehensive. They include an extensive consideration of studies needed.

The response of fishes to sound is determined by whether the species is classified as a “specialist” or “generalist” (Popper et al., 2003). Specialists have biologic accessory structures for perception of pressure changes, enabling high sound-pressure sensitivity and lower hearing thresholds than generalists. Specialists can detect sounds at more than 3 kilohertz (kHz) with peak sensitivity between about 300 to 1,000 Hz (Popper et al., 2003).

Fishes are sensitive to particle motion in addition to, or instead of, sound pressure (Popper et al., 2003/2004). Fishes are very sensitive to hydraulic flow fields caused by the motion of predators or prey. Such flows are low frequency (40 to 300 Hz) and depend on the size of the animal (Kalmijn, 1988, 1994).

Many fish species such as elasmobranchs (sharks, skates, rays), flatfish such as flounder and whiff, and pelagic species such as mackerel and tuna, do not posses swim bladders, and they do not have the accessory structures associated with a swim bladder. These species perceive sounds up to 500 to 1,000 Hz, with best hearing generally from 100 to 400 Hz (Chapman and Hawkins, 1973; Popper et al., 2003/2004). In an examination of the literature on sound reception by fishes and potential for damage caused by pile driving, Engell-Sorensen and Skyt (2001) found that fishes with swim bladders such as cod, whiting, and eels can detect frequencies up to 300 to 500 Hz, and their auditory threshold is 75 to 100 dB. Bottomliving fish that lack a swim bladder (flatfish, sea robins, gobies, elasmobranches) do not detect sound frequencies above 250 Hz, and their auditory threshold is in the range of 90 to 110 dB. Thus, it is very likely that sounds such as pile driving associated with wind park construction will be within the audible range of most species. Fishes react to such sounds with short-term changes in behavior such as alarm and startle responses (Hastings and Popper, 2005).

A swim bladder is very sensitive to compression from sharp high-pressure waves such as those generated by pile driving and seismic guns. Abrupt changes in pressure can tear a swim bladder and be lethal for fishes (Hastings and Popper, 2005).

It is well known that there is a significant increase in the level and duration of ambient sound in the oceans (Andrew, Howe, and Mercer, 2002; NRC, 2003). Generally fishes are insensitive to frequencies more than 500 to 2,000 Hz, although some fish can respond to intense ultrasound, and some fishes have sensitivities to frequencies as high as 130 kHz (Nestler et al., 1992; Mann et al., 1998; Astrup, 1999). Fishes are sensitive to boat engine noise, which can result in behavior shifts and alteration of migratory patterns (Sarà et al., 2007). Much of this behavior shift is attributed to sound generated by increases in commercial shipping traffic and fishing vessels. The vessel traffic associated with the construction phase of offshore energy systems will become part of that mix. For example, a 25-meter (m) tug pulling an empty barge, a scenario that is likely to occur during wind park construction, has been reported to have a 170 decibels (dB) relative to 1 Pascal at (re 1 Pa @) 1 m source level (Nedwell and Howell, 2004). Although there will be an increase in background noise because of increased boat traffic to, from, and in the construction zone, most fishes become habituated or move out of the area without physical damage.

Thomsen et al. (2006) conducted a comprehensive review of the effects of offshore wind park sound. Their summary of the sound levels generated by the different construction techniques shows that the levels present are sufficient to be physically harmful to different species of fishes (Popper and Clarke, 1976; Popper, 1977; Popper et al., 2006), but at sublethal levels it is also possible that sounds can mask intraspecific communication. All the authors emphasize the difficulty of calculating a zone of responsiveness because site-specific characteristics can alter sound transmission and many species of fishes have a wide range of sensitivities.

There is a developing literature on the effects of air guns used during seismic surveys (Pearson, Skalski, and Malme, 1992; McCauley et al., 2000), which is of interest because the type of sound generated is relevant to the sound generated during high energy pile driving—pressure generated in a very short period. In a recent study, McCauley, Fewtrell, and Popper (2003) investigated the effects of exposure to air gun sounds on the pink snapper (*Pagrus auratus*), a commercial fish found in Australian waters. Fishes were enclosed in a large cage in a large bay, and then exposed to air gun sounds over several hours in an approach-depart exposure method. Fishes were sacrificed at intervals after exposure, and their hearing apparatus was examined for damage from the exposure. The results showed extensive damage to the sensory level of the hearing apparatus. The level of damage increased the longer the fish were allowed to survive postexposure, up to at least 58 days, which was the maximum tested. This study demonstrates the risk of postimpact latent mortality in fishes.

Skalski (1992) found that air guns negatively impacted catch per unit of effort for rockfish in a hook-and-line fishery. Dalen et al. (1996) studied the impact of air gun arrays on fish stock levels and concluded that mortality rates and damages were limited to distances of less than 5 m from the air guns, with most frequent and serious injuries at distances of less than 1.5 m. Further, this damage on a stock level would account for only a mortality rate per day on a worst case scenario of less than 0.018 percent, which is insignificant compared to an assumed natural mortality rate of about 15 percent per day for the exposed species. Impacts might be different for periods when fishes are concentrated or more vulnerable such as during migration and spawning.

A carefully designed experiment on the impact of seismic shooting on an important North Sea fishery, the sand eel (*Ammodytes marinus*), was conducted off the coast of Norway (Hassel et al., 2003). Researchers found that sand eels confined to cages showed a shift in swimming behavior during the shooting, but the fish did not burrow into the sand, and they resumed normal swimming soon after the shooting. Mortality in exposure cages was the same as in the control cages. There were changes in landings after the pre- and postshooting, but they were within the normal day-to-day variation in landings for the fishery.

Hastings and Popper (2005) reviewed all pertinent peer-reviewed and unpublished papers about sound exposure effects on fishes through early 2005. The researchers found that exposure of short duration and high amplitude can result in instant mortality, damage to the hearing apparatus, and delayed mortality. Various treatments have been tried to reduce the risk of injury to fishes during pile driving, and an air curtain technique (Nestler et al. 1992; Wursig, Greene, and Jefferson, 2000; California Dept. Transportation, 2001) used in driving pilings for a large bridge in San Francisco Bay was partially effective. On the other hand, the noise and anchoring impacts generated by boat activity necessary to support the technology was itself a problem.

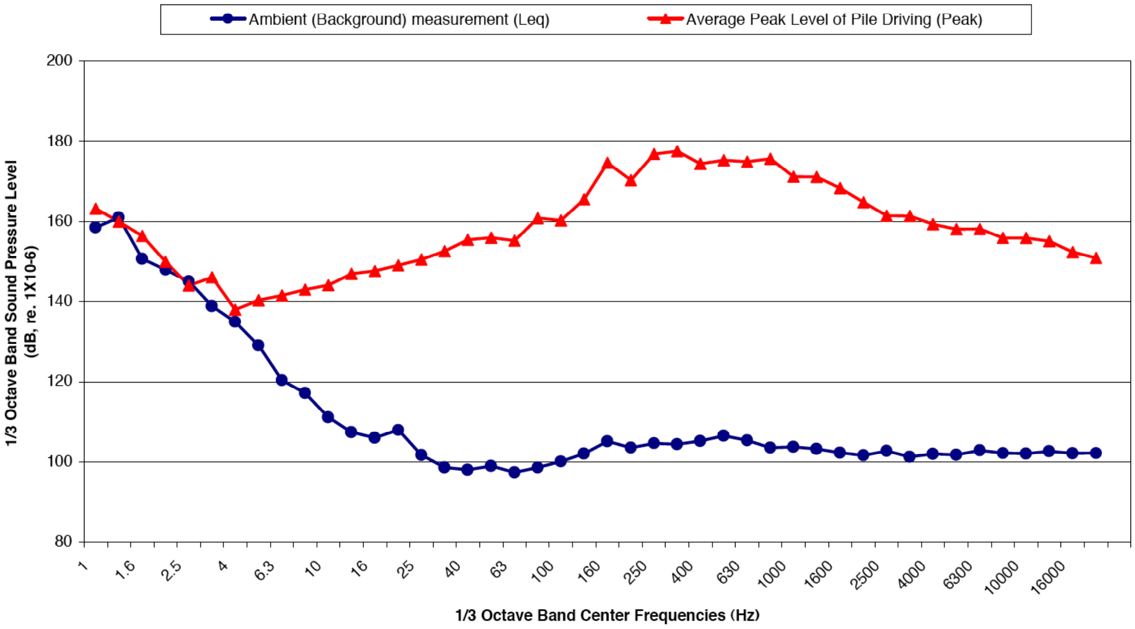
Popper et al. (2003/2004) describe the sound and vibration during pile driving as the most serious impact from sound on fishes. The pressure that is generated is of short duration but high energy (Hastings and Popper, 2005). The researchers describe the effects of anthropogenic sound on the behavior and physiology of fishes that range from a sharp movement and startle responses, to movement away from sound, to mortality. Maxon (2000) measured the underwater and above water sound in a pile driving experiment. His hydrophone measurements 320 m from the pile (figure 5-5) show the frequency range of the pile-driving sound that exceeds the existing ambient level. The peak sound pressure level (SPL) to time history plots at 30 m (figure 5-6) and 320 m (figure 5-7) show how the time to rise is longer at distance, and the peak is lower and decreases with distance. Nedwell et al. (2003) found the sound level at 417 m distant could not be detected above background in a comprehensive study of the sound levels and effect on fishes from vibropiling (a specialized technique for piling construction in Europe). Trout in cages 50 m from the vibropiling showed no evidence of damage. There was also no evident gross physical injury to trout from a distance of 400 m to impact piling.

Habitat Alteration

Pile driving of monopiles, installing foundations and scour protection, and setting of anchors can suspend sediment and generate drill cuttings that can be very different in sediment composition than the surface sediments. The temporary increase in turbidity will disturb fishes; however, they will return to the area after the sediment clears (Hoffmann et al., 2000) if the type of sediment remaining meets their life-cycle requirements. The reciprocal is also true, and fishes can be excluded because of the sediment changes.

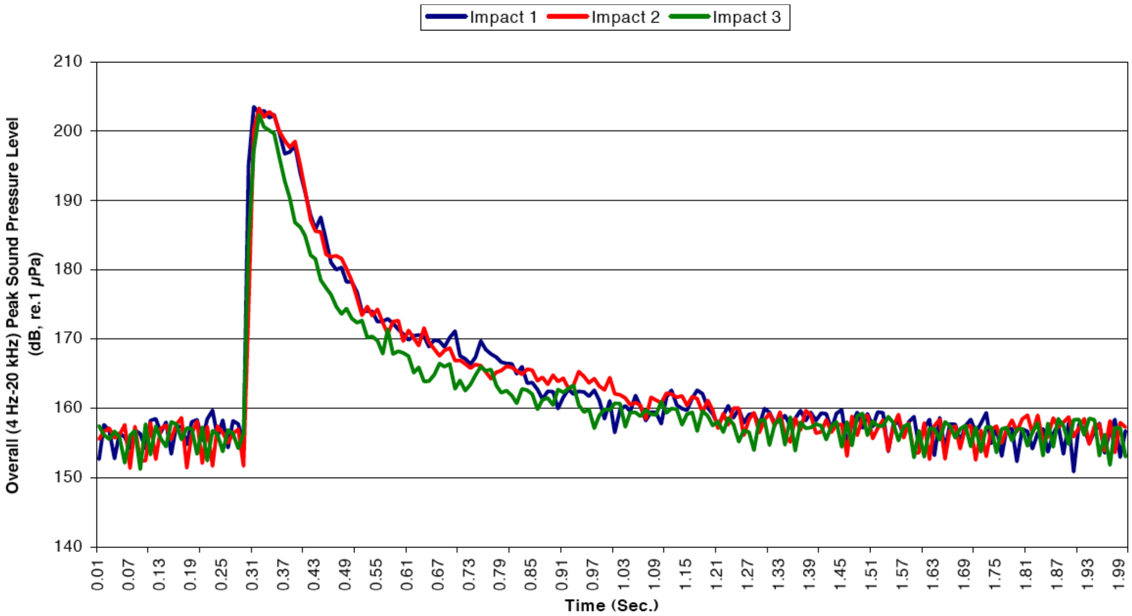
Dredged materials can be generated from drilling in hard sediments to install monopiles and excavation to install gravity foundations. Dredged material is usually disposed of offsite in approved disposal areas, and therefore, it would not impact fishes in the wind park area.

The biggest habitat change would come from introduction of hard substrates and the resulting associated fouling communities on both foundations and scour protection in areas of soft sediments. Schroeder et al. (2000) described in quantitative terms the use of oil and gas



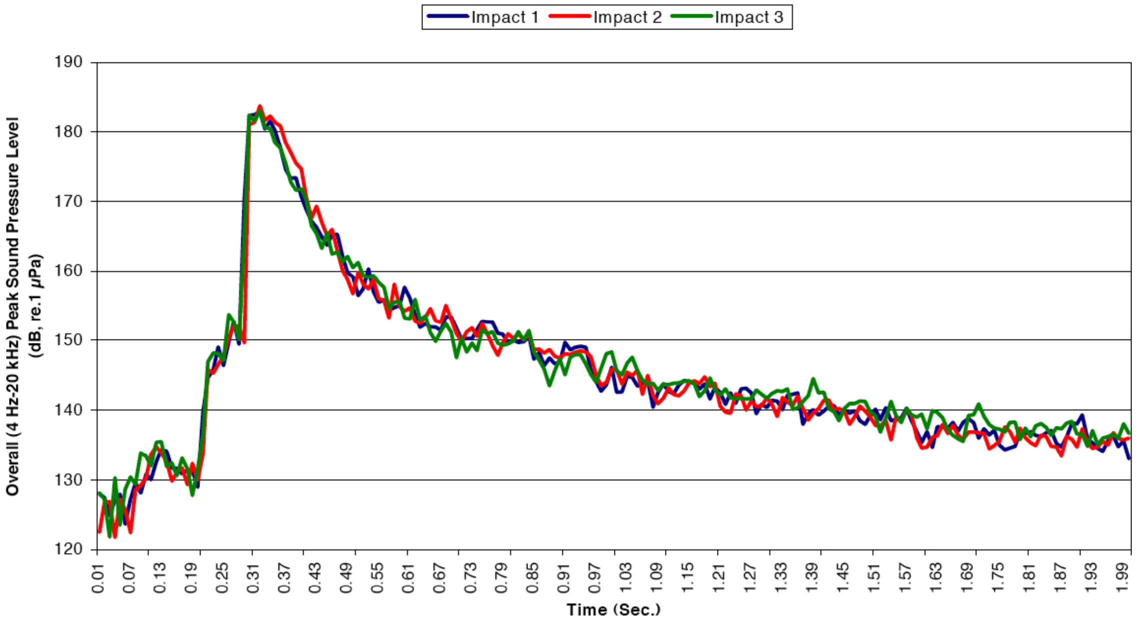
Source: Maxon, 2000.

Figure 5-5: Underwater sound measured 320 m from a pile-driving operation at the Nysted offshore wind park compared with ambient sound.



Source: Maxon, 2000.

Figure 5-6: Overall (4 Hz to 20 Hz) peak sound pressure level time-history plots for three different pile drives at 30 m from the pile-driving operation.



Source: Maxon, 2000.

Figure 5-7: Overall (4 Hz to 20 kHz) peak sound pressure level time-history plots for three different pile drives at 320 m from the pile-driving operation.

production platforms and their potential utility for fish assemblages in southern California waters. The researchers found the habitat value and species richness were lower on platforms than natural reefs, but platforms did support a greater abundance and diversity of rockfish (*Sebastes spp.)* juveniles. Because this fish family is at risk on the Pacific coast, this is an important finding on the role of artificial structures. They also found that the variability in platform habitat values and species richness was large compared to natural reef values, which demonstrates the highly site-specific nature of structures and fish populations. Ambrose and

Swarbrick (1989) compared artificial and natural reefs and found significant differences in the fish community structure. Wilson, Pierce, and Miller (2003) found that many reef-dwelling fishes become established in the structural complex of oil and gas platforms, and biomass increases can be very large.

The structural base for wind turbines and the anchors for other energy technologies provide a habitat for epibenthic communities to become established. In tropical waters, they can become a site for harmful algae, such as *Gambierdiscus toxicus,* the dinoflagellate responsible for the production of ciguatoxin, which is accumulated in certain species of fish, such as the barracuda. Villareal et al. (2007) studied six oil and gas platforms in the Gulf of Mexico and found that all of them harbored this dinoflagellate, leading them to conclude that the introduced hard substrate provided sites for the expansion of ciguatera into otherwise poor habitat. Wind park structures could provide the same substrate for the introduction of invasive or exotic species, of particular concern if sea-surface temperatures rise.

Whether the overall impact from introduction of hard substrates is perceived as positive or negative depends on the objectives of the user group or perception of results of the activity. For example, some consider the development of hard structures on soft sediments to be desirable because the structures create a new habitat type; others consider it to be an opportunity for invasive species to occupy an area where they otherwise would be excluded and compete for resources with the original soft-bottom species (SenterNovem, 2005; Reggio, 1989; Rigs-to-Reefs, 2000).

Electromagnetic Fields

Electricity generated by wind parks is transmitted to shore with power cables that usually are buried. The current in the cable is an alternating current, unlike the fixed pleomagnetism that exists in the sediments of the ocean (Engell-Sorensen, 2002; Garrison, 2002). The power cable will induce both magnetic and electric fields (E-fields). Some elasmobranches (sharks, skates, rays) are the fish most sensitive to EMF. Gill and Taylor (2001) found that elasmobranches “could detect direct current (DC) voltage gradients less than 0.01 microvolt per centimeter (μV/cm) and sometimes as low as 0.005 μV/cm in the frequency range of up to 8 Hz” and the response varied with species. Even with technologic innovations (changes in permeability or conductivity), the E-fields from transmission cables are still within the lower range that can be detected by elasmobranches (Tricas and New, 1998). The level of E-fields is on the boundary of E-field emissions that are expected to attract or repel elasmobranches. University of Liverpool (2003) conducted a baseline assessment and found little evidence that the field levels would alter behaviors, but the authors did suggest that further research needs to be done.

Few studies are available to help determine which fishery species might be affected by electric and magnetic fields and at what levels they are affected. Engell-Sorenson (2002) surveyed the literature on the response of fishes to EMF. The researcher’s calculations of the magnetic field in the near vicinity of a cable showed it might be sufficiently high to affect sensitive fishes. The report on the effect of electromagnetic electrical fields on fish by Gill et al. (2005) is very comprehensive, and it has an excellent summary and extensive literature review on this subject. The information that does exist primarily concerns the elasmobranches (Adair, Astumiant, and Weaver, 1998). Magnetic orientation has been shown in elasmobranches (Kalmijn, 1988) as an indirect consequence of highly sensitive electrosensory organs and central pathways and processors capable of extracting this information and using it in normal behavior. Stingrays showed the ability to orient relative to uniform electric fields and voltage gradients of only 5 nanovolts per centimeter (nV/cm), and dogfish and blue sharks were observed to execute apparent feeding responses to dipole electric fields designed to mimic prey (Kilmijn, 1988). Stingray, *Daysyatis sabena*, a common fish of the Atlantic and Gulf coasts, could locate two different prey species that were encased in electrically transparent agar, which was buried under sand. Goodness of fit analysis showed the stingrays were electroreceptive, although they did not discriminate between the prey types (Blonder and Alevizon, 1988). An experiment tested whether the unique head morphology of the scalloped hammerhead gave it an advantage relative to sandbar sharks in responding to prey-simulating electric stimuli (Kajiura and Holland, 2002). The researchers found that both species gave similar behavioral responses to the stimuli, but the orientation pathways and behaviors differed, and thus, demonstrated the importance of experimental studies with different species before management decisions are made.

An experiment with sharks conditioned by activation of an artificial magnetic field paired with a reward control demonstrated that they could detect a magnetic field, and the experiment provides a behavioral assay to determine how sharks detect magnetic fields and measure detection thresholds (Meyer, Holland, and Papastamatiou, 2005). Yellowfin tuna, a pelagic highly migratory species, was able to learn magnetic field discrimination in laboratory experiments (Walker, 1984). Engell-Sorensen et al. (2000) reviewed the literature of wind park operations and found "fields comparable to geomagnetism (30 to 50 micro tesla) will only be expected to occur at distances of less than 1 m from the current bearing structures in the park. The size of the magnetic field at a distance of 100 m from a 15 kV line is thus considered to be 2 to 4 times weaker than geomagnetism, depending upon the type of cable." The researchers concluded there would be no magnetic field impacts to pelagic fishes for cables buried deeper than 1 m. It is hypothesized that some demersal teleosts such as the flatfish are sensitive (Kalmijn, 1988; Formicki et al., 2004); however, very little experimental data are available.

Changes in Fishing Activity

The exclusion of trawl fisheries potentially could have direct effects (reduced catch) in the wind park area and indirect effects (increased fishing pressure) outside the exclusion area as well as reduced bottom disturbance from cessation of trawling. There is a growing literature on fish habitat and the effects of fishing, and much of the literature concerns the alteration of benthic habitat that results from fishing activities. That information is well summarized in the NRC (2002) report "Effects of Trawling and Dredging on Seafloor Habitat." The study includes an extensive bibliography and access to numerous maps demonstrating the scale of fishing effort that results in benthic impact for U.S. coastal oceans.

5.1.4.2 Results of Monitoring at Existing Offshore Wind Parks—Fishery Resources

It is important to understand that monitoring fish populations is a very demanding task that requires multiple gear types and sampling designs over seasonal and annual periods, and the samples must be collected in three dimensions—horizontally, vertically, and temporally. Fish populations vary greatly year to year, and they move in time and space. It is common to have highly variable results from sampling for short periods, especially among small areas (Rijnsdorp and von Keeken, 2004). This means that, for monitoring projects to be meaningful, they must be carried out for many years.

Sound

Potential impacts from wind park operations on fishes include sound and vibration generated by operating turbines. Westerberg (1999) conducted the first measurements of underwater sound from an operating 220-kW turbine on a 35-m tower near the shore on the southeast coast of Sweden. He found that at wind speeds between 6 and 12 m per second (m/s), wind turbine sound consisted of harmonics of the turbine's frequency of rotation (between 2.08 to 2.13 Hz). There were peaks at 8 and 16 Hz for a wind speed of 12 m/s, and a single peak at 16 Hz for 6 m/s wind speed. The 16 Hz peak for both wind speeds remained at a constant level above background noise. Westerberg (1999) suggested that the low-frequency hydrodynamic and acoustic fields from the wind turbines were not expected to create a problem for fishes because fishes could detect and interpret whether the fields were from wind turbines or animals.

Engell-Sorensen (2002) measured the sound generated by wind turbines at the Vindeby, Denmark, wind park while operating and stopped, and the researcher related those impacts to the sensitivity of fishes. The underwater sound coming from the turbines was 5 to 33 dB above the background noise. Although more noise would be generated at higher wind velocities, background sound also would increase. Engell-Sorensen (2002) determined the underwater sound was 85 to 120 dB in the frequency range of 0 to 14 Hz at a wind speed of 13 m/s measured 14 m from the turbines. The researcher concluded, as did Westerberg (1999), that under such conditions it is unlikely that fishes would suffer damage.

Electromagnetic Field Effect (EMF)

A literature analysis of the potential for electroreception in elasmobranches showed no published refereed literature research on the effects of EMF produced by undersea cables. Gill and Taylor (2001) conducted an experimental study with a worst-case scenario assumption using an unburied 150-kV cable with a current of 600 amperes (A) using a shark, the European spotted dogfish (*S. canicula*). The fish avoided experimental electric fields of 1,000 volts per meter but the results were highly variable among individuals, and the same species was attracted to a current of 8 A. The results are consistent with the predicted bioelectric field of their prey.

A study was conducted at Nysted to determine if there was a cable trace effect from EMF emissions from the transmission cable (Hvidt et al., 2006). Specially designed bidirectional and quadricdirectional pound nets were set on the east and west side of the cable. The objective was to determine if the cable affected the migration of fish and to estimate the number of fish crossing the cable. In addition, a tag-and-release study was conducted using the common eel (*Anguilla anguilla*) to determine success in crossing the cable and direction of migration. The results of the eel study were inconclusive. Analyzing the data for other species was difficult because of the complexity, but the analysis did suggest that some species might alter their behavior; but, in no case was migration blocked. The 2003 data indicated that Atlantic cod accumulated close to the cable route; however, the EMF around the cable was not measured, and there was no clear control or knowledge of fine-scale fish movement without a cable. When assumptions were made on power production at the wind park, a correlation test was applied to the data and a positive correlation was found for flounder. Flounder primarily crossed the cable when the strength of the EMF was estimated to be low, during calm periods. An alternative interpretation was that the fish changed their behavior on the cable route because of differences in the sediment types and food sources, if the benthic community was not re-established. Data to test that interpretation were not collected.

The Danish government convened an International Advisory Panel of Experts on Marine Ecology (IAPEME) to provide an independent review of the monitoring programs at Horns Rev and Nysted. The report from its meeting in 2002 discussed the potential for introduction of new species because of habitat change with the establishment of epibenthic communities on the foundations and piling, changing sediment characteristics, introduction of electronic cables that might interfere with fish migration, and sound (IAPEME, 2002). All of these are clearly issues identified by multiple sources. The important factor is that the external technical advice provides the guidance for development of monitoring programs and an independent review of the results. This effort was followed by a review of the results as of 2003 (IAPEME, 2006). IAPEME emphasized the need for more integration of benthic community studies with fish and bird studies to be able to assess effects of increased prey based on predator attraction. IAPEME discussed how changes in water quality and food resources can also affect the distribution as well as the species of fishes in the area of a wind park. Sand eels and sprats as well as other benthic feeding fishes are very sensitive to the quality of the sand as suitable habitat for feeding and reproduction. The changes that might result in changes in fish abundance also can result from changes in bird and mammal populations as they prey on the fishes. IAPEME suggested that an increase in fish abundance could change mammal abundance because of an abundance of food for the mammals. These potential and demonstrated impacts emphasize the need for long-term monitoring.

Habitat Alteration

The longest postconstruction studies of fishery resources have been conducted at Horns Rev, Denmark. Those studies covered 2 years of preconstruction and 3 years of operational data comparing stations within the wind park and at a reference site (Larsen and Kjaer, 2006; Dong Energy and Vattenfall, 2006). Control data on fish populations were derived from a long-term North Sea trawl monitoring program conducted by the Dutch Institute for Fisheries Research (Rijnsdorp and von Keeken, 2004). Onsite studies at Horns Rev used hydroacoustic monitoring (Hvidt et al., 2005, 2006) supplemented with conventional net techniques to assess wind park impacts on fishery resources. Hydroacoustic monitoring aids analysis of the density, diversity, and location of individual fish, although additional surveys are needed to identify species. Researchers found the wind park caused very little or no effect on fish densities; however, the studies did show a need for alternations in survey methods including extended night surveys, adding more or longer transects, and considering seabed topography, time of year, and weather conditions (Hvidt and Jensen, 2005). Following is a list of study results:

- The hydroacoustic survey method is useful.
- Fish densities have large diurnal variation.
- Fishes are attracted to the wind park from more than 500 m, meaning reference sites should be located at more than that distance.
- In only one out of four transects was fish density higher in the region of turbine foundations.
- No significant impacts have been observed at the Horns Rev wind park to date.

A study conducted at the Horns Rev site assessed the role of foundation and scour protection structures as artificial reefs (Tech-Wise, 2002). Multimesh, multipanel gill nets 80 m long were developed to catch fishes of all size classes. In a period of 4 fishing days, 6 gillnets at each position were used to fish at 3 locations in the wind park and 3 locations in the reference area. No differences were found in fish species diversity between the reference and wind park sites. In addition, there was no significant difference in the fish assemblages (community structure) between the sites; however, it is possible that this was a result of a low sample number, and a larger set of samples might yield different results.

The baseline studies at the Nysted wind park at Rødsand collected fishes using a pelagic net, biological survey net, pelagic gill net, turbot gill net, standard fyke net, and fry fyke net in the wind park area and a reference area (Hvidt, Engell-Sorensen, and Klaustrup, 2003). The researchers concluded that the statistical results from this set of studies lacked rigor and most of the selected species did not fulfill the test assumptions. Hvidt, Engell-Sorensen, and Klaustrup (2003) concluded that the design was not appropriate because of the number of empty cells recorded in many samples. By applying nonparametric multivariate statistical tests and grouping the individual species as stationary, prey, and reef species, the researchers obtained better statistical results. Their recommendation was that, in the future, the groupings should be done a priori and not be based on the results of the collections. The nonparametric multivariate analysis of variance (ANOVA) showed the reference area and the wind park areas were not significantly different than the present abundance of fishes and number of species. Results of the fry collection sampling efforts were not productive because of the temporal and spatial distribution of the fry, and thus, the collection methods used were not appropriate for the current statistical methods.

A sophisticated series of observations and statistical analyses was conducted as part of the ongoing monitoring at Nysted (Leonhard et al., 2006). The hydroacoustic studies achieved higher resolution with increased observations, and the statistical tests were rigorous. The outcomes of the monitoring studies showed no significant differences inside and outside the wind park except for the impact of the foundation structure. A significant new fish community had become established in the area of the foundations, and the fishes were spatially distributed in relationship to the current flows around the foundations and pylons. Day-night differences also were obvious. The presence of the new fish community at the base of the monopiles was interpreted as an indication that the fishes became habituated to the wind turbine sound (Elsam Engineering and Energi E2, 2005).

The role of the monopile as a type of unique habitat with its fouling community becomes attractive for certain species of fishes (Rilov and Benayahu, 2000, 2002). The monopiles and scour protection have been investigated as an artificial reef effect at the Horns Rev site (Bio/Consult, 2002). The studies showed that the total abundance of fish was significantly greater on the turbine pilings than on the seabed from 1 to 5 m and 20 m away. In addition, no fishes were recorded in the survey of the water column in the control sites more than 1 m above the bottom. Diversity and species richness were significantly lower on the turbine monopiles than in the control areas. This outcome is consistent with the findings of habitat alteration in relation to oil and gas platforms in the Gulf of Mexico and the Pacific Coast. The small footprint of the structures relative to the surrounding area creates a totally new habitat with a new fish community. The fish community structure (abundance, biomass, species diversity, and turnover) as measured with different statistical techniques is modified. Whether the results are a positive or negative attribute is a function of the objective of the viewer (Reggio, 1989; Rigs-to-Reefs, 2000).

There were dramatic increases in the biomass of the epibenthos within two years after construction (eight times higher than baseline), which provides habitat and some prey for fishes for the foundation and scour structures at Horns Rev (Dong Energy and Vattenfall, 2006). Monitoring results from 2004 showed the epifauna biomass on the foundations and scour-protection structures to be approximately 60 times higher than the surrounding soft seabed biomass. This is interpreted to mean higher food availability for fishes. Comparisons of fish communities inside wind parks with those of wrecks in other parts of the North Sea were not significantly different.

Hydroacoustic data makes it possible to analyze diurnal activity data, and the data showed markedly higher fish activity at night, that fishes were attracted to the site from afar, and that larger fishes were associated with coarse sand and gravel substrates. The 2005 monitoring by hydroacoustics continued to be productive, and the results from inside and outside the wind park showed no significant differences for temporal or spatial distribution of fishes or diurnal variation. No statistical difference existed in the densities of pelagic and semipelagic fishes from near the turbines and between the turbines. The conclusion from the fish monitoring data is that there were no significant effects on the fish communities at the scale of the wind park or the local scale from around the foundations. There was high variability in the biotic and abiotic factors that influence fish communities. It is extremely difficult to achieve statistically valid replicates and geographical reference areas.

Rilov and Benayahu (1998) stated there was a need for “long-term monitoring of both wind parks to provide an appreciation of how the communities will develop and contribute to the ecology of the area, so providing a long-term dataset against which other wind farm developments can be judged.” The authors were particularly concerned about the cumulative effects of introduction of hard scour protection structures with future expansions that may increase populations of mobile species attracted to these habitats. There could be both positive effects in terms of increases in commercial species and negative effects from a feeding halo around the foundations. “Data collected shows that whilst some changes in infaunal biology and sediment characteristics have taken place these do not seem to be focused within either wind farm area.” Fish are intimately entwined with the changes in infaunal biology and sediments because sediments are the source of food and spawning habitat for many of them.

Monitoring data from North Hoyle, United Kingdom, are very limited (Npower Renewables, 2005). Researchers conducted a beam trawl sampling effort, but it had very low catches before construction, so there were no comparable pre- and postconstruction survey data on the fish community. The researchers were dependent on agency data and sampling for assessment of fishery impacts.

Wilhelmsson, Malm, and Ohman (2006) studied the influence of offshore wind parks on demersal fishes in the central Baltic Sea off Sweden. They found higher fish abundance but similar species richness and diversity in the vicinity of the turbines compared to surrounding areas. However, the small demersal fish community on the monopiles was different, with higher fish abundance and lower species richness and diversity, indicating that the wind park did function as FADs through habitat alteration.

5.1.4.3 Current Models Used to Determine Fishery Resource Impacts

There are several different approaches to conducting an environmental assessment of impacts to fishes at wind parks in Europe. Some assessment methods for fishery resources such as that for the Lynn offshore wind park (AMEC, 2002) are very comprehensive. The methods call for an assessment of the site in terms of importance of the fisheries resource perspective, which is accomplished with consultation responses from a variety of experts. That is followed by a complete analysis of the fish community from a biologic perspective addressing the following areas of literature:

- Spawning and nursery grounds
- Migratory pathways
- Status of protection or rarity
- Importance as prey for highly valued commercial species such as cod

- Landings
- Abundance estimates and other conventional fishery data
- Sensitivity of fishes to changes in water quality from literature values

Maps are developed of the habitats and location of fishing activity and expressed on local, regional, and national scales. Fishery resources depend heavily on fishing activity, which must be considered in an assessment. The assembled information is then put into a decisionmaking structure that considers the resource as it is impacted by the negative effect of fish emigration caused by the following factors:

- Disturbance from sound and EMF
- Direct loss of habitat
- Indirect effect of sediment redistribution
- Assumed positive effect of creation of new habitat
- Changes in fishing activity

One of the most difficult aspects of assessments is the necessity of analyzing the findings in a spatial and temporal way, and it is critical to do so for fishery resources. A detailed recommendation for sampling methodologies for fishes that integrates the assessment process with the baseline surveys and construction and operations monitoring programs is developed in a report, “Standards for Environmental Impact Assessments of Offshore Wind Turbines in the Marine Environment” (Beurskens and de Noord, 2003). The report constitutes a framework for thematic and technical minimum requirements for marine environmental surveys and monitoring to assess compliance with regulatory requirements. It is based upon extensive experience gained from monitoring programs in the North Sea and northeast Atlantic by different government agencies working under inter-governmental conventions. The Standards for Environmental Impact Assessments have been developed from practice and consultation with operational and outside experts. Although the report is specific to northwestern European marine environments, the principles are relevant for the United States and is a useful document for review and consideration of the framework as a template that can be modified and adapted on a regionally specific basis. The approach emphasizes the absolute need for coherence and continuity for quality of an assessment and monitoring.

In a similar approach, CEFAS (2004) prepared a thorough guidance document that gives detailed methods to develop an assessment document for fishery resources that will withstand critical examination. The assessment also must consider the ability of the fish community to recover from the disturbances of construction. For many of these factors, there are no existing data, and much of the data that does exist are not independent or quantitative. Expert knowledge is incorporated in the process. CEFAS (2004) guidelines emphasize that “Fishery issues must be addressed from the perspective of the user groups; commercial and recreational fishers”. The concerns of environmental and conservation groups will also be important. Evaluation of the biology and ecology of the fishery resources now requires documentation and analysis on an ecosystem basis. Special attention must be paid species such as the Snapper-Grouper complex in the South Atlantic and Gulf of Mexico, the rockfish of the Pacific coast, and species of conservation importance. Each project has certain site specificity and must evaluate the relative importance of the area to the region as a whole. Because there is considerable information in different agency documents, those materials should be rigorously reviewed prior to initiation of field studies. With that in hand, it will be possible to design sampling programs to validate existing information and fill the identified needs. The data collection and analysis programs must include the following:

> What fishery resources are present at the site and surrounding area and what are their characteristics?
>
> > Which are of commercial and recreational importance?
> > Which are of conservation interest?
> > What other species are locally abundant?
>
> For those of commercial and recreational importance:
>
> > Where are their spawning grounds?
> > Are there local spawning and nursery grounds?
> > Are there local feeding grounds?
> > Are there migratory pathways that pass through the area?
>
> For those of conservation importance:
>
> > Are they present in the area, and if so, how abundant are they?
> > Is the area critical habitat for them?
> > Where are their spawning grounds?
> > Are there local spawning and nursery grounds?
> > Are there local feeding grounds?
> > Are there migratory pathways that pass through the area?

Even though the sites are offshore, there will be nearshore impacts and those need to be evaluated as a part of the total analysis. Many of the commercially and recreationally important species (the estimate is as much as 75%) of the species of the southeastern United States and Gulf of Mexico are dependent upon estuarine systems for a portion of their life cycle. Therefore any impact on the quality of those systems must be comprehensively addressed.

The results of all of the assessments above reach the general conclusion that the impacts of the wind park are negligible or minor. Permanent habitat changes from displacement caused by construction of foundations and scour protection are evaluated as minor and local because of the size of the impact footprint, which is less than 1 percent of a wind park. In addition, the present sites are almost all in shallow water with sandy sediments, and studies have shown they recover quickly. Fishes are very opportunistic when it concerns prey; the fishes will return when the prey returns.

5.1.4.4 Mitigation Measures Used at Existing Wind Parks—Fishery Resources

Mitigation measures typically are identified for wind park projects in scoping papers and refined in the design process. The measures are further clarified in the environmental assessments. The activities can be viewed as best management practices; they do not include fish-specific mitigation alternatives. Mitigation measures typically proposed at wind parks are listed below:

- Use air curtains and sound generators to move fishes beyond lethal range during pile driving.

- Use soft starts for pile driving equipment.
- Develop a specific plan to avoid onsite in-water construction during the spawning period of a priority species of fish.
- Use a jet plow for cable installation.
- Bury inner-array cables a minimum of 1 to 2 m.
- Develop a monitoring plan for fishery resources.
- Place no restrictions on fishing activities in the wind park site.

This list of mitigation activities for fish resources is not intended as a complete list of possible measures for all wind parks. By their very nature, mitigation measures must be developed by stakeholders in the specific site of the proposed activity, and thus, they address site-specific needs.

5.1.4.5 Information Needs–Fishery Resources

Baseline Studies

The most critical need for evaluation of the impact of wind parks on fishes is site-specific information on the fish community and its habitat. Fishery habitat maps that show spatially recognizable areas where the physical, chemical, and biologic environment is distinctly different from surrounding environments provide important data for regional assessments of areas for potential development of offshore alternative energy technologies, site-specific assessments, and determination of potential cumulative impacts. Habitat maps are essential in the design of surveys to ensure that wind park operators address all habitat types in the area, use proper methodology to characterize the resources, and reference baseline conditions for a monitoring program.

Fishes are absolutely dependent on benthic habitat, which is why the South Atlantic FMC (SAFMC) is establishing MPAs for the deepwater snapper and grouper community (SAFMC, 2007a). It helps to understand the issues of MPAs (NRC, 2001) in considering impacts of wind parks on fishes. The interaction of sediments and fisheries is presented in Auster and Langton (1998) and Langton and Auster (1999) in critical analyses of the literature and extensive discussion of the implications. The researchers found that groundfish, flatfish, and cod, for example, depend on the benthos for shelter and sustenance, and feedback loops inevitably exist between predators and prey. The information needs identified for benthos and the information developed to address those needs are also critical for fishes. Much more work needs to be done to develop models that will aid in complex analyses for fishes and benthos, as demonstrated by Auster, Joy, and Valentine (2001). The U.S. Geological Survey, Coastal and Marine Geology Program has been coordinating among NOAA, the regional FMCs, and states on the National Benthic Habitat Mapping Program to develop regional benthic habitat classification protocols. These groups have started work on regional pilot areas but this effort needs expansion. Example project descriptions can be seen online at http://walrus.wr.usgs.gov/research/projects/nearshorehab.html for the Pacific region, http://woodshole.er.usgs.gov/project-pages/stellwagen/ for the Atlantic region, and http://coastal.er.usgs.gov/flash/ for the Florida Shelf Habitat (FlaSH) map project. Areas targeted for offshore alternative energy facilities should be mapped as part of these regional programs.

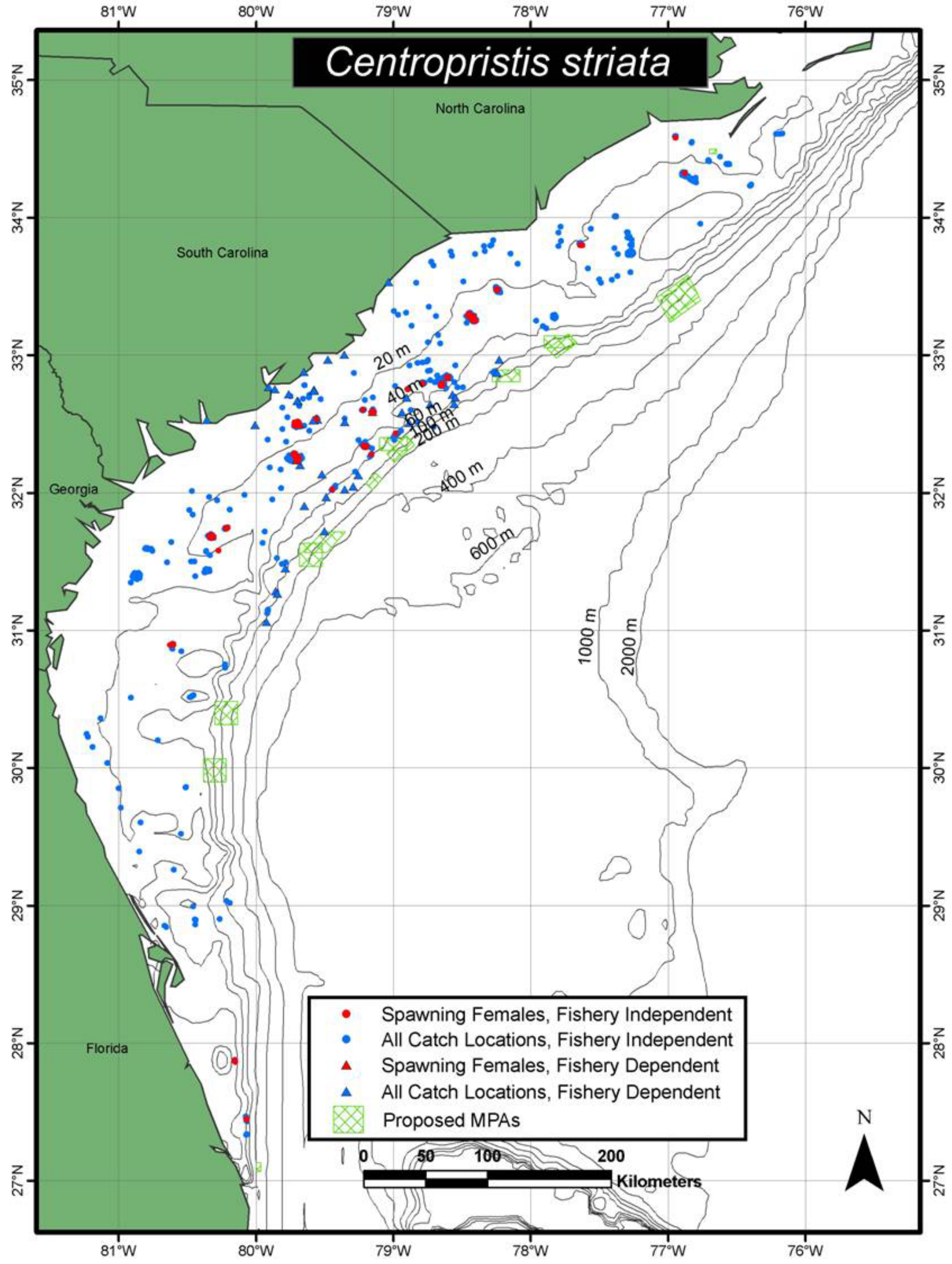
A significant amount of background information on fishery resources is available in the files of federal and state agencies that have responsibilities for managing the resources. Fishes do not recognize geopolitical boundaries, which means different organizations must work together such as State fishery agencies, interjurisdictional marine fisheries commissions, line offices of the National Oceanic and Atmospheric Administration (NOAA) and particularly the National Marine Fisheries Service, and the Department of the Interior. The Regional Fishery Management Councils (FMC) are responsible for managing U.S. Exclusive Economic Zone (EEZ) fishery resources, and the National Marine Fisheries Service is the implementing entity with enforcement of regulations at sea by the Coast Guard and State enforcement units. The FMCs were created and operate under the authority of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (Magnuson-Stevens, 2007). Each management plan has a requirement for the FMCs to consider the role of the fishery in a total economic sense, which means the FMCs must pay attention to the people who depend on fishery resources as well as the numbers of fishes. The South Atlantic FMC (SAFMC, 2005) has a policy that addresses energy development projects. This issue has been addressed in the developing wind park plans of the United Kingdom by McTaggart et al. (2006).

The councils manage the resources regionally, and each plan has a rigorously reviewed habitat component, economic analysis, and a research needs section. Details of species managed and areas of jurisdiction are available on each council's Web site. As an example, the fishery resources information available from a council can be found at SAFMC.net and specifically in the records of the SAFMC Habitat Plan and Actions (2007b), the Snapper–Grouper Plan and Actions (2007c), and amendments in the record on the process for site selection for the Marine Protected Areas (MPAs) under consideration by the South Atlantic FMC off the states of North Carolina, South Carolina, Georgia, and the east coast of Florida (Amendment 14) (SAFMC, 2007a). A map of habitats for species is found at the South Atlantic Fishery Management Council Web site (SAFMC.net under GIS mapping systems). A good example is the habitat map for the black sea bass off the coast of South Carolina as shown in Figure 5-8.

Similarly, information is abundant on Gulf of Mexico fishery resources, particularly the resources interaction with oil and gas platforms (Patterson et al., 2004). The platform structures can be considered as analogous to the monopiles for wind generators, although platforms have more surface area than a monopile. Also, MMS supports numerous studies (Dauterive, 2000; Avent, 2004; McKay, Nides, and Vigil, 2000; Wilson, Pierce, and Miller, 2003; Wilson, 2006; Peabody and Wilson, 2006).

MMS also supports extensive fishery resources studies for the West Coast. The research and data needs for that group of fishes are found in a report in the Groundfish Plan by the Pacific Fisheries Management Council (Pacific FMC, 2007). One of the most pressing needs is life history information, which is missing for most fish in the U.S. EEZ. Lacking such information, it is difficult for managers to develop management plans based on scientific information.

Demersal fish communities have been characterized as part of the site-specific studies on existing conditions for the Atlantic and Gulf Coast States undertaken by the MMS Marine Minerals Program concerning offshore sand mining and dredging (most of these studies are available online at http://www.mms.gov/). Analyses of the demersal fish abundances and benthic characterizations completed within these studies may be of particular relevance to alternative energy projects being developed on or nearby these sites.



Source: South Atlantic Fishery Management Council.

Figure 5-8: Habitat map for black sea bass as prepared by the South Atlantic Fishery Management Council.

In contrast with the European experience, the U.S. EEZ has great physical and biologic diversity. Contrasting the range in oceanic depths and benthic substrates illustrates how complex the ecosystems are that must be considered for each project. In addition to the physical and biologic environment, a major issue that wind park projects must consider is that marine resources management in the United States is fundamentally different than it is in Europe. Fishery resources in the U.S. EEZ are now managed on an ecosystem basis under the Magnuson-Stevens Act, and single-species management and solutions proposed for single species of great economic interest are not the sole driving force for decisionmaking purposes. Ignoring that fact will lead to great frustration and time delays.

It is obvious that each site will require standard baseline monitoring of the fish community; however, because of the range of habitats, each site will require some special methods to accomplish the objective. The biggest deficiency in the studies reviewed is that the baseline survey was too limited spatially and temporally. That must be addressed in a comprehensive manner to cover diurnal and seasonal changes in the fish populations. Existing data sets of fish community and population that will fulfill the needs for an impact assessment are uncommon.

New methodologies for impact assessment need to be developed. Marine fisheries are now going to be managed on an ecosystem basis (Magnuson-Stevens, 2007) and simple listings of species presence or absence will not be sufficient. The literature on ecosystem-based fishery management is rich and growing (Babcock and Pikitch, 2004; de la Mare, 2005; Guerry, 2005; Arkema et al., 2006; Frid, 2006). At present, most of the material is hypothetical and theoretical, and it is being implemented as a management tool on a limited basis. The United States is not alone in this effort (Fluharty and Cyr, 2001). Australia is moving from theory to practice (Scandol, 2006; Fletcher, 2006). A critical aspect for this approach is the integration of ecology with socio-economic methods (Sumaila, 2005; Browman and Stergiou, 2004). Canada is moving very quickly to the implementation phase (O'Boyle, 2005; O'Boyle and Jamieson, 2006; Guenette and Alder, 2007). New methods need to be developed for full utilization to occur (Kauman et al. 2004; Steele, 2006). Several RFMCs have studies underway to determine feasibility (SAFMC, 2007d,e). Impact assessment using a before-after control-impact (BACI) model was proposed by Smith, Orvos, and Cairns (1993). The technique has potential for use in wind park analyses but its application has been extremely limited in the U.S. EEZ (Stokesbury and Harris, 2006). Blyth et al. (2002, 2004) show approaches to the issue of spatial allocation for fishery resources.

Impact Assessment Studies

Information needs to support better impact assessments are listed below in the four main topics of potential impacts:

Sound and Vibration

Sound and vibration potentially can have a negative impact on certain fishes. Hastings and Popper (2005; Fig. 9) provide specific and detailed research topics that consider need addressing along with a very understandable flow chart of possible impacts. Sound impacts are also perceived by the fishing community and public as negative impacts, whether that is or is not correct. Studies for the following issues addressing sound and vibration impacts on fishes from offshore wind parks would improve the ability to assess impacts:

- Representative or surrogate species for different regions should be selected for criteria development and testing because it is not feasible to do so for all species. Knowledgeable experts (RFMC staff and advisory committee members) can recommend which representative and surrogate species are appropriate for different regions.
- There are no current standards for sound levels that result in the onset of injury to fishes. Studies should determine a dose and response level for pile driving sounds including lethal and sublethal effects (behavior, damaged sound reception) on representative fish species.

- Laboratory experiments would provide the basis for developing a model to evaluate sound perception capabilities and impacts to fishes of field exposures to sound levels. The experiments should include observations of behavior of fishes in cages (cages at different distances from source) and non-restrained fishes subjected to pile driving sound.
- The effectiveness of techniques to reduce the risk of injury to fishes during pile driving in the OCS such as the air curtain technique or slow starts (level of sound and time frames) to drive fishes away from the site (Popper and Carlson, 1998) should be evaluated. Based upon the results, performance criteria could be developed.
- Because different substrates modify the character of underwater sound, the characteristics of underwater sound fields for different sites needs definition.
- The mathematical models of Hastings and Popper (2005) to estimate the potential for fish mortality from sound should be further evaluated.

EMF

- It is necessary to conduct laboratory and field studies on electroreception and the behavioral responses of fishes, particularly the elasmobranches of that region to electrical fields and magnetic fields typically generated by transmission cables from wind parks.

Introduction of Hard Substrates and Changes in Fishing Activities

These two potential impacts are discussed together because they are very inter-related. It is clear from all the European work that offshore wind park structures will function as artificial reefs and fish aggregation devices, and as such, projects will need specific management strategies. A possibility is to consider them as MPAs (Schroeder and Love, 2002). The concept has been applied principally to sedentary reef fisheries in the tropics. Proponents claim that they can result in increased diversity of fish species, and greater abundance of both larger and smaller fish of a given species. Fishing interests often fear that catches will substantially reduce due to exclusion. The applicability of observed benefits in tropical areas to northern European temperate seas needs careful consideration. Particular impacts will be case specific and depend upon the proportion of stock maintained within the boundaries of the MPA, the biological characteristics of fish, their spatial distribution, the level of fishing effort employed and the relative catchability of fish outside of the MPA, and the other fisheries management systems that exist (Hooker and Gerber, 2004). In general, many commercial species such as mackerel, cod, and herring are highly migratory and unlikely to benefit from MPAs, unless they covered large expanses of their migratory ranges. On the other hand, more sedentary and sessile species such as lobsters, oysters, and mussel populations could benefit from even small protected areas (Hart et al., 2004). In order to benefit a fishery, however, a build up of spawning biomass needs to occur within the MPA that results in spill-over effects beyond the MPA boundaries. This effect has yet to be conclusively demonstrated, but in cases where it does occur, it opens up the prospect for more relaxed regulations outside of MPAs (Horwood et al., 1998). In the case of offshore wind parks, their size would imply that any exclusion zones would represent relatively small MPAs. It is unlikely that most sites would coincide with those most suited as MPAs from a fisheries management perspective, though that does not mean they could not have fisheries benefits. Although bottom trawling or dredging could be prevented, for example, the elimination of seabed damage from these practices could offer opportunities for other types of fishing, such as enhancing shellfish stocks (Stokesbury and Harris, 2006). Furthermore, artificial reefs created by turbine foundations could add further enhancement to fisheries and may be viewed as a trade off for having fishing exclusions (Schroeder and Love, 2002). What is clear is that, as in the case of MPAs in general, any potential benefits or disadvantages to fisheries from the imposition of exclusion zones around offshore wind parks need to be examined on a case-by-case basis.

One of the most critical issues for the management of MPAs is that of enforcement. Unless there is rigorous and vigorous enforcement, the public does not support MPAs. The Oculina Banks Habitat Area of Particular Concern and Tortugas Marine Sanctuary show how critical enforcement is and that vessel-monitoring systems are the most powerful and cost-effective enforcement tool. The establishment of an offshore wind park as a marine reserve (no-take area) with a well-funded program of research could be an excellent mitigation activity and have some probability of support by the fishing public and enhancement of marine resources.

Specific studies to address these issues are outlined below.

- There is a lack of region specific knowledge of the consequences of the introduction of artificial hard substrates on fishery resources. Such information is necessary to assess fishery sustainability and energy flow. There is a lack of understanding how individual foundations interact with each other, as well as on a larger scale and with the fisheries communities.
- Techniques for pre-and postconstruction monitoring of fish communities and fishing activities must be statistically rigorous and based upon the characteristics of the fish community of the site.
- Models and methods to evaluate management of alternative offshore energy park sites as fishery resource enhancement areas require development and testing.

5.1.5 Marine Mammals

5.1.5.1 Potential Impacts of Wind Technologies—Marine Mammals

Cetaceans (dolphins, whales, and porpoise) and pinnipeds (seals) are potentially at risk from activities involved in the development of an offshore wind park in OCS waters. Marine mammals use the OCS for foraging, breeding, calving, nursing, resting, and migration. Sea otter and manatee are found in nearshore waters and, therefore, would not likely be directly affected by the offshore wind park structures. However, activities associated with the construction and maintenance operations at an offshore wind park could increase the risks of impacts in areas where sea otters and manatees are found.

A number of potential impacts are addressed in this report. Of these, two are predominant: (1) direct effect of vessel collisions (e.g., construction related as well as service vessels), and (2) direct as well as indirect effects of noise (principally construction related, but also perhaps operational). Potential impacts to marine mammals from offshore wind parks are summarized in table 5-6 for the construction (includes seismic surveys) and operational phases of offshore wind parks. The construction of an offshore wind park is a short-term event (months to a year) relative to the operational phase of a wind park (years), and each phase has a different set of activities.

The following paragraphs, organized according to construction and operation phases, briefly describe each impact. The construction phase is divided into three main impact categories:

Table 5-6: Potential impacts of wind technology on OCS marine mammals.

Construction Phase	Potential Impacts—Marine Mammals
Construction Vessels	Masking of sounds, behavioral changes, and displacement from noise Increased risk of collision
Seismic Surveys	High intensity noise that may cause behavioral changes, displacement, temporary/permanent hearing threshold shifts, physical impairment, mortality
Foundation Installation	
Pile Driving	Impulse noises that may cause behavioral changes, displacement, temporary/permanent hearing threshold shifts, physical impairment, mortality
Foundation Installation	Prey displacement, increased turbidity
Scour Protection	Habitat alteration, increased turbidity, noise and vibration
Dredged Materials Disposal	NA
Cable Laying	NA
Trenching	Habitat alteration during cable laying
Anchoring	Entanglement
Operations Phase	**Potential Impacts—Marine Mammals**
Turbine Towers	Continual noise and vibration transmitted through water and seafloor causing masking of sounds, behavioral changes, and displacement
Turbine Foundations and Scour Protection	Changes in prey due to habitat alteration, introduction of artificial hard substrate
Cables	Electromagnetic field induced orientation issues for some marine mammals
Service Vessels	Behavioral changes, displacement, masking of sounds, entanglement, and collision due to increased vessel traffic

(1) increased vessel activity, (2) impulse noise, and (3) habitat alteration. The operational phase is divided into four main categories: (1) continual operation noise and vibration, (2) physical presence of structures, (3) electromagnetic fields (EMF), and (4) increased vessel activity.

Of all the impacts discussed in the literature, noise is considered to be the most critical because the complexities of submarine sound make it difficult to study or model. Furthermore, noise may affect marine mammals in various ways including behavioral changes, masking of sounds, temporary or permanent hearing threshold shifts, and even death. Direct potential impact from vessel traffic and vessel collision likewise is a priority consideration.

Construction Phase–Increased Vessel Activity

Vessel activity in the location of a proposed wind park will increase during the construction phase. Increased vessel activity has the potential to affect marine mammals through an increase in noise level, visual impacts, and collisions with fast-moving boats.

Disturbance of marine mammals by boats may be caused by noise from the boat or by visual cues; it is difficult to differentiate between the two in animal studies (Richardson et al., 1995). Pinnipeds may react more strongly to visual cues, as reported in several studies that show harbor seals moving into the water as boats approach their haul-out sites. Because some of the boats had engines and others did not, it appeared that the visual sense of the boat was the cause of the avoidance reaction rather than the noise (Nedwell and Howell, 2004). The reaction of baleen whales to vessel noise included changes in swimming direction and speed, blow rate, and the type of vocalizations that were produced (Richardson et al., 1995). Baleen whales may approach slow-moving or stationary boats, but the most common reaction is avoidance, especially when the vessel is approaching the animal or the noise from the vessel changes quickly. A 25-year study on whales showed that right whales consistently were uninterested or had a negative reaction to vessels, whereas minke and finback whales changed from a positive and negative reaction, respectively, to over time becoming uninterested (Watkins, 1986). Buckstaff (2004) observed an increase in whistles by bottlenose dolphin with the approach of a vessel in Sarasota, FL, as opposed to the whistling observed after the vessel had approached. The author suggests that an increase in whistling indicates a heightened awareness and desire for the animals to come together, or it is a method used to compensate for signal masking.

Manatees may leave preferred habitats or alter behaviors such as feeding, suckling, or resting, when disturbed by vessel activities (O’Shea, 1995; Wright et al., 1995). The disturbance is likely the result of the noise created by the vessel (Mann et al., 2005). The results of Nowacek et al. (2004) indicate that manatees can detect oncoming vessels and respond to approaching vessels with a flight response. Manatees were observed moving towards deeper waters with the approach of vessels (Nowacek et al., 2004). Sea otters may tolerate vessels within close range; however, they tend to avoid areas of heavy disturbance and return to areas once vessel activity has decreased (MMS, 2007).

Increased vessel activity, as well as other sources of sound (e.g., continuous wind turbine operation) can cause masking of sounds for marine mammals, as well as disturbance and habitat displacement. Masking occurs when another noise of the same frequency is produced and consequently “masks” or interferes with an animal hearing or receiving a biologically significant noise. A noise-induced disturbance or masking of important biological sounds may have the potential to disrupt breeding, locating prey, caring for young, or migration. Underwater anthropogenic activities normally generate low-frequency sound; therefore, the baleen whales and some toothed whales (e.g., sperm whales) may be subject to masking more so than animals that produce and receive high frequency sounds. Very few studies have been conducted on the masking capabilities of anthropogenic noises on marine mammals (Foote et al., 2004; Lesage et al., 1999; Southall et al., 2000), so the magnitude of the impacts is not known.

Increased collision with marine mammals is of concern when an increase in vessels is expected to occur. The Cape Wind draft environmental impact statement (DEIS) stated that an additional 504 round-trip vessel trips per year needed for the construction and operation of the Massachusetts wind park would cause a 4 percent increase in traffic (Jarvis, 2005). Unfortunately, there is no correlation between the number of vessels and the number of marine mammals in a given area, thus the risk of increased collisions cannot be estimated. Collisions with vessels are the leading anthropogenic cause of mortality for the North Atlantic right whale (NOAA Fisheries, 2007) and the Florida manatee (Ackerman et al., 1995; Wright et al., 1995), both federally endangered species. If right whales or manatees are present in or near a given area where vessel traffic increases, vessel collisions will likely be a priority issue. Knowlton and Brown (2007) provide a comprehensive and useful description of the issue of vessel collisions and right whales. Further information on manatees and vessel interactions is provided by O’Shea (1995), Nowacek et al. (2004), and Wright et al. (1995).

It is unlikely sea otters will be impacted by increased vessel traffic in relation to offshore wind parks. Accidental collisions with vessels do occur but mainly with nearshore recreational boaters (L. Carswell, pers. comm., 2007; MMS, 2007). The mobility of the sea otter allows the animal to avoid the majority of oncoming boat traffic (MMS, 2007).

Construction Phase–Impulse Noise

Seismic surveys during the preconstruction phase and pile driving during construction are the two loudest noises produced (Burbo Offshore Wind Farm, 2002a) and are expected to have the most significant impact to marine mammals. Before construction of an offshore wind park begins, different types of surveys are used to obtain data on the geology of the ocean floor and identify potential cultural resources. Site characterization of the ocean floor is accomplished using tools such as a magnetometer, side-scan sonar, and sub-bottom profiling devices (e.g., “chirp” and “boomer”). The equipment for each activity is towed behind a vessel in the area of interest to collect data from the seafloor through acoustic signals (e.g., sub-bottom profiling devices, side-scan sonar) or by recording changes in the magnetic field (e.g., magnetometer). Equipment that uses acoustic signals may have an effect on marine mammals. NMFS (Federal Register Vol. 68 No. 71 April 14, 2003) has established conservative distances for marine mammal safety around seismic surveys based on sound pressure levels that animals receive during the activity. NMFS provides guidelines to protect marine mammals from temporary or permanent hearing damage by requiring that sound pressure levels do not exceed 180 decibels (dB) for cetaceans and 190 dB for pinnipeds.

When monopiles are used as the turbine foundations, they are installed using a pile driver (Madsen et al., 2006) at 1-second (s) intervals. It may take several hours of pile driving to construct one monopile foundation (Madsen et al., 2006), and this activity may take from 3 to 4 months for an entire wind park (Nedwell and Howell, 2004), depending on size and location. Pile driving is of great concern to the scientific community studying the effects of noise on marine mammals because of the intense sound it produces.

The NRC (2003) lists several factors that play a role in the response of a marine mammal to a specific sound:

- Sound level and the properties of the sound
- Physical and behavioral state of the animal
- Ecological features and acoustic capabilities of the environment

To understand the impacts of impulse noises on marine mammals, it is important to discuss what is known about the hearing capabilities of different species or groups of animals.

Marine mammals have anatomical and physical adaptations that allow them to hear underwater. They use hearing as their primary sense, producing and receiving sound over a great range of frequencies for communication, foraging, and orientation (NRC, 2003). Cetacean and pinniped vocalizations overall cover a wide range of frequencies, from 10 hertz (Hz) to 200 kHz (NRC, 2003). The absolute hearing range and sensitivity among different species varies widely, and even varies among individuals of the same species. Baleen whales tend to produce sounds at low frequencies, mainly between 15 Hz and 20 kHz (NRC, 2003). Whales produce powerful low-frequency, long-duration calls that are thought to travel over long distances (Madsen et al., 2006).

Although no actual data have been collected on hearing in larger species such as blue, fin, and bowhead whales, functional models predict that these animals are capable of receiving sounds in this lower range as well. Odontocetes (dolphins, porpoise, and toothed whales) produce species-specific broadband click sounds between 10,000 and 200,000 Hz during echolocation and whistle sounds for communication (Department of the Navy, 2003). Thus, odontocetes have been shown to have higher frequency hearing compared to the large baleen whales which have a hearing range between 200 and 100,000 Hz (NRC, 2003). Some of toothed whales such as the sperm whale produce only clicks, which may be used for both communication and echolocation (NRC, 2003). Manatees were found to have best hearing sensitivities between 10,000 Hz and 20,000 Hz (Gerstein et al., 1999).

Pinnipeds have ear structures that allow them to hear above and below water. Their amphibious lifestyle allows them to hear moderately well in both habitats, and pinnipeds are most sensitive to sounds received between 1,000 and 20,000 Hz (NRC, 2003).

In summary, baleen whales and pinnipeds are more sensitive to low- and mid-frequency sounds, while manatees, dolphins and other toothed whales tend to be more sensitive to high-frequency sounds. No data could be found on hearing capabilities or sensitivities for sea otters.

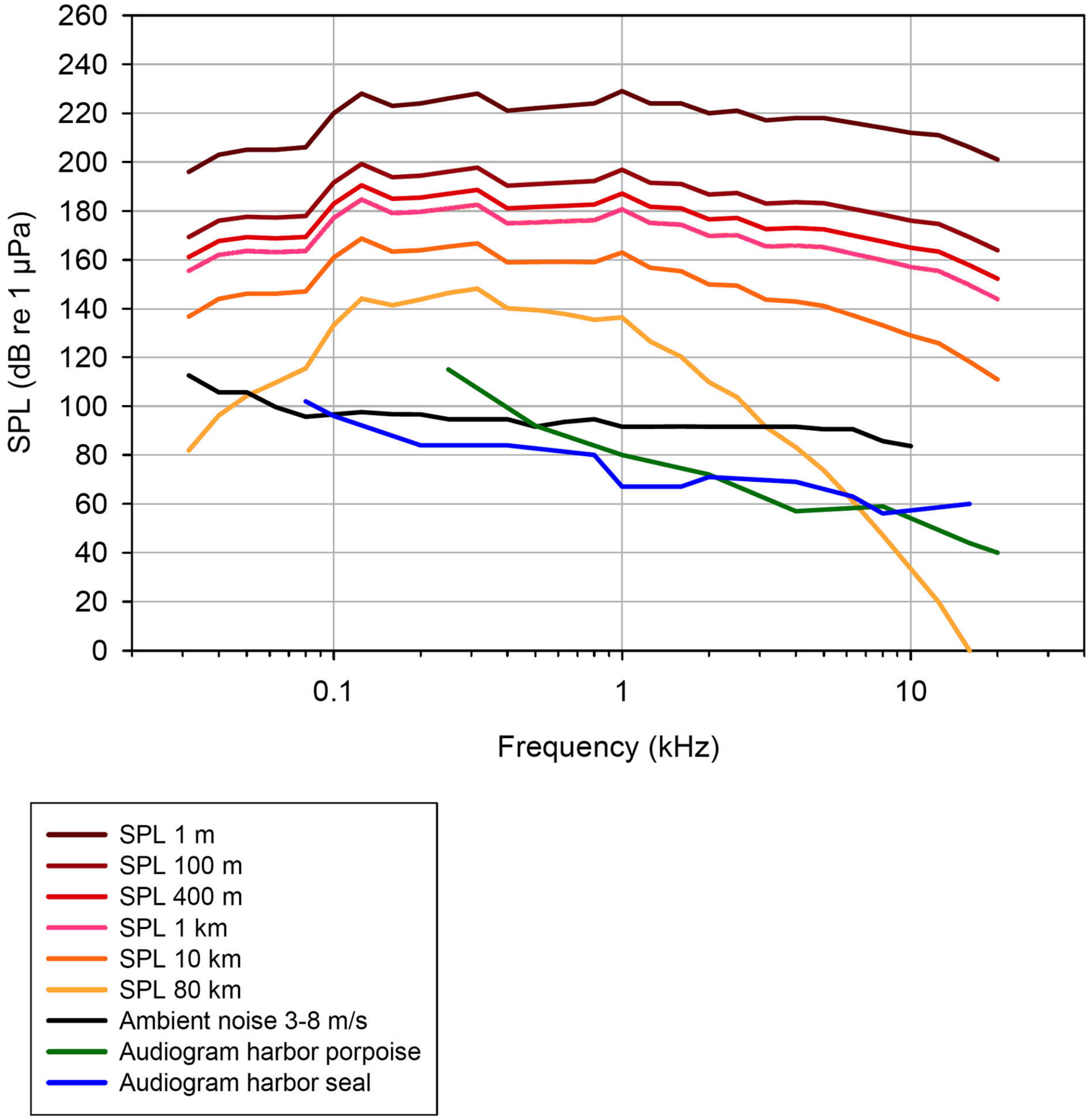
To determine the level of impact on marine mammals, the level of sound as a result of the activity must be measured. The perception of sound is based on two properties: frequency and sound level (or pressure). Frequency is the number of vibrations or pressure fluctuations per second, measured in Hz. The most common measure of sound is the sound pressure level (SPL) measured in decibels referenced to 1 microPascal (dB re 1 µPa), which is based on the average pressure over a short period of time. The San Francisco Public Utilities Commission (2006) measured SPLs of subbottom profilers operating at 350 joules at 204 dB re 1 µPa-m root mean square (rms) with a frequency between 750 and 3,500 Hz. Burgess and Lawson (2000) measured sounds traveling horizontally from a subbottom profiler at 205 dB re 1 µPa-m rms during a survey in Alaska. At 20 m and 8 m from the source, the SPLs were reduced to 160 and 180 dB re 1 µPa-m rms. Sidescan sonar has been measured between 200 and 225 dB re 1 µPa-m rms with a frequency of 100 kHz -500 kHz (NMFS, 2002, 2003b).

There are currently no studies on the effects of the sound from sub-bottom profilers on pinnipeds and cetaceans. Subbottom profilers used during preconstruction of offshore wind parks are not expected to cause hearing impairments or physical injury as the activity has relatively low power output, low duty cycle, and there is only a brief period when an animal would be within a sonar's beam (NMFS, 2005b). In addition, the frequencies used during sub-bottom profiling do not overlap with the frequencies used by odontocetes. However, avoidance behavior or temporary displacement may occur, especially for baleen whales that are more sensitive to sounds with lower frequencies (San Francisco Public Utilities Commission, 2006). Richardson et al. (1995) observed baleen whales (gray and bowhead whales, specifically) reacting to SPLs of 160 dB re 1 µPa during seismic surveys where airguns were used. Bowhead whales showed strong avoidance reactions and a change in surfacing, respiration, and dive patterns when whales were within a few kilometers of the seismic vessel (Richardson et al., 1995). Gray whales showed little reaction to seismic exploration until explosions were within a few kilometers of a migration corridor. Then an interruption in migration was observed as well as snorkeling behavior (Richardson et al., 1995). Airguns would not be used in the shallow-water environment of the OCS, however they have comparable SPLs (210-259 dB re 1 μPa at 1 m) to other subbottom profilers and sidescan sonars.

No specific data have been collected on the effects of side-scan sonar on marine mammals; however, NMFS (2002) implemented a 30 m safety zone around side-scan sonar activities for pinnipeds and odontocetes and a 250 m safety zone for mysticetes and sperm whales for seismic surveys conducted off the coast of southern California. Odontocetes are not likely to be affected by the frequency emitted by the side-scan sonar and pinnipeds have shown various reactions when exposed to seismic surveys, ranging from avoidance to confrontation (NMFS, 2002). The San Francisco Utilities Commission (2006) stated that the anticipated impact to marine mammals as a result of seismic surveys without the use of airguns is disturbance from the brief pulse of sound that may cause temporary displacement of animals from an area. However, it is likely that animals would return to the area once the surveys were completed.

Measurements taken during pile driving recorded sound levels between 192 and 261 dB re 1 μPa, with piles ranging from 208 millimeters (mm) to 4 m in diameter (Nedwell and Howell, 2004). Richardson et al. (1995) listed sound levels for pile driving activities at <150 to 235 dB re 1 μPa. An Alaskan study on the impacts of pile driving on ringed seals showed little reaction from seals to pulses of at least 150 dB re 1 μPa (Madsen et al., 2006); however, harbor seals showed significant changes in haul-out behavior during pile driving at the Nysted wind park in the Western Baltic (Madsen et al., 2006). Seals have shown both attraction and avoidance reactions to human activities and noises; however, it is thought that seals likely will habituate to noises that occur often (Burbo Offshore Wind Farm, 2002a).

The response of marine mammals to sound levels also will depend on the proximity of the animal to the sound source. Figure 5-9 from Thomsen et al. (2006) shows the attenuation of pile-driving sound for large pile diameters at various distances from the source. These data were modeled using a transmission loss calculation (to account for the decrease in intensity as the sound travels away from the source) and ambient sound at wind speeds of 3 to 8 meters per second (m/s). The model shows that pile driving sound decreases with distance and that a reduction in amplitude and intensity occurs more quickly for higher frequencies than for lower frequencies. Thomsen et al. (2006) concluded that, based on this model, the harbor porpoise and harbor seal could detect the pile driving sound at least 80 km away from the source and possibly longer distances. There are no studies to date that analyze the reactions of whales to pile driving, but scientists expect similar reactions as to what has been observed in seismic surveys—the prominent reaction is avoidance. Pile driving may affect whales over long ranges (100 to 1,000 km) depending on the environmental conditions (Madsen et al., 2006; Thomsen et al., 2006). Low frequency sounds from activities such as pile driving will attenuate less and, therefore, could have a potential impact over a greater distance. Toothed dolphins, sensitive to the higher frequency sounds, may experience negative impacts closer to the noise source but are probably not as at risk at greater distances since the higher frequency sounds attenuate more quickly.



Source: Thomsen et al., 2006.

Figure 5-9: Attenuation of pile-driving noise at various distances from the source and the audiograms from harbor porpoise and harbor seal.

Temporary threshold shifts (TTS) occur when an animal's ability to hear after being exposed to an intense sound decreases (Nachtigall, 2004). If the noise is intense enough for an extended period of time, an animal may experience a permanent threshold shift (PTS). Data are currently available only on TTS in some cetaceans. TTS was observed in bottlenose dolphin and beluga whales using 1-second tones near 200 dB re 1 µPa (imitating sonar pings) (Schlundt et al., 2000). TTS also was seen in these same two species with brief impulses at 224 dB re 1 µPa (Finneran et al., 2002). No studies show a clear demonstration of cause and effect between intense underwater noise and PTS, physical impairment, or mortality (NRC, 2003); however, these impacts are of concern because of the lack of data currently available on the hearing abilities of marine mammals and the difficult environment in which the necessary data must be collected. Mass strandings of beaked whales have occurred after high-energy sonar events during military exercises (NRC, 2003), and some evidence suggests that high-intensity sounds may cause injury to nonauditory structures (e.g., lungs, gas-containing structures) (Finneran et al., 2002). More indepth studies would provide the basis for assessment of the full impacts of high-intensity underwater noises from anthropogenic sources.

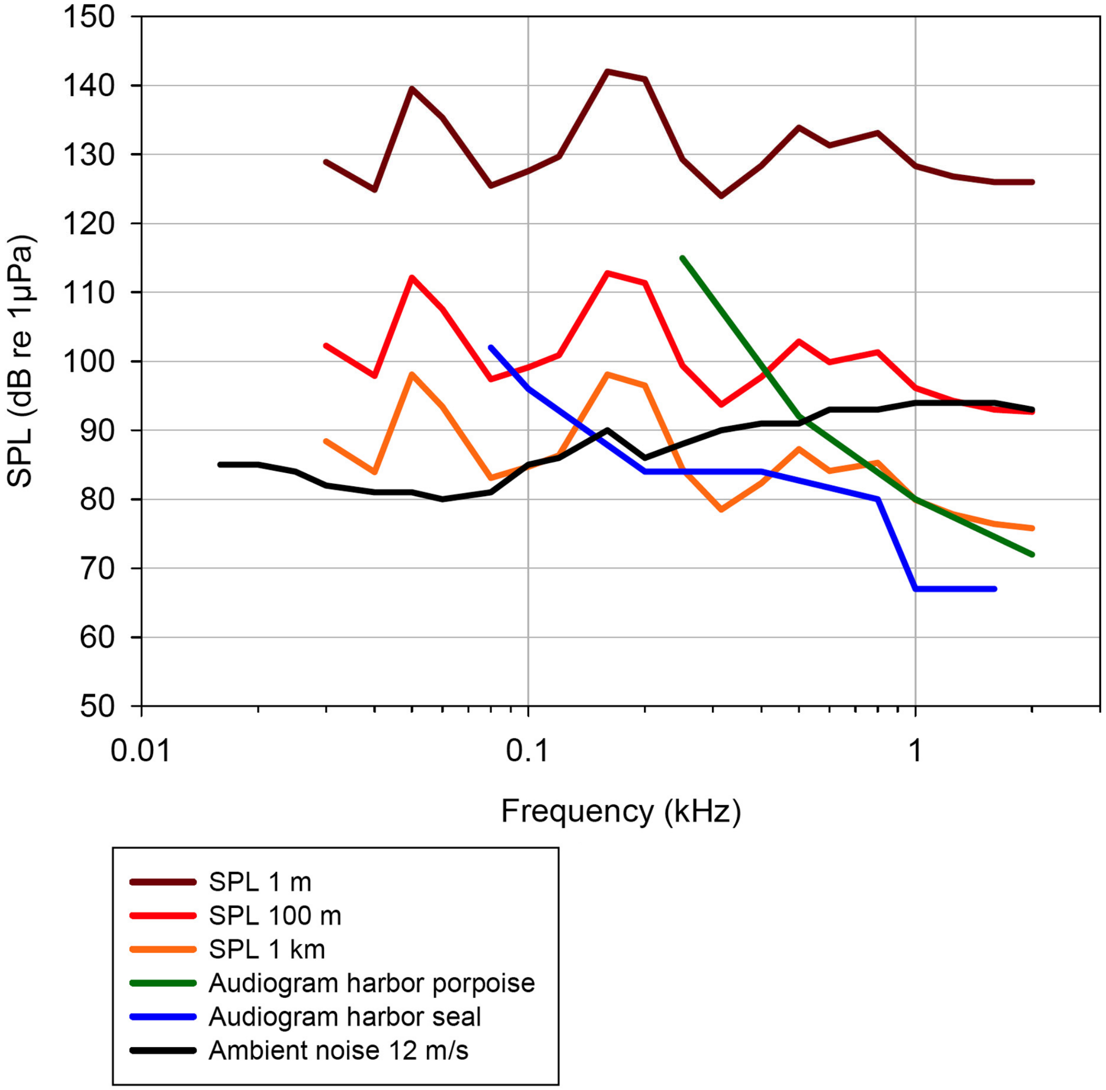
Construction Phase—Habitat Alteration

Construction of an offshore wind park could alter the habitat used by marine mammals. The construction of foundations, scour control mats, and laying of cable may cause an increase in the total suspended sediment in the area (Tougaard et al., 2006a). An increase in turbidity may cause temporary displacement of prey and, consequently, displacement of marine mammals. This is thought to be a short-term impact because marine mammals may find prey in areas adjacent to a park, where construction is not occurring. Turbidity also would be a short-term impact (sediments likely would settle after a few tidal cycles), and eventually the prey and marine mammals would return. The introduction of hard substrates to the location may increase the areas available for algae and filter feeding epifauna. This new source of prey may increase the number of finfishes around the parks and, in turn, attract marine mammals.

The laying of cable may impact seagrass beds, which in turn, may affect manatee feeding behavior and movement. The loss of seagrass beds during the laying of cable may force manatees to travel greater distances for food or to forage in less desirable locations (Haubold et al., 2006). The decline of seagrass beds in Florida waters as a result of population growth and development has increased the importance of the remaining beds for manatees, as well as for other aquatic life. Although a cable would likely impact a small area (3 m wide along the length of the cable), any additional loss to the beds may have negative impacts on an already endangered population of marine animals.

Operational Phase—Continual Operational Noise and Vibrations

The continual production of underwater noise from operating wind turbines may impact marine mammals acoustically by impeding communication among groups of animals, disrupting normal activities of foraging and breeding, or changing migration routes (Nedwell and Howell, 2004). Based on field experiments and calculations, harbor porpoise might hear individual wind turbines up to 100 m away (Koschinski et al., 2003). Constant low-frequency operational noise emitted from wind turbines may mask sounds such as mating calls or warning noises to avoid prey species (Koschinski et al., 2003). The geology and geography of the location will determine the amount of noise generated from an offshore wind park and the distance the sound travels. Cetaceans and pinnipeds initially may avoid offshore wind parks, but then, they may eventually habituate to the noise levels (Jarvis, 2005). Currently, noise measurements are taken only for a single wind turbine in a park, not for an entire wind park. The cumulative effects from a group of turbines may substantially increase the noise levels compared to the noise from a single turbine (Madsen et al., 2006). This cumulative effect needs to be evaluated. The noisiest wind turbine measured to date was a single 1.4 megawatt (MW) turbine at the Utgrunden wind park that measured 126 dB re 1 uPa at 180 Hz at 83 m (Tougaard et al., 2006a). Using an audiogram of a harbor porpoise, Tougaard et al. (2006a) showed that the SPL and frequency would just barely be audible to a porpoise at 83 m from the turbine, where the measurement was taken. Figure 5-10 from Thomsen et al. (2006) shows the SPLs of a 1.5 MW turbine in operation at three different



Source: Thomsen et al., 2006.

Figure 5-10: Sound pressure levels from three different distances from a single wind turbine in operation and the audiograms from harbor porpoise and harbor seal.

distances (1 m, 100 m, and 1 km) as well as the audiograms of harbor porpoise and harbor seals. Using these data, Thomsen et al. concludes that at 100 m, the operational noise would be audible to both porpoise and seal, but at 1 km, the noise is not likely detected by harbor porpoise. Harbor seals may detect the noise in the 125 to 160 Hz range at distances greater than 1 km.

Sea otters and manatees are not expected to be affected by the sound and vibrations from the offshore wind turbines because they mainly reside in nearshore habitats.

Operational Phase—Physical Presence of Structures

The presence of an offshore wind park will cause a loss of original habitat and create the physical presence of new structures above and beneath the water. The loss of original habitat may temporarily cause prey displacement; however, this displacement may be short term, as discussed above. The alteration of habitat to include the monopile foundations may serve as a fish-aggregating device (Jarvis, 2005) just as an artificial reef would have a positive impact on marine mammals in the area. Some impact assessments estimate that the surface area introduced into the marine environment as a result of the foundations will be small relative to the area marine mammals use (e.g., Cape Wind proposed wind park is estimated to be 111.5 m^2 per tower); therefore, the amount of the foundation surface area is not expected to impact the feeding habitats or other daily activities of marine mammals in the area (Jarvis, 2005). There is a concern that large wind parks may push migrating animals away from their usual pathways (Jarvis, 2005). The habitat shift from a nonstructured system to a structure-oriented system could affect marine mammal movement and behavior. Seals are sensitive to rapid changes on the horizon, which normally indicates a predator; however, seals are also known to habituate to constant structures (and regular, predictable noise). As a result, only minor impacts are expected from the physical presence of wind turbines (AMEC, 2002). No information is available to predict how whales might respond to the presence of an array of turbines. Due to their nearshore habitat, sea otters and manatees are not expected to be affected by the physical presence of an offshore wind park.

Operational Phase–Electromagnetic Fields

Electromagnetic fields (EMF) are produced when electricity is generated through cables buried in the seafloor. The cables are used in offshore wind parks to transfer the energy from the parks to a site onshore. Some marine mammals use the earth’s magnetic field for orientation and migration, and the EMF from the wind parks may interfere with those natural cues (Jarvis, 2005). Some reports have shown that cables buried at least 1 m below the seafloor have a magnetic field that is extremely weak compared to the earth’s magnetic field (Jarvis, 2005; Tougaard et al., 2006b) and therefore no adverse impacts to marine mammals should occur. However, Gill et al. (2005) concluded that cable burial was ineffective in weakening the magnetic field, and more data are needed to determine potential impacts for marine mammals.

Operational Phase—Increased Service Vessel Activity

The operation of a wind park will require a regular maintenance routine that will result in increased vessel activity to and from the wind park. Potential impacts from increased service vessel traffic include behavioral changes (e.g., avoidance, attraction, habituation, changes in vocalization, nondirectional swimming), masking of sounds, entanglement, and collision.

5.1.5.2 Results of Monitoring at Existing Facilities—Marine Mammals

Currently the studies that document potential impacts from existing offshore wind parks are available only for smaller cetaceans (harbor porpoise) and pinnipeds (gray seal, harbor seal); no studies are available on the impacts of offshore wind parks on larger whales, manatees, or sea otters, primarily because these groups of marine mammals were not present or of concern at the existing sites where studies have been conducted. The following paragraphs discuss the findings from studies that were conducted at four offshore wind parks: Nysted, Horns Rev, Scroby Sands, and Gøtland. One simulation study from Fortune Channel, British Columbia, also was reviewed.

Of the impacts discussed in the previous section, only behavioral changes (changes in swimming or haul-out activity, vocalization changes) and displacement (measured by abundance of animals in the area) as a result of physical presence and noise (impulse and continual) were analyzed. Observational studies using the before-after control-impact (BACI) method were conducted to determine differences between baseline, construction, and postconstruction periods. A brief description of the studies is provided in table 5-7; the following paragraphs present the findings from each study.

Nysted Offshore Wind Park, Denmark

Harbor porpoise. Using acoustic dataloggers called Porpoise Click Detectors (T-PODs), Tougaard et al. (2006a) studied the abundance and behavior of harbor porpoise during baseline (2001), construction (2002–2003), and operation (2004–2005) phases at the Nysted wind park. Three reference sites (10 km east of wind park) and three wind park sites were measured. The T-PODs collected the time and length of echolocation sounds from harbor porpoise.

Following is a list of results found from studies on harbor porpoise abundance at Nysted wind park:

- The baseline data showed no differences between the wind park and the reference area in respect to porpoises entering the area or in echolocation activity.
- Fewer porpoises were present in the wind park area during construction and after 2 years of operation compared to baseline.
- Porpoise activity showed a diurnal pattern with more activity occurring in the wind park at night than during the day during construction and operation. No diurnal patterns were observed during the baseline period.
- A small but significant increase of porpoise activity was observed in the reference area during construction and after 2 years of operation.
- Although a decrease in porpoise activity was still evident 2 years into the operation phase, a tendency toward a return to baseline levels was noted in the wind park, indicating habituation to the noise and a return of some animals to the wind park area.
- Porpoise activity in the reference area returned to baseline levels 2 years after construction.

Tougaard et al. (2006a) concluded that the abundance of harbor porpoise was affected significantly during construction and operation of the wind park in relation to the reference site and baseline period. Following is a list of results on porpoise behavior (Tougaard et al., 2006a):

- Echolocation behavior in the wind park decreased significantly from baseline during construction, indicating that not only were there fewer porpoises in the wind park area, but their echolocation was also affected.
- Echolocation behavior returned to baseline le+vels in the second year of operation.

Tougaard et al. (2006a) concluded that the behavior of harbor porpoise was affected significantly during construction and operation of the wind park in relation to the reference site and baseline period.

Table 5-7: Available studies and survey types conducted to determine impact of offshore wind parks on marine mammals.

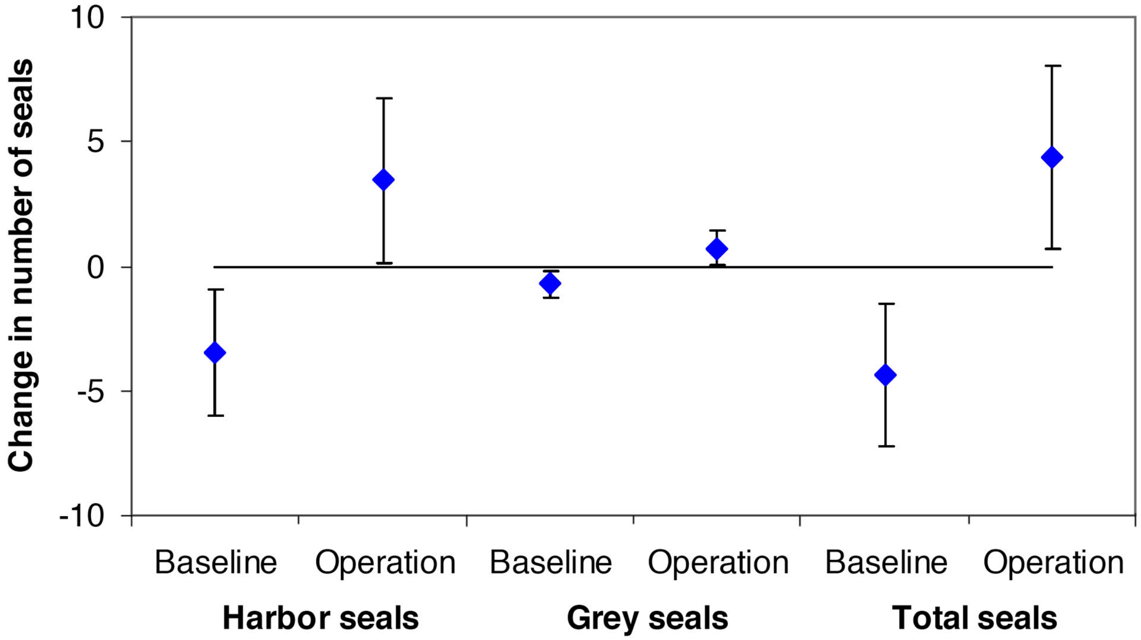
Wind Park	Survey Years/Citation	Survey Types	Objectives
Nysted, Denmark; 72 wind turbines, online since 2004	2001–2005; Tougaard et al., 2006a	Acoustic dataloggers: Porpoise Click Detectors (T-PODs)	Determine harbor porpoise abundance and behavioral changes between pre- and postconstruction phases and compare to a reference site throughout each phase
Nysted, Denmark; 72 wind turbines, online since 2004	2002–2005; Teilmann et al., 2006a	1. Aerial surveys 2. Remote video registration	Determine seal abundance for pre- and postconstruction phases. Used baseline surveys from previous years as a comparison
Horns Rev, Denmark; 80 wind turbines, online since Dec 2002	1999–2006; Tougaard et al., 2006b	1. Acoustic dataloggers: T-PODs 2. Ship surveys	Determine harbor porpoise abundance between pre- and postconstruction phases and compare to a reference site throughout each phase
Horns Rev, Denmark; 80 wind turbines, online since Dec 2002	2002–2005; Tougaard et al., 2006c	1. Satellite transmitters and datalogger 2. Ship surveys	Determine importance of Horns Rev as a foraging area for seals pre- and postconstruction; Determine the presence and behavior of seals after construction
Gøtland (Bockstigen), Sweden; 5 wind turbines, online since 1997	1996–1999: Sundberg and Soderman, 2001	Visual counts	Determine possible impacts on seals as a result of wind parks through numbers of seals at haul-out sites and behavioral changes in response to activities
Scroby Sands, UK; 30 wind turbines; online since 2004	2002–2005; E.ON UK Renewables, 2005	Aerial survey	Observe changes in seal numbers during construction and operation of the wind park
Fortune Channel, BC (simulation study)	June 2001 to July 2001; Koschinski et al., 2003	1. Visual observations using electronic theodolite 2. Acoustic dataloggers: T-PODs	Study changes in behavior and echolocation of porpoises and seals in British Columbia after playing a recording of wind turbine sounds generated from a European wind park

Seals. Aerial surveys and remote video registration of harbor seals and grey seals were used to determine the changes in abundance as a result of wind park activity (construction and operation). Baseline data from aerial surveys flown from 1990 to 2000 were compared to the 2002 to 2005 data, which provided information on the seasonal and interannual use of the haul-out sites near the Nysted wind park. The Rødsand seal sanctuary (4 km from the wind park) is the closest haul-out site to the wind park; it is believed to have a closed-harbor seal population with five other haul-out sites with little exchange to other populations (Teilmann et al., 2006a). The six haul-out sites are considered one management area.

Following is a list of results on the abundance of seals (Teilmann et al., 2006a):

- During construction of the wind park, the importance (based on the number of seals using the sanctuary as a haul-out site) of the Rødsand seal sanctuary decreased slightly (not significantly) as compared to other haul-out sites in the area.
- The number of seals increased at Rødsand seal sanctuary by 34 percent and 33 percent during the operation phase of the wind park in 2004 and 2005, respectively, in comparison to other haul-out sites in the management area.

Teilmann et al. (2006a) concluded there was no evidence that the construction or operation phases of the wind park negatively affected local harbor and grey seals at Rødsand seal sanctuary in comparison to other haul-out sites in the management area. Figure 5-11 shows the changes in population of harbor seals and grey seals during baseline (1990 to 2000) and operations (2002 to 2005) phases at the Rødsand seal sanctuary.



Source: Teilmann et al., 2006b.

Figure 5-11: Estimated change in numbers of seals during baseline and operation phases at Rødsand seal sanctuary.

Horns Rev Offshore Wind Park, Denmark

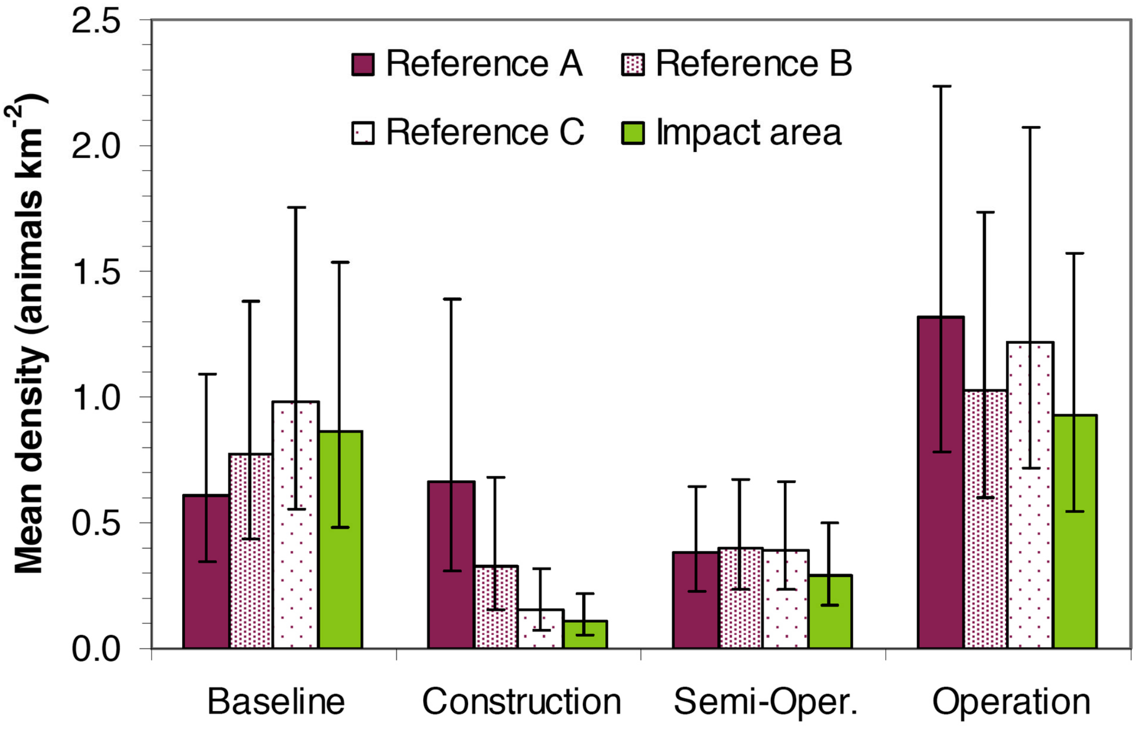
Harbor porpoise. Using T-PODs and ship surveys, the abundance of harbor porpoise was observed from baseline (1999–2001), construction (2002), and operation (December 2002–2006) phases at the Horns Rev wind park. Three reference sites outside of the wind park were measured. The T-PODs collected the time and length of echolocation sounds from harbor porpoise. The ship surveys documented the occurrence of porpoises using transects oriented east-to-west and covering 800 km^2.

Following is a list of results on abundance of harbor porpoise at the Horns Rev wind park (Tougaard et al., 2006b):

- No significant change in abundance in the wind park during construction was observed from the T-PODs acoustical recordings.
- Acoustic data indicated that porpoises left the Horns Rev area in response to the impulse sound from the pile-driving operation. Porpoise acoustic activity returned to normal construction levels within 6 to 8 hours.
- A significant difference between semi-operation (when intensive maintenance work took place) and operation was observed from the acoustic recordings.
- There were no detectable effects on the abundance of porpoises during the operating phase of the wind park (contrary to the porpoise study at Nysted), indicating that the underwater noise from the turbines did not impact the porpoises. Other wind parks or other locations may produce different results (noisier turbines or quieter background noise).
- The operation phase showed higher porpoise acoustic activity than during baseline, but this was seen in the reference area as well.

Tougaard et al. (2006b) observed that harbor porpoise experienced a weak negative and temporary effect specifically related to pile driving during construction and semi-operations. No impacts were observed from the operating wind park as shown in figure 5-12.

Seals. The primary objective of this study was to determine the importance of the Horns Rev location as a foraging area to harbor seals. The investigators also looked at the presence and behavior of seals after the construction to determine what impacts the activity had on the animals. Harbor seals have been documented as using the entire eastern part of the German Bight, where Horns Rev is located, for primary foraging habitat. Satellite transmitters and dataloggers were used to collect information on the presence of seals in the Horns Rev area. Unfortunately, the accuracy of the positions received from the transmitters was not precise enough to conclude how much of an impact the wind park had on the presence of seals.



Source: Teilmann et al., 2006c.

Figure 5-12: Mean densities of harbor porpoise indicate a weak negative effect from pile driving during construction and semi-operation of the Horns Rev wind park.

Following is a list of results on the importance of Horns Rev as a foraging area to seals (Tougaard et al. 2006c):

- Harbor seals forage much farther offshore than was previously thought, but Horns Rev is an important foraging area.
- Horns Rev was determined to be an important area for harbor seals to use for foraging; however, it was part of a much larger foraging area, and it was not observed to be more important than other areas.

Following is a list of results on the presence and behavior of harbor seals in relation to the Horns Rev wind park (Tougaard et al., 2006c):

- Satellite tracks showed no signs of a deterring effect on harbor seals as a result of construction activities.
- Ship survey data did show an indication of an effect on harbor seals from construction activities. An effect of pile driving on the distribution of seals on the reef was observed. (No seals were sighted in the wind park or even a few kilometers away during pile driving.)
- Visual sightings observed that the number of seals inside the wind park during operation was not noticeably different than the number outside the wind park.
- Satellite data showed seals present in the wind park area during the operational phase.

- Visual sightings during ship surveys observed no negative effects during operation of the wind park (e.g., avoidance behavior, changes in diving behavior inside the wind park).

Tougaard et al. (2006c) concluded from observations that the wind park caused no significant effects on harbor seals; however, because of equipment limitations, the effects would have had to be very strong to be detectable. Researchers proposed that the artificial reef effect may be a positive effect through an increase in food availability and the fishery exclusion in the wind park. They also noted several limitations to the study. Satellite transmitters and dataloggers did not have the spatial accuracy to give definite conclusions on whether animals were inside or near the wind park, and some of the dataloggers still have not been retrieved after being separated from the animal, therefore, the data have not been collected. Only 7 out of the 23 tagged animals had their dataloggers retrieved, and this dataset was insufficient to show strong effects.

Gotland, Sweden

Seals. Observations on grey seal behavior and seal counts were conducted at two haul-out sites (Killingholm and Nasrevet) within 2.5 km and 1.5 km, respectively, to five wind turbines near Goltand, Sweden. The study was conducted during construction (1996–1997) and operation (1998–1999). Baseline data collected in a previous study were used for comparative purposes. The following behavior classifications were used: (1) resting on land, (2) looking around, and (3) vigilant.

Sundberg and Soderman (2001) reported the following results on the number of seals at haul-out sites:

- Lower occurrence and reduced number of seals were observed during construction and operation periods; however, no evidence of the wind plants affecting grey seals was found. Lower occurrence could have been a result of weather factors.
- Human-induced disturbances (boat and helicopter traffic) reduced the number of seals. Some of these disturbances were related to maintenance activities.
- The number of seals present on the haul-out site was independent of the number of turbines running.
- A shift in the use of the two haul-out sites, from Killingholm to Nasrevet, was observed. Nasrevet is closer to the wind turbines, and the shift became more prominent in the last few years.
- Work activity was positively related to the number of seals observed at Nasrevet and negatively related at Killingholm; however, Killingholm was exposed to unusual weather patterns and never exceeded 12 individuals during this period.

Sundberg and Soderman (2001) reported the following results on the behavior of seals at haul-out sites:

- Human-induced disturbances (boat and helicopter traffic) caused behavior changes in seals (e.g., looking around, vigilant).
- Of the 37 disturbances (approaching boats, airplanes) recorded, 61 percent resulted in all seals diving into the water when activities were within 1.5 km of the haul-out site.

- Boats used during the construction and operation periods caused seals to leave the haul-out sites; however, they returned to the site after a short time.
- When boats were still and anchored, the seals returned to land with no obvious sign of stress. When the boats restarted, the seals became disturbed, indicating that more frequent disturbance could prolong recovery. Consequently, abandonment of the haul-out site could occur.

There were no evident signs of negative effects caused by the wind park. No direct disturbance of the seals was observed during the construction or operational periods; however, secondary effects such as maintenance by boats or helicopters may be a potential threat to seals.

Scroby Sands, United Kindgom

Seals. During the construction and operation phases of the Scroby Sands offshore wind park, 15 aerial surveys were conducted to document common seal and grey seal populations. Although the actual report that describes the methods and findings of the study has not been located, the executive summary of the E.ON UK Renewables (2005) indicated that there were no significant changes in the common seal populations. The grey seals were observed to be increasing in numbers, which followed a trend observed in the United Kingdom.

Fortune Channel, British Columbia, Simulation Study

Harbor Porpoise. Using T-PODs and visual observations through an electronic theodolite situated 14 m above sea level on a cliff, scientists studied the behavior and echolocation of harbor porpoise responding to recorded and modified sounds of a wind park located near Gotland, Sweden. The original noise was emitted underwater at 8 m/s by a 550-kW WindWorld wind-turbine. After the noise was recorded, it was modified to imitate a 2-MW wind-turbine (Koschinski et al., 2003). The recording was played back underwater in Fortune Channel in order to observe the effect on harbor porpoise and harbor seals in the area.

Koschinski et al. (2003) reported the following results on porpoise behavior:

- Harbor porpoise used echolocation more often during the replay of the wind turbine sound than in the control situation (no turbine sound).
- The number of closest approaches increased during the wind turbine sound.
- No schooling or fast swimming was observed, indicating no fright reactions occurred.
- Avoidance behavior was less intense than what has been observed during gillnet pinger experiments (used to scare porpoise away from gillnets).
- The duration of presence during the wind turbine noise was not different from the control situation.

Koschinski et al. (2003) concluded that harbor porpoise can hear the low-frequency simulated wind turbine noise. Porpoise appeared to be cautious (e.g., showing some avoidance behavior) when the wind turbine noise was played, and they actively investigated the source of the noise with their sonar.

Harbor Seal. Using visual observations through an electronic theodolite, scientists observed the behavior of harbor seals responding to recorded and modified sounds of a wind park located near

Gotland, Sweden, as described above for harbor porpoise. A haul-out site was located just outside the observation area.

Koschinski et al. (2003) reported the following results on harbor seal behavior:

- Surfacing increased significantly during the replayed wind turbine noise compared to the control situation (no turbine sound).
- Distance from the noise source increased when surfacing (239 m during control, 284 m during wind-turbine noise).
- The closest approach to the noise source (9.6 m) occurred during the control situation; the closest approach during the replayed turbine noise was 12.0 m.

Koschinski et al. (2003) concluded that harbor seals can hear the low-frequency simulated wind turbine noise and show some behavioral changes (e.g., surfacing, increasing distance to sound) in response to the sound.

Conclusions from Existing Studies

Although the studies listed above focused on abundance and behavioral changes for only a few species (harbor porpoise, harbor seal, and grey seal), the data provided some important results on the potential impacts of wind parks to marine mammals. Harbor porpoise appeared to hear the low-frequency simulated wind turbine noise provided in the simulation study and showed avoidance behavior when the noise was played. Both offshore wind park studies concluded that harbor porpoise were affected significantly by the noise. One study observed effects during construction and operation of the offshore wind parks (Nysted), and the other study observed effects just during construction (Horns Rev). All studies concluded that harbor seals were not affected significantly during construction and operation of offshore wind parks. The simulation study observed that harbor seals could hear the low-frequency noise associated with wind turbines, and observation showed the seals changed their behavior as a result of the sound.

A valuable finding from the Danish wind park studies (Dong Energy et al., 2006) was that the two areas under study differed and featured different sensitivity issues, and therefore, the regulatory requirements for the construction phase varied considerably. Prudent caution is appropriate when transporting findings, mitigation measures, and management systems from one site to another.

5.1.5.3 Current Models Used to Determine Impacts

Several different methods have been used to assess the impacts of offshore wind parks on cetaceans and pinnipeds, although most impact assessments have followed a similar pattern that involve three main steps: (1) collecting baseline data on species and habitats in the area, (2) assessing impacts, and (3) determining the importance of the impacts using a set of criteria and ranking system. A more detailed description of each of these steps follows.

Collection of Baseline Data

Endangered and threatened species including marine mammals is a principal consideration in the evaluation of offshore energy facilities. Distribution, abundance, habitat use, and behavior vary by geographic and temporal factors. Baseline data on the species and habitat are necessary to begin evaluating the possible impacts of the offshore wind park on marine mammals. The following information should be collected during a baseline study (as specified in CEFAS, 2004):

- Types of species in the area
- Number, distribution, and location of sightings
- Known routes and movements in, around, or through the site
- Relative importance of the site to each species
- Specific uses of the site including temporal and spatial use (e.g., haul-out areas, pupping areas, feeding and breeding grounds)

Most recent impact assessments evaluate at least several of the above categories, if not all. Methods used to gather these data include a literature search or desktop study on previously collected data, line-transect observational surveys in the area, and spatial modeling to identify key habitats. Spatial modeling uses observations of marine mammals to predict abundance and habitat suitability across large areas. Predictive models such as ENFA (Ecological Niche Factor Analysis) models were used in the Horns Rev 2 environmental impact assessment (EIA) (Skov et al., 2006). AMEC (2002) used line-transect surveys to collect data on marine mammals present in the proposed wind park site.

At the Horns Rev offshore wind park, baseline data were collected through surveys that covered the wind park and areas just outside of the wind park. Observations were collected on harbor porpoise as well as salinity, temperature, depth, and tides to develop a spatial model of the distribution of porpoises for each survey. From these data, porpoise density maps were made for the entire area surveyed. The maps were compared to one another to show the relative density of porpoises within and around the proposed wind park site (Dong Energy et al., 2006).

Assessment of Potential Impacts

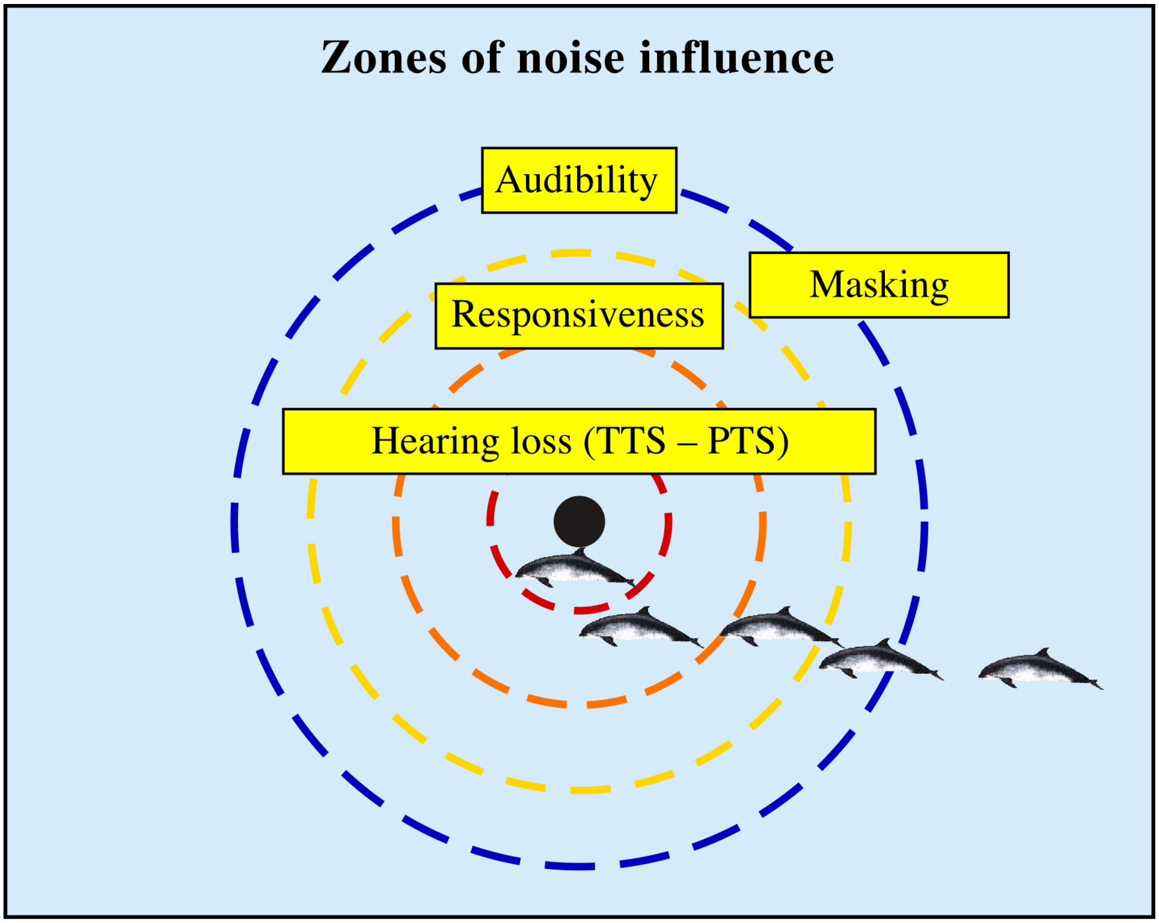
Acoustic assessment. An assessment generally is performed on what animals are present and how noise will affect those species based on the location and size of the wind park. Methods to collect this information include reviewing noise data from existing wind parks and applying those sound levels to determine the distance at which noise may travel based on the habitat. Through evaluation of ambient noise, the hearing range of different species, anthropogenic noise levels, and transmission conditions, predictions can be made on where wind park noise is most likely to affect marine mammals. From this, the four zones of influence, originally defined in Richardson et al. (1995) and illustrated in figure 5-13, can be determined around the proposed wind park. The omnidirectional spread of sound from a source requires that a radius rather than a straight line be drawn as the potential area of impact. The four zones are described below:

- Zone of Audibility—area within which the animal is able to detect the sound.
- Zone of Responsiveness—area within which an animal responds to sound through changes in behavior or physiology.
- Zone of Masking—region within which noise can interfere or mask other biologically important sounds.

- Zone of Hearing Loss (TTS/PTS)—area nearest the noise source where the sound level is high enough to cause temporary or permanent damage to the animal.

If a noise is within the hearing threshold of a marine mammal, the distance the animal is from the noise source will determine what effect the level of noise will have on an animal. The hearing of the relevant species is described using an audiogram, a measure of the lowest level of sound that the species can hear. Unfortunately, audiograms are available for only a few marine mammal species, and then only for a few individuals within a species. Behavioral responses to certain noise levels also are documented from previous studies where applicable.

A transmission loss calculation generally is applied to all noise levels because the intensity of a noise is expected to decrease the farther away from the source it travels. Impact assessments determine where the zones are in relation to the noise source based on the noise level and the attenuation that occurs as the noise travels away from the source. In the Burbo offshore wind park EIA, Skov et al. (2006) used the zones of influence to describe the possible impacts based on the noise levels that were anticipated.



Source: Richardson et al., 1995.

Figure 5-13: The four zones of influence from a noise source such as a wind park to a receiver such as a marine mammal.

Sound levels for construction noise (e.g., pile driving) and operational noise are estimated for each wind park. Pile driving noise levels are based on the size and diameter of the monopile. Some assessments use the sound levels measured on other wind parks that may be similar. The Aberdeen offshore wind park EIA (AMEC, 2005) used noise data from other wind parks including background noise levels and noise measurements collected during specific construction operations such as rock socket drilling, cable trenching, and monopile hammering to determine the potential impacts of the wind park.

Assessment of Increased Vessel Traffic. EIAs estimate the increase in vessel activity annually based on maintenance schedules (U.S. Army Corps of Engineers, 2004). Because no established relationship exists between an increase in vessels and collision, this information does not provide a strong basis for evaluating the impacts on marine mammals. Generally vessels travel at speeds slow enough to avoid collisions.

Importance and Ranking

Impacts are estimated from the baseline and acoustic data collected as described above. A set of criteria then may be used to evaluate the impact and rank the significance of the impact. Tables 5-8 and 5-9 provide examples of sets of criteria used for the Horns Rev 2 offshore wind park EIA (Skov et al., 2006).

Table 5-8: Criteria for assessing impacts.

Criteria	Factor (by rank)	Note
Importance of the Issue	1. International interests 2. National interests 3. Regional interests 4. Local areas and areas immediately outside the condition 5. Only to the local area 6. Negligible to no importance	In physical and biological environment, local area is defined as wind park area
Magnitude of the impact or change	1. Major 2. Moderate 3. Minor 4. Negligible or no change	Levels of magnitude may apply to both beneficial/positive and adverse/negative impacts
Persistence	1. Permanent—for the lifetime of the project or longer 2. Temporary (long term)—more than 5 yrs 3. Temporary (medium term)—1 to 5 yrs 4. Temporary (short term)—less than 1 yr	
Likelihood of occurring	1. High (>75%) 2. Medium (25–75%) 3. Low (<25%)	
Other	Direct/indirect impact—caused directly by the activity or indirectly by affecting other issues as an effect of the direct impact	

Source: Skov et al., 2006.

Table 5-9: Ranking of significance of environmental impacts.

Significance	Description
Major impact	Of sufficient importance to call for serious consideration of change to the project
Moderate Impact	Of sufficient importance to call for consideration of mitigating measures
Minor Impact	Unlikely to be sufficiently important to call for mitigation measures
Negligible—No impact	Of such low significance that impacts are not considered relevant to the decision-making process

Source: Skov et al., 2006.

Most impact assessments indicate little to no impacts on marine mammals during operation and only some impacts during construction.

5.1.5.4 Proposed Mitigation Measures

Numerous mitigation measures have been recommended to protect marine mammals from potential adverse effects as a result of offshore wind parks. Most measures are related to noise control, the impact of highest concern. Countries usually have guidelines to follow based on specific data collected from their region. For example, in the United States, NMFS has implemented safety conservation guidelines for marine mammals around seismic surveys to avoid potential injuries; the sound levels are not to exceed 180 dB for the cetaceans and 190 dB for pinnipeds (Federal Register Vol. 68, No.71 April 14, 2003). A safety zone of 500 m is used for most projects. The United Kingdom also enforces a 500-m safety zone around all seismic survey arrays to reduce impacts to marine mammals (Burbo Offshore Wind Farm, 2002a). The following bullet lists are grouped according to impact: sound, increased vessel traffic, and EMF and summarize other mitigation measures that have been proposed during the construction and operation of offshore wind parks.

Sound

- Soft-start technique (a gradual increase in the sound source level allowing marine mammals to respond to the noise and move away from the site before they are harmed) is used for activities that generate impulse noise (Jarvis, 2005).
- Onsite government-appointed marine mammal observers survey the area for marine mammals before and during activities that generate high-intensity sound levels (Jarvis, 2005). If an animal enters the area, activities are halted until the animal leaves the area.
- Noise monitoring is conducted by installing real-time detection buoys to monitor sound levels to ensure they do not exceed NMFS requirements.
- Foundations are installed by digging or jetting instead of pile driving.
- Bubble curtains can attenuate sound levels during pile driving (Nedwell and Howell, 2004).
- Acoustic deterrents such as seal scarers and porpoise pingers can discourage marine mammals away from the area during pile driving activities (Nedwell and Howell, 2004).

- Engineering can specify appropriate piles and pile driver to keep sound levels at a minimum, thus avoiding use of more energy during pile driving than what is really necessary (Nedwell, Langworthy, and Howell, 2003).
- Use of smaller diameter monopiles may lower the sound level, but more studies are needed. Using two or three smaller piles instead of one large pile may help to reduce intense sound levels (Nedwell, Langworthy, and Howell, 2003).
- Vibratory pile drivers may reduce sound levels because they apply a rapidly alternating force using rotating eccentric weights to drive the pile; thus, they are quieter than impact driving. However, they cannot fully drive a pile into a hard seafloor (Nedwell, Langworthy, and Howell, 2003).
- Passive or Active Acoustic Monitoring may help detect marine mammals in the vicinity of the offshore wind park (Nedwell, Langworthy, and Howell, 2003).
- Scheduling activities with high sound levels when species are not in the area (i.e., avoiding migratory periods or periods where local breeding grounds are used) may help avoid sound impacts (Nedwell, Langworthy, and Howell, 2003).

Increased Service Vessel Traffic

- Areas with high marine mammal population densities may require setting mandatory speed restrictions for vessels.
- Awareness can be increased by requiring personnel and crew members to have NOAA-certified training regarding marine mammal presence and emergency collision avoidance procedures.
- Use of knotless and nonfloating lines, ensuring adherence to regulations for all mandated gear modifications on service vessels, and keeping all slack out of any potentially entangling material can help reduce marine mammal entanglements.
- Requiring service vessels to follow normal shipping routes and avoid known marine mammal migratory pathways can help reduce collision risks and behavioral changes.

Electromagnetic Field

- Burying cable at least 1 m below the seafloor can reduce marine mammal exposure to EMF as well as to their prey (University of Liverpool, 2003).
- Increasing cable permeability and conductivity can decrease EMF (University of Liverpool, 2003).
- Insulating cables and secure earthing at both joints helps reduce EMF (Burbo Offshore Wind Farm, 2002b).

5.1.5.5 Information Needs

Baseline Studies

Baseline studies provide the information on which to predict potential impacts, develop appropriate mitigation strategies, and monitor for actual impacts during construction and operations. Evaluation of potential impacts will be challenging because of incomplete species characterizations and a high degree of both biologic and environmental variability. Traditional sampling methods such as shipboard and aerial surveys may be inadequate. Likewise, typical BACI methodologies studies may not produce useful results. Any proposed activity in U.S. federal waters will need to evaluate the distribution and abundance of marine mammals that may use the area. While coarse-grained and somewhat outdated information is available on abundance and distribution of marine mammals, fine-grained spatial and temporal information on marine mammals that may be affected by proposed projects is lacking. More site-specific data will be needed after proposed locations for offshore wind parks are chosen. Clear information needs include studies to develop, refine, and improve the methodology for identifying the abundance and distribution of marine mammals in small, localized areas. New and innovative methodologies will be required to provide better fine-grained and higher resolution data to account for variability. Platforms, sensors, and methodologies likely need to be modified and integrated into a comprehensive plan to accurately assess and monitor fine-grained marine mammal distribution and abundance at proposed sites.

Establishing baseline characterizations for a specific site is a two-step process: (1) synthesize existing information, and (2) address information needs with current fine-grained information. The challenges in fine-grained and high-resolution sampling of oceanic species have been well documented (e.g., Hain et al., 1999). Sampling resolution is also a factor in determining if an impact has occurred. In a recent study (J. Bell, pers. comm., 2006), the U.S. Navy contracted for a project involving computer simulations based on the BACI method to evaluate the survey effort and methodologies that would be required to detect effects of activities at the local population level for a relatively small area of about 1700 km^2. The results of the simulations indicated that effects would be undetectable at most realistic sampling resolutions. The study suggested that a useful monitoring program would be a multidisciplinary approach combining several different tools (J. Bell, pers. comm., 2006). Danish wind park studies (Dong Energy et al., 2006) likewise described that development of new methods were required. Exploration and development of platforms and methodologies for improved monitoring and assessment of marine species is a priority. A review of the effects on harbor porpoise from the offshore wind park at Horns Rev indicated that the following models were necessary when developing baseline studies:

- Dynamic models that link environmental conditions at the time of each sighting (whether it is a sighting of an animal or a line without animals). Currents and weather cause constantly changing salinity gradients and hydrographic frontal structures, and these variables may affect the presence or absence of marine mammals within an area more so than the presence of alternative energy facilities would (Tougaard et al., 2005a); and
- Spatial modeling of different species of cetacea that incorporate improved methods.

An important component of a baseline study is to conduct a literature search and review of past studies for certain patterns in the life history of a species. With the high spatial and temporal variation that naturally occurs within a population, as well as long-term interannual changes, data collected during a 3-5 year baseline study may be misleading. Extracting historical patterns from past data collections may alleviate some of the stochastic population variation that will arise in studies with shorter time periods.

Approximately 100 datasets from past survey studies are available for review in the Ocean Biogeographic Information System - Spatial Ecological Analysis of Megavertebrate Populations

(OBIS-SEAMAP) database. This online database is a repository for aerial, ship-board, and telemetry data collected on marine mammal species in most U.S. and some international waters from 1944 – 2006 (Read et al., 2007). This database would be an important source to review after more specific locations are chosen for offshore wind parks.

A literature search and analysis of the different survey methods available for marine mammals studies are recommended to determine the best possible approach for collecting small-scale data. During the literature synthesis, other survey methods, such as blimps, for estimating marine mammal abundance and geographic distribution studies should be reviewed to supplement the more typical aerial and vessel surveys.

Some baseline data (e.g., population size, stock structure, geographic range) for marine mammals are available in the Stock Assessment Reports prepared by NMFS (Waring et al., 2007; Caretta et al., 2007). These reports cover all three regions (Atlantic, Pacific, and Gulf of Mexico) and most of the marine mammal species that would occur in the OCS. However, due to financial and other constraints, data are incomplete. The Cetacean and Turtle Assessment Program (CETAP) conducted population surveys for whales, dolphins, and sea turtles in OCS waters from Cape Hatteras, NC, to the Gulf of Maine between 1978 and 1982 (CETAP, 1982). This study assessed distribution and abundance of cetaceans and sea turtles from shore to 9.3 km seaward of the 1,000 fathom isobath. The U.S. Navy has also compiled a number of assessments and technical reports that address marine mammal distribution, abundance, and life history data in the Gulf of Mexico and the Atlantic (Department of the Navy, 2001, 2002a, 2002b, 2003).

Aerial surveys of the Florida manatee have been conducted over ten years to determine the seasonal distribution and relative abundance of the species in Florida waters (J. Lake, pers. comm., 2007). Surveys are flown in nearshore waters every two weeks (weather dependent) over a two-year period in certain regions of Florida. Six research groups currently conduct these surveys: Florida Fish and Wildlife Research Institute (FWRI), Jacksonville University, Kennedy Space Center, Dade County Department of Environmental Resource Management, Mote Marine Lab, and Chassahowitzka National Wildlife Refuge. The survey data are then transposed onto maps and entered into the Marine Resources Geographic Information System, a database maintained by FWRI and used for resource management. FWRI also coordinates synoptic aerial surveys conducted during the winter months that cover all manatee habitats in Florida in a short time span (days) to obtain a minimum population estimate. These surveys typically occur 1 to 3 times a year and have been conducted 24 times between 1991 and 2007 (FWRI, 2007).

The following paragraphs discuss information needs for species in three geographical areas. The species that are found in the areas where OCS structures would be located and regional keystone species suggested by researchers are identified.

Atlantic Region

Key species in the Atlantic include harbor seal, Florida manatee, North Atlantic right whale, humpback whale, bottlenose dolphin, and harbor porpoise (W. McFee and J. Hain, pers. comm., 2006). Aerial counts of harbor seal surveys have been conducted off the coast of Maine from 1981 to 2001 (Gilbert et al., 2005) and from the Maine/New Hampshire border to eastern Long Island and New Jersey (Payne and Selzer, 1989; Barlas, 1999; deHart, 2002) to show changes in abundance over time. However, very little is known about the harbor seals' habitat use, distribution, or stock structure in the Atlantic (Waring et al., 2006). Studies to date are general at best and do not provide the detailed information necessary to understand the impacts of offshore wind parks on harbor seal populations. Specific studies that may be appropriate if a North Atlantic offshore wind park site is proposed may include:

- A study on predation of harbor seals in Long Island Sound (Maritime Aquarium at Norwalk, 2005) and the impact of temporary or long-term displacement in relation to predation.
- A study on the structure (e.g., age, sex, hierarchy) and group composition of harbor seals in the Cape Cod region (NOS, 2004). Seals are relatively easy to survey because of their semi-terrestrial nature and a health assessment on the stock structure in specific locations may provide critical information for determining impacts of anthropogenic activities.

Although manatees reside in a localized region of the United States, abundance and distribution data are lacking for the less populated areas of Florida (e.g., the Everglades and the southern tip of south Florida) (J. Lake, pers. comm., 2007). Surveys have been completed in these areas but have not received the same amount of coverage that the more metropolitan areas of Florida have received (e.g., St. Johns Bay, Tampa Bay, Ft. Meyers, and Miami). Consequently, the datasets in these less populated areas are not as robust as they are in other areas of Florida. In addition, some manatees migrate north along the East coast during the summer months to forage. Currently, there are no survey efforts occurring in other coastal states (e.g., GA, SC, NC, and VA) on a regular basis to understand the abundance of this species in Mid-Atlantic waters.

A priority species for baseline as well as site-specific characterization is the North Atlantic right whale, *Eubalaena glacialis*. This small, endangered population, which occurs in coastal habitats, is the focus of both studies and conservation efforts (Kraus and Rolland, 2007). Appropriately it will receive consideration for any OCS activities. Several areas off the U.S. East Coast, such as the southeastern United States and Cape Cod region, are well studied. In other areas, such as North Carolina to Block Island, data are sparse. Nearshore waters in these areas may constitute a seasonal habitat or migratory pathway (J. Hain, pers. comm., 2006). There is also no information on where the majority of right whales reside during the winter months (NMFS, 2005a). Current population trends are unknown for the humpback whale in the North Atlantic (NOAA Fisheries, 2005a). Most surveys for this species are conducted in the Gulf of Maine where they feed during the summer months or in the West Indies where they breed during the winter months (Smith et al., 1999; Stevick et al., 2003). Data are lacking on the wintering population of humpback whales that have been observed in the Mid-Atlantic and Southeastern states (Barco et al., 2002). The population identity of these animals is unknown (e.g., are they the same animals found in Gulf of Maine, Newfoundland, or Gulf of St. Lawrence during the summer?). Do the increased sightings of humpback whales in the Mid-Atlantic and Southeastern states represent an increase in abundance, a distributional change, or an increase in observation efforts? The CETAP study mentioned previously identified the two ecotypes of bottlenose dolphin—coastal and offshore. Coastal bottlenose dolphins are normally found within 5-7 km of the shore and are studied extensively along the east coast (Palka, 2001; McClellan, 2000; Read et al., 2003). Offshore bottlenose dolphins are usually found 11 km or more from the coast and are not well studied (W. McFee, pers. comm., 2006). Tissue samples from large vessel surveys in 1998 and 1999 indicated that there is some overlap in the 5 to 11 km range where both ecotypes may coexist (Torres et al., 2003). Surveys are recommended to obtain data on the abundance and distribution of the offshore group of bottlenose dolphin.

The Northeast Fisheries Science Center and the Southeast Fisheries Science Center conducted shipboard and aerial surveys for harbor porpoise in the Gulf of Maine/Bay of Fundy region between 1991 and 1999. Abundance estimates were derived from these surveys (Waring et al., 2007); however, additional data are necessary to determine the population trends for harbor porpoise in the Gulf of Maine. Several attempts have been made to determine the percentage in growth of the population (NOAA Fisheries, 2005b), but the current reported rate is only a rough estimate because of the few direct observations for maximum rate of increase. Data are also lacking on the abundance and distribution of harbor porpoise in the winter months.

Pacific Region

Key species found in the Pacific region include southern sea otter, harbor seal, California sea lion, harbor porpoise, bottlenose dolphin, humpback whale, gray whale, and killer whale (J. Barlow, pers. comm., 2006). Other species that may be found in the OCS include Steller sea lion, northern elephant seal, northern fur seal, Risso's dolphin, Dall's porpoise, Pacific white-sided dolphin, and blue whale (NCCOS, 2003).

Spring surveys of southern sea otter have been conducted from 1983-2006 by the USGS from Half Moon Bay to Santa Barbara, California to provide abundance data for this federally threatened population of sea otters (L. Carswell, pers. comm., 2007). This is a well-studied subspecies (Estes, 1990; Siniff and Ralls, 1991; Wilson et al., 1991) as a result of the federal listing; however, the population growth is much slower than other populations, and biologists are currently unable to explain the variation (Estes, 1990). In addition, biologists are unsure of the causes of death for this species. The northern sea otter population found in Washington has been surveyed by the WA Department of Fish and Wildlife since 1989 to collect data on size and distribution. The distribution of this reintroduced population of sea otters continues to change each year (Jameson and Jeffries, 2006). This annual spatial variation emphasizes the importance of continuing the annual surveys to track population trends and changes in distribution.

Several different stocks of harbor porpoise have been defined on the Pacific coast from California to Washington. Aerial surveys of the stocks in California and southern Oregon from 1988-1995 were conducted to estimate abundance for harbor porpoise (Barlow and Forney, 1994; Forney, 1999); however, these surveys were conducted only in late summer and early autumn. Additional aerial surveys during winter and summer would provide the data to understand the seasonal differences in abundance and distribution (Caretta et al., 2001). Aerial surveys were conducted in 1989-1990 (Green et al., 1992) and 1990-1991 (Calambokidis et al., 1993) to determine abundance of the stocks of central to northern Oregon and Washington. However, as with California stocks, data are lacking in determining seasonal distributions for the harbor porpoise in the Oregon and Washington stocks.

Bottlenose dolphins also are divided into two ecotypes along the Pacific coast of California, Oregon, and Washington—coastal and offshore. The coastal dolphins of California (that are normally found between 500-1000 m from the shoreline) have been surveyed through photo mark-recapture studies (Dudzik, 1999; Dudzik et al., 2006) to determine abundance estimates. However, the distribution of these coastal animals is quite varied based on monthly counts during surveys between the U.S./Mexican border and Point Conception (Carretta et al., 1998) and may also change with oceanographic events (Hanson and Defran, 1990). Aerial surveys were conducted during the winter and spring of 1991-92 (Forney et al., 1995) and shipboard surveys were conducted in the summer and fall of 1991 (Barlow, 1995), however no seasonality in distribution was determined from either study (Forney and Barlow, 1998). Abundance estimates are based on the most recent shipboard surveys in 1996 (Barlow 1997) and 2001 (Barlow, 2003) conducted within 556 km of the shoreline of California and Oregon; however trends in abundance are unknown (Caretta et al., 2006). Additional surveys are warranted to understand the distribution for both ecotypes.

Abundance of the North Pacific stock of humpback whales was estimated using mark-recapture methods of photo-identified whales between 1990 and 1993 (NOAA, 2006). This study provided some data on stock structure and site fidelity for wintering and feeding areas, but data are lacking on the numbers, sizes, and potential boundaries of most feeding areas in the North Pacific. Humpback populations are managed based on feeding concentrations rather than breeding areas, which increases the need for data on abundance in individual feeding areas and movement between areas. The international SPLASH program (Structure of Populations, Levels of Abundance, and Status of Humpbacks) that began conducting studies in the summer of 2004 should provide some important information through genetic analysis, photo-identification, and observational surveys.

Gray whale abundance has been estimated from surveys at Granite Canyon, California from 1993-1996 (Laake et al., 1994; Hobbs et al., in press) and 2001-2002 (Rugh et al., in press) and at Granite Canyon and Point Lobos, California in 1997-1998 (Rugh et al., 1999). However, additional site surveys along the Pacific Coast including Washington and Oregon would allow an accurate estimate on abundance and distribution of the species (J. Barlow, pers. comm., 2006).

The distribution and abundance of the killer whale (eastern North Pacific, southern resident stock) in Oregon, Washington and California have been documented (Green et al., 1992; Barlow 1995, 1997; Forney et al., 1995); however, most sightings occurred during the summer. The winter range of this stock is less understood. Killer whale feeding ecology, prey abundance and distribution, and year-round range determination also need further research (NMFS, 2003a).

Gulf of Mexico

The key species in the Gulf of Mexico region include Florida manatee, bottlenose dolphin, Atlantic spotted dolphin, Bryde's whale, fin whale, and humpback whales (W. Hoggard, pers. comm., 2006; Department of the Navy, 2003). Texas A&M and NMFS jointly conducted the GulfCet program for the MMS to provide a more comprehensive survey of marine mammals in the Gulf of Mexico. The first study, GulfCet I, occurred from 1992–1995 and focused on the north-central and western Gulf of Mexico. GulfCet II, conducted during 1996 and 1997, focused on the northeastern Gulf of Mexico. Both studies compiled data on the abundance and distribution of marine mammal species, but the surveys occurred mostly on the continental slope between 100 m and 2,000 m isobaths, not the outer continental shelf (Davis, Evans, and Wursig, 2000).

As was discussed above for the Atlantic region, abundance and distribution data for the Florida manatee are lacking for some areas of Florida's Gulf of Mexico coast where surveys are not being conducted on a regular basis. Areas such as the Florida Panhandle and the Everglades do not have the robust dataset for estimating abundance of the manatee population in the Gulf of Mexico.

Historical distribution and abundance of bottlenose dolphin and Atlantic spotted dolphin are well studied (Davis et al., 1998; Davis et al., 2000; Würsig et al., 2000), but no survey data have been collected since Hurricane Katrina and, in that time, scientists have noted displacement among fish populations (W. Hoggard, pers. comm., 2006). This observation suggests displacement may have occurred with dolphin populations as well (W. Hoggard, pers. comm., 2006). Additional surveys may be warranted to determine the movements of these two species in relation to the OCS. Much of the data needed to accurately identify the different stocks of bottlenose dolphin are lacking for most of the Gulf of Mexico (Department of the Navy, 2003). Genetic, photo-identification, and tagging data would provide the basis to determine the number and distribution of the various stocks.

Data on the seasonal movements of Bryde's whale are lacking. Specimens of this species are seen in winter and spring months along the Florida panhandle in the eastern Gulf of Mexico between the 100 m and 1000 m isobath (Mullin and Fulling, 2004), but it is uncertain where they travel or reside during the summer and fall months (W. Hoggard, pers. comm., 2006).

Data are lacking on the abundance of fin and humpback whales in the OCS of the Gulf of Mexico. The few humpback whales that have been sighted east of the Mississippi River Delta in the fall, winter, and spring may be passing through the area during migration from the northern feeding grounds to the breeding areas in the Caribbean (Department of the Navy, 2003). Further surveys would provide the data to determine actual estimates of both species in this area if a resident or transient population does exist.

A survey of the predominant species in the OCS should be conducted using satellite and conventional radio tracking. Data on diving behavior should be collected to provide clues on potential prey species and resource partitioning among marine mammals, which will provide information on factors that influence the distribution of cetaceans. Behavioral data should be collected to determine whether animals are using various geographic areas for certain activities such as social and sexual behavior, feeding, resting, or transiting (Davis and Fargion, 1996).

In summary, the collection of baseline data (e.g., abundance, distribution, importance of site for foraging or breeding) of key species within an area will be necessary once a proposed offshore wind park site has been chosen. A list of objectives was presented above under *Collection of Baseline Studies* under Section 5.1.1.6 *Current Models Used to Determine Impacts* and should be used to focus research efforts once proposed sites are chosen. Following the collection of baseline data on key species, impact assessment studies should be developed and implemented based on concerns to species in the area.

Impact Assessment Studies

Sound. Of all the impacts discussed above, the effect of sound on marine mammals from offshore wind parks is considered to be of most concern among the scientific community. It is also the most complex to study. A review of the existing literature and the monitoring results from offshore wind parks suggests that intense, repetitive sounds related to pile driving or seismic surveys during construction or preconstruction phases of offshore alternative energy facilities may be a significant impact. Some key research objectives to quantify sound impacts on marine mammals in relation to offshore wind parks include the following:

- Explore datasets currently available from U.S. Naval activities and European offshore wind parks to determine what data have already been collected, what can be applied to U.S. waters, and what data are still needed. Develop a database that houses all the relevant information.
- Understand the hearing capabilities and sensitivities of some of the key marine mammal species.
- Understand the range of sounds used for marine mammal communication and the significance of communication between animals.
- Determine what distance from a sound source a marine mammal will elicit a behavior response and how repetitive sounds may affect this distance, i.e., define the zones of influence for similar groups or species of marine mammals.
- Determine what effect (e.g., behavioral responses, masking of sounds) sound may have on an animal or population.
- Analyze the intensity of sound levels generated by pile-driving in shallow U.S. waters.
- Define the sound levels that may be generated by wind parks with various environmental conditions (e.g., shallow waters, changing wind conditions), turbine number and arrangement, and foundation type. Understand the effects of mitigation on preconstruction and construction activities.

A body of literature exists for the potential impact of U.S. Navy activities including sonar on several species. In addition, the Naval Undersea Warfare Center in Newport, RI, models sound impacts from naval activities using the density of animals in the area coupled with a computer simulation of the propagation of sound. The computer simulations are populated with site-specific data of the habitat in which the activity is being conducted (J. Bell, pers. comm., 2006). These models and literature should be reviewed to determine what may apply to species in potential wind park areas and what information is absent. Measurements and modeling will be required to understand the sound radiation patterns and propagation from each wind park in question. Commonly used and simplified sound propagation models are often different for complex shallow-water habitats. Reliable modeling requires extensive measurements of several environmental variables (Madsen et al., 2006). While specific measurements will be tied to a proposed site, it would be prudent to review literature for shallow-water sound characteristics and propagation in the frequency ranges expected, and then develop methodologies and protocols for collecting required information after a site is proposed. Initial sites and projects will serve as templates and models for those that follow.

Relevant studies from the existing literature should be reviewed to determine what information is and is not transferable from European studies considering the differences between priority sites in the United States and the already developed sites in European countries. Differences in the physical parameters (e.g., water depths, salinity, substrate types, structural differences) or biological parameters (e.g., species presence) may be identified that would highlight data that would be useful for the U.S. review.

Following the literature reviews, a database needs to be compiled and organized to list all historical literature on marine sound from anthropogenic sources. The database should include international data as well as data collected from shipping industry groups and military organizations (NRC, 2003).

Data on hearing thresholds are lacking. The majority of audiograms are derived from studies using only one animal. The age, health, motivation of the animal, and history of the animal can affect the hearing threshold. Free-living individuals could have lower hearing thresholds than confined individuals (Koschinski et al., 2003). Currently audiograms are available for only a small number of species (10 odontocetes, 11 pinnipeds) of the 119 marine mammal species present today. All audiograms were made for smaller species that were held in captivity (NRC, 2003); thus, data are lacking for large whale species. Some smaller species may need to be re-evaluated for sound impacts from offshore wind parks. The Nysted offshore wind park study observed measurable effects in harbor porpoise during the weak operating wind park sound. Turbines produce energy at very low frequencies and that energy was thought to be barely audible to porpoise at a distance of 100 m based on previous studies. More studies would help determine if the sound from Nysted wind parks is different or more intense, or if the hearing of harbor porpoise is better at lower frequencies than originally thought (Tougaard et al., 2006a). Hearing studies should focus on key species found in OCS waters.

Information is insufficient to assess the potential impacts of operational turbine sounds to key species such as endangered whales. It is important to determine if low-frequency sounds from wind turbines mask sounds from fish or potential prey (Tougaard et al., 2005b). More studies would assist in determining the impact of short- and long-term behavioral disruption, including abandonment of important feeding and breeding habitats, energetic implications, and the effects of stress.

Pile driving operations involve sound pressure levels that are high enough to impair the hearing system of marine mammals near the source and disrupt their behavior at considerable distances from the source (Thomsen et al., 2006). Data are insufficient to predict the distances at which different kinds of effects are likely to occur for species at greatest risk of exposure, mainly baleen whales and pinnipeds. This information is needed to define different zones of sound influence, as well as to set the distance at which operations must be halted if a marine mammal enters the area. Studies are also recommended that analyze the cumulative effects of a series of single pile driving activities (Neumann, 2005).

Although some measurements of the sounds created by wind farms have been taken, measurements of the sound produced from different numbers, arrangements, foundation types, and sizes of wind turbines in different areas, coastal morphology, seabed characteristics, and conditions (e.g., wind speeds and temperature) are lacking (Dolman et al., 2003).

Studies that assess the impact and critical values of mitigation measures such as scheduling activities to minimize impact (e.g., avoiding work during calving and reproductive periods in critical areas) and allowing for sufficiently large low-noise habitat reducing sound emissions by using technical measures such as bubble curtains (Koschinski et al., 2003) should also be considered.

*Electromagnetic Fields***.** Electromagnetic fields created by the electric underwater cables between turbines and to shore may affect orientation and disrupt navigational abilities for marine mammals (Gill et al., 2005). The high voltage that is transmitting power between devices and the mainland has the potential to interact with marine mammals that may be sensitive to electromagnetic fields. The potential for disturbance from OCS alternative energy structures may/may not be significant but few studies have been done to determine possible impacts (Gill et al., 2005). Further studies on the variability in the B-fields and their potential impact on magneto-sensitive species (University of Liverpool, 2003), and the electric and magnetic field strengths associated with new design 245 kV submarine power cables that may be used in offshore wind park sites (Gill et al., 2005), would provide the basis for more informed assessments.

Increased Vessel Traffic. Current literature suggests that effects on marine mammals from vessel traffic (e.g., sound, disturbance, harassment) are short term and unlikely to be permanent; however, there is a lack of appropriate measures and data on behavioral reactions of exposed animals and the short- and long-term consequences of exposure (Madsen et al., 2006). Studies have shown that an elevation in ambient sound levels as a result of increased vessel traffic may cause changes in marine mammals such as motor behavior (Janik and Thompson, 1996; Nowacek et al., 2001; Hastie et al., 2003) and vocalization changes (Au and Green, 2000; Buckstaff, 2004), which in turn could affect foraging, reproductive activities, and navigation. Currently most studies that assess the effects of anthropogenic sound are observational rather than experimental, and thus, they lack appropriate controls (NOAA, 2004). Recent studies on right whales have measured behavioral changes in response to shipping vessels using acoustic tags that monitored movements, received sound fields, and set physiological parameters (NOAA, 2004). Behavior studies should include examination of both acclimation and avoidance.

NOAA (2004) recommended the following topics that needed further examination:

- Additional and more extensive controlled exposure experiments on behavioral reactions of marine animals to vessel noise (i.e., determine species-dependent dose-and-response relations for noise from various vessel classes).
- A continued investigation of behavioral responses of marine animals to periods of increased ambient noise levels (from both natural and anthropogenic factors), including changes in calling characteristics and other acoustic displays.
- Continued and accelerated development of acoustic tag technologies and deployments.
- Determination of the relationship between acoustic dosage and behavioral response both within and between species in a variety of environmental conditions.

Use of a matrix will aid in site-specific identification of species, information needs, and potential impacts. Endangered species including the North Atlantic right whale will be a priority. Noise, particularly during the construction phase, may lead to disturbance, behavioral modification, and habitat displacement. Vessel traffic may increase jeopardy. New methods to supplement more traditional ones will be required for fine-grain, site-specific characterizations, determination of possible impacts, and implementation of mitigation measures.

Caution is advisable when transferring information about findings, mitigation measures, and management systems from one site to another because differences among sites may be significant.

Baseline information, whether from existing literature or from site-specific surveys, is important in identifying sites with minimal impacts and in determining if and when an impact has occurred.

5.1.6 Sea Turtles

5.1.6.1 Potential Impacts

Sea turtles are similar to marine mammals—they are endangered or threatened, oceanic, and difficult to study. Sea turtles may spend as little as 3 to 6 percent of their time at the surface of the water (Lutcavage and Lutz, 1997). In addition, they are linked to the benthic environment, and at times they hibernate in the substrate. Potential impacts that may affect sea turtles in outer continental shelf (OCS) waters during offshore wind park construction and operation are listed in table 5-10. These impacts have the potential to create chronic, sublethal effects (e.g., stress) that may induce behavioral or physiological changes. Behavioral changes (e.g., avoidance of foraging sites, changes in migration patterns) may lead to a decrease in sea turtle productivity or survival.

Table 5-10: Potential impacts to sea turtles from offshore wind parks.

Construction Phase	Potential Impacts—Sea Turtles
Construction Vessels	Behavioral changes, displacement from noise; increased risk of ingestion of trash and debris from service vessels; Increased risk of collision; attraction from brightly lit vessels
Seismic Surveys	Behavioral changes, displacement from noise
Foundation Installation	
Pile Driving	Impulse sound may cause behavioral changes, displacement
Foundation Installation	Attraction to brightly lit sites; prey displacement, increased turbidity
Scour Protection	Attraction to brightly lit sites; habitat alteration, increased turbidity, sound and vibration, displacement
Cable Laying	
Trenching	Attraction to brightly lit sites; habitat alteration during cable laying
Anchoring	Entanglement
Operations Phase	**Potential Impacts—Sea Turtles**
Turbine Towers	Displacement from noise
Turbine Foundations and Scour Protection	Changes in prey due to habitat alteration—introduction of artificial substrate
Cables	Electromagnetic fields–orientation and migration issues
Service Vessels	Behavioral changes and/or displacement from noise; increased risk of ingestion of trash and debris from service vessels; increased risk of collision

Increased service vessel activity has the potential to increase the risk of collisions with sea turtles. Of the stranded sea turtles collected between 1987 and 1993, 17 percent on the U.S. Atlantic coast had boat-related injuries (Teas, 1994 a, b). Collisions with vessels may kill 50 to 500 loggerhead sea turtles per year (NRC, 1990). Sea turtles do not appear to be overly agitated by the presence or sounds of vessels, but they may avoid areas of high activity or dive when approached by a vessel (NMFS, 2002).

An increase in vessels in the OCS also may increase the amount of gear or debris entering the marine environment. Sea turtles are quite vulnerable to commercial fishing gear that has been discarded from boats (NRC, 1990). Monofilament line is the most common type of equipment to entangle turtles; other debris includes rope, plastic bags, plastic sheets, and trawl and gill netting (NRC, 1990). Any lost equipment or trash from a service vessel is a potential risk to sea turtles because they may become entangled in discarded gear or mistake some types of debris for prey.

It is assumed that sea turtles can detect sound associated with increased vessel activity, and they may experience some temporary impacts, although to what degree is unknown (NMFS, 2002). One observation of a leatherback responding to a boat motor indicates that this species may be sensitive to low-frequency sounds, or to the mid- or high-frequency components of the motor sound (NMFS, 2002).

Activities that occur during the construction period may cause adverse effects to sea turtles within the area. Brightly lit sites or lights on vessels used during construction activities may impact sea turtles if construction occurs after daylight hours. Hatchlings are known to be attracted to light (Witherington and Martin, 1996) and, if wind parks are in close proximity to nesting beaches, hatchlings may orient toward the lighted areas or vessels, potentially disrupting their migration to the open ocean. Attraction to lights around construction sites may also lead to predation of hatchings because birds and fishes also congregate around lighted areas (Witherington and Martin, 1996), just as light naturally attracts other prey such as crabs.

The sounds from construction activities (e.g., pile driving, placement of scour protection) potentially may affect sea turtles. The skull and shell of sea turtles act as the receiving mechanism for sound (NMFS, 2002). Little information is available on the hearing capabilities of sea turtles, but some studies indicate that they hear in the lower frequencies (below 1,000 hertz [Hz]) (ONR, 2005). Startle responses including head retraction and limb extension were observed in loggerhead and Kemp’s ridley sea turtles when exposed to short, audio-frequency vibrations while in captivity (NMFS, 2002). Other studies observed turtles swimming toward the surface of the water when exposed to low-frequency, high-intensity sounds (20 to 80 Hz, 175 to 180 decibels [dB]) (Lenhardt, 1994). Swimming toward the water surface may be the quickest response a sea turtle has to lessen the impact of an intense sound. McCauley et al. (2000) observed sea turtles showing avoidance behavior at 2 kilometers (km) away from a sound source at 165 dB re microPascal (μPa), and at 1 km away from a sound source at 175 dB re 1 μPa. Those data were based on very few observations and need further examination. Klima, Gitschlag, and Renaud (1988) exposed Kemp’s ridley and loggerhead sea turtles to underwater explosives (detonated during the removal of an oil platform in the Gulf of Mexico) by placing the animals in cages located at various distances from the source: 229 m, 366 m, 549 m, and 915 m. Mathematical models estimated the pressure level of the explosives to be at 221, 217, 213, and 209 dB, respective to the distances. Two Kemp’s ridley and two loggerheads were found unconscious at 366 m, and one loggerhead was found unconscious at 915 m. Other physical problems (e.g., dilated blood vessels at the base of the throat and flippers) were observed at 229 m, 549 m, and 915 m, and persisted for several weeks after the explosion. A letter from the National Marine Fisheries Service (NMFS) to the U.S. Army Corps of Engineers on the Cape Wind offshore wind park stated that sound levels should not exceed 180 dB to protect sea turtles from stress or injury (Battelle, 2004).

Construction activities such as foundation installation and cable laying that cause a decrease in water quality from seafloor disturbances may also impact seagrass beds and livebottom that are preferred sea turtle habitat. These impacts may be temporary, but they could have indirect impacts on sea turtles by causing a temporary loss of habitat for foraging or hibernating (NMFS, 2002). Total suspended solids associated with seafloor disturbance during these activities may cause displacement of sea turtles from critical foraging areas caused by displacement of prey; however, this is expected to be a short-term effect (Battelle, 2004). A secondary impact may occur from the release of contaminants in the disturbed sediments. Sea turtles are known to bioaccumulate contaminants from the ocean through consumption of contaminated prey (Gardner et al., 2006).

Lower intensity, continuous sounds such as those generated by wind turbine operation may have the ability to interfere with communication, location of prey, and orientation for sea turtles if they are within the same frequency ranges heard and used by sea turtles (Richardson et al., 1991). Sea turtles may also use acoustic signals along with other cues to locate natal nesting beaches (Battelle, 2004). The sensitivity of sea turtles to sound levels has not been well studied, and more measurements would allow better understanding of the response of sea turtles to operating wind parks.

The physical presence of wind parks may interrupt typical movements of sea turtles as they forage or travel to nesting beaches. The habitat change from open shoals to a structure-oriented habitat may disrupt their seasonal movements to important feeding or nesting areas (Battelle, 2004). Sea turtles have been observed to use areas of topographic relief (e.g., natural reefs) and oil and gas structures for foraging (Gitschlag and Herczeg, 1994). Offshore wind parks may have a similar attractive effect for sea turtles by aggregating food sources. Lohoefener et al. (1990) found that sea turtles were positively associated with oil and gas platform locations (i.e., generally closer in distance to platforms than expected) for all seasons, with the exception of winter, in the north central Gulf of Mexico. Other platforms showed no associations. Platforms that did have regular associations with sea turtles had two commonalities: (a) platforms were smaller than those with no associations, and (b) platforms were unmanned. The study did not identify what characteristics attracted the sea turtles to the platform (i.e., prey).

Sea turtles may be affected by the electromagnetic field (EMF) produced by buried cables between turbines and from the turbines to shore. Studies have shown that sea turtles use the earth's magnetic field for orientation and migration (Irwin and Lohmann, 2003). Female sea turtles are also thought to use the earth's magnetic field for returning to their natal nesting beaches (Lohmann and Lohmann, 1994). The EMF from wind park cables may interfere with the natural ability of sea turtles to sense the earth's magnetic field and potentially hinder their movements. Some studies show that sea turtles may not be affected if they are unable to use magnetic cues because other signals may be used. Papi et al. (2000) observed that magnetic cues were not essential for adult green sea turtles to navigate 2,000 km, and the sea turtle's navigational performance was not weakened when it was unable to detect magnetic north. The use of the earth's magnetic field may vary among species and individual animals within a species.

Some reports have shown that cables buried at least 1 m below the sea floor have a magnetic field that is extremely weak compared to the earth's magnetic field (SEAS, 2000), and therefore, no adverse impacts may occur. The magnetic field from the Nysted wind park cable to shore was approximately 5 microtesla (µT), used to define the intensity of a magnetic field, at 1 m above the cable; the natural magnetic field in Denmark is 45 µT (Tougaard et al., 2006). The weak magnetic field of the cable compared to the natural magnetic field may indicate that impacts to marine animals would be minor. Gill et al. (2005) concluded that burial of the cables had no weakening effect on the magnetic field. Further studies on the production of EMF from buried cables associated with offshore wind parks would improve the ability to determine potential impacts.

Regular maintenance of an offshore wind park will increase the service vessel traffic during the operational phase of the wind park. An increase in vessel traffic may cause an increase in sea turtle collisions or boat-related injuries, behavioral changes, or displacement from the area. Other impacts include an increased risk of ingestion or entanglement with lost gear or debris.

5.1.6.2 Results of Monitoring at Existing Offshore Wind Facilities

No monitoring studies have been completed for sea turtles at existing offshore wind parks, as sea turtles are not present in the areas where offshore wind parks are located. The lack of monitoring data at offshore wind parks represents an information need in determining impacts for this resource.

5.1.6.3 Current Models Used to Determine Impacts

Currently only one environmental impact assessment has been completed for an offshore wind park that occurs within sea turtle habitat (i.e., Cape Wind, MA). The following tasks were completed before the analysis of impacts (Battelle, 2004):

- Completed a comprehensive literature search for the offshore wind park location to determine what species were present and what impacts the proposed project may have on the species.
- Consulted with resource agencies for more information on stock assessments, sightings, strandings, and population studies data.
- Analyzed sediment cores from the project area to determine if contaminant levels were below established thresholds set in reference guidelines.
- Analyzed service vessel routes and known sea turtle concentration areas.
- Estimated sound levels to be produced by the wind park using acoustic modeling. Determined if sound levels exceeded the 180 dB threshold established by NMFS at or beyond the 500-m safety radius.
- Determined cumulative impacts that may occur in the area (e.g., dredging operations in close proximity to the wind park) and the effect on sea turtles by analyzing sound levels, space and available habitat, and harassment and collision risks.

The Cape Wind EIR determined that no direct, indirect, or cumulative impacts were expected other than minor, temporary impacts that may occur during initial construction activities (Battelle, 2004).

5.1.6.4 Proposed Mitigation Measures

Several mitigation measures have been proposed to lessen impacts to sea turtles, although most have been developed for other offshore projects. Several measures would apply in the construction and operation of offshore wind parks as well:

Construction

- Use soft-start techniques for activities that generate impulse noise—a gradual increase in the sound source level allowing sea turtles to respond to the sound and move away from the site before they are harmed (Jarvis, 2005).
- Use onsite, government-appointed observers to survey the area for sea turtles before and during activities that generate high-intensity sound levels (Jarvis, 2005). If an animal enters the area, activities cease.
- Use short-term, temporary, and transient lighting on vessels. Deck lights are downshielded to prevent upward illumination, which can cause illumination of surrounding waters.
- Monitor underwater sound during initial monopile construction to ensure that sound levels do not exceed acceptable levels (Battelle, 2004).

Increased Service Vessel Traffic

- Enforce mandatory speed restrictions for vessels in areas of high sea turtle population densities (Battelle, 2004).
- Use knotless and nonfloating lines and all mandated gear modifications on service vessels, keeping all slack out of any potentially entangling material.
- Require review of NMFS *Responsible Marine Wildlife Viewing* documents by all personnel and crew members aboard service vessels (http://www.nmfs.noaa.gov/pr/education/viewing.htm).

Electromagnetic Field

- Bury cable to at least 1 m below the seafloor to reduce the exposure of marine mammals or their prey to EMF (University of Liverpool, 2003).
- Increase the permeability and conductivity of the cable to decrease EMF (University of Liverpool, 2003).
- Insulate cables and secure earthing at both joints to reduce EMF (University of Liverpool, 2002).

5.1.6.5 Information Needs

Baseline Studies

Approximately 65 datasets from past survey studies are available for review in the OBIS-SEAMAP database. This online database provides aerial, ship-board, and telemetry data collected on sea turtles in most U.S. and some international waters from 1978 to 2007 (Read et al., 2007). This database would be an important source to review after more specific site locations are chosen for offshore wind parks. Some baseline data are available for sea turtles in the Recovery Plans and Assessment Reports for each species (NOAA Fisheries, 2007); however, these data are mostly for sea turtle nesting sites as opposed to offshore areas. The U.S. Navy has compiled a number of assessments and technical reports that address sea turtle distribution, abundance, and life history data in specific locations in the Gulf of Mexico and the Atlantic (Charleston to Jacksonville, central North Carolina, and eastern Gulf of Mexico) (Department of the Navy, 2001; 2002a; 2002b; 2003). Any proposed offshore wind park locations will need to be evaluated to determine if there are major foraging areas or migration paths in close proximity to the proposed location. Fine-grained spatial and temporal information on sea turtles in OCS waters is lacking. Standardized methodologies would improve the ability to identify abundance and distribution of sea turtles in localized areas that account for non-nesting turtles as well as nesting turtles. The following paragraphs address some of the baseline studies that are available as well as information needs associated with each region of interest.

The following species of sea turtles are present in the Atlantic, Pacific, and Gulf of Mexico waters of the United States: green, leatherback, loggerhead, and hawksbill sea turtles. Kemp's ridley sea turtles are found in the Atlantic and Gulf of Mexico regions, and the olive ridley sea turtle occurs in Pacific waters of the United States (but it is assumed to be rare in U.S. waters).

Fishery-independent, in-water studies have been completed at several sites in the Gulf of Mexico and in Atlantic waters for loggerhead and Kemp's ridley sea turtles (Schmid, 1995, 1998; Schmid and Witzell, 1997). It is difficult to evaluate trends in abundance based on these surveys because there is no standardized catch per unit effort between sites (TEWG, 2000). The Southeast Area Monitoring & Assessment Program (SEAMAP) conducted a trawl survey from Cape Canaveral, FL, to Cape Hatteras, NC, between 1990 and 2000 (NMFS-SEFSC, 2001). These surveys originally were used to assess finfish populations, but the numbers of captured sea turtles were also recorded during the nearshore tows. Although the number of sea turtles captured was low, the survey represents a decade of data that can be used to analyze trends in abundance. A 3-year study in the mid-1990s was conducted to develop density estimates for leatherback sea turtles between Cape Hatteras, NC, and the Gulf of Maine out to the 2,000 m isobath (Shoop and Kenney, 1992). The study provided seasonal abundance data, but for only one sea turtle species. Data on the distribution of sea turtles in the Atlantic are lacking, although it is known that juvenile loggerheads and Kemp's ridleys move northward along the Atlantic coast to forage as sea temperatures increase and have been found foraging as far north as the New England (Lutcavage and Musick, 1985; Henwood and Ogren, 1987; Shoop and Kenney, 1992).

Ship and aerial surveys during the GulfCet I program (1991–1994) provided seasonal abundance and distribution data on sea turtles (mainly leatherbacks) in continental shelf and slope waters (100 to 2,000 m in depth) of the north-central and northwestern Gulf of Mexico (Davis, Evans, and Wursig, 2000). The GulfCet II program (1996–1997) provided seasonal abundance and distribution data for the northeastern Gulf of Mexico (Davis, Evans, and Wursig, 2000), although the latter dataset focused mainly on the continental slope with only a small portion of the shelf waters studied. It is still unknown what specific areas in the Gulf of Mexico may be important to leatherback sea turtles seasonally or for short periods of time. Similar information needs are present for Kemp's ridley sea turtles. The Kemp's ridley Sea Turtle Recovery Team stakeholder meeting (2004) identified data needs for Kemp's ridley sea turtles in the Gulf of Mexico which included regional inshore use, geographic distribution changes, and distribution of each life history stage in all habitats. In both the Atlantic and the Gulf of Mexico, additional mark-recapture surveys in multiple areas of known utilization would improve our understanding of abundance, age/growth parameters, and seasonal migratory patterns of sea turtles (TEWG, 2000).

In Pacific waters, line-transect surveys, molecular genetics, and telemetry have been conducted in California and Oregon since 1990 to identify key foraging areas in the Pacific for the leatherback sea turtle (NOAA Fisheries, 2006). Annual surveys also have been conducted along the central and northern California coast to estimate abundance and determine distribution for leatherbacks (NOAA Fisheries, 2006). The nesting habitats outside of the United States have been well studied, but little is known about this species in open waters. Leatherback sea turtles are an oceanic species, and estimates of their population have been difficult to obtain (Battelle, 2004). The abundance and distribution of green sea turtles in the northeastern Pacific are also unknown (NMFS and USFWS, 1998). Foraging habitats have not yet been identified for the green sea turtle. This type of information is necessary for analyzing impacts of offshore wind parks on sea turtles.

An important component of baseline studies is to conduct a literature search and review past studies for certain patterns in the life history of a species. With the high spatial and temporal variation that naturally occur within a population, as well as long-term interannual changes, data collected during a 3-5 year baseline study may be misleading. Extracting historical patterns from past data collections may alleviate some of the stochastic population variation that will arise in studies with shorter time periods.

In summary, baseline studies should acquire more detailed spatial data on abundance and distribution for sea turtle species in all three regions, specific to proposed offshore wind park locations. Vessel surveys can identify high-concentration areas or high-use sites (e.g., foraging sites), but in-water survey data (e.g., mark-recapture studies) at foraging sites are needed to determine shifts in abundance and age structure. Baselines studies should focus on obtaining the following information for each proposed wind park location:

- Species present in the area
- Number, distribution, and location of sightings
- Known routes and movements in, around, or through the site
- Relative importance of the site to each species
- Specific uses of the site including temporal and spatial use (e.g., foraging grounds, proximity to nesting sites)

The data collected during baseline studies will help guide the development of the impact assessment studies by focusing on the correct species and their behavior as well as impacts of greatest concern.

Impact Assessment Studies

At present no impact assessment studies on the effects of offshore wind parks on sea turtles are available. Monitoring data on actual impacts from wind parks may not be collected until an offshore wind park is built and put in operation in U.S. waters. Baseline monitoring before construction as well as monitoring of animals during construction and operation will be necessary to alleviate this significant information need. Studies that may be conducted before offshore wind park development include impact studies on sound and hearing, EMF, increased service vessel use, and lighting.

Sound

Sub-surface sound as a result of construction activities for offshore wind parks may have significant impacts on sea turtles. Therefore, baseline and assessment studies must be developed to understand the effects. Some key research objectives that will aid in quantifying the impacts of sound from offshore wind parks on sea turtles include:

- Collection of additional data on sea turtle hearing capabilities and sensitivities.
- Determining the distance from a sound source at which effects may occur for sea turtles.
- Determining what effect (e.g., behavioral responses, displacement) sounds typical of wind parks in the OCS may have on a sea turtle or population.
- Analyzing the intensity of sound levels generated by pile driving activities in shallow U.S. waters.
- Defining the sound levels that may be generated by wind parks with various environmental conditions (e.g., shallow waters, changing wind conditions), turbine number and arrangement, and foundation type.
- Understanding the effects of mitigation on preconstruction and construction activities.

Data on the hearing thresholds among different species of sea turtles are lacking, as well as threshold data for individuals of the same species and different ages. Information on the hearing capabilities of sea turtles is necessary to determine the impacts on turtles from construction and operational sounds associated with wind parks.

Further studies would provide the data on which to estimate the distances at which different kinds of effects (e.g., pile driving, increased service vessel noise) are likely to occur for sea turtles for settings similar to where wind parks will be located in the OCS. Studies that evaluate the area that will be affected by sound associated with a proposed offshore wind park would provide the basis to fully analyze the effects on sea turtle populations. This information may help predict whether sea turtles will be displaced during migrations or from foraging areas as a result of the sound.

Measurements and modeling will be required to understand the sound radiation patterns and propagation from offshore wind park operations. Sound will vary by factors such as location, depth, number of turbines, and wind condition. A comprehensive analysis of sound propagation will be needed for each proposed wind park location using transmission-loss calculations and incorporating the background sound already present in the local area to determine cumulative effects of sound. Understanding sound that potentially will be received by sea turtles is critical in determining the degree of the impact.

Behavior responses elicited from sea turtles when sounds or activities occur, and the consequences of such responses, need to be better understood. Startle responses, avoidance behavior, physical injury, and mortality were observed in sea turtles when they were exposed to various sounds (NMFS, 2002; Lenhardt, 1994; McCauley et al., 2000; Klima, Gitschlag, and Renaud, 1988) as discussed above. These data were based on very few observations, thus further studies would improve the ability to determine what effect the response has on individuals as well as on the population.

It is not known if wind park sound will interfere with acoustic signals sea turtles use to locate prey, find nesting beaches, or communicate. No studies were available that evaluate the masking or interference of wind turbine sound on signals routinely used by sea turtles. Further studies on acoustic parameters of the signals also will improve analysis of potential effects.

The effectiveness and critical values of proposed mitigation measures are unknown. Few studies are currently available that evaluate the mitigation proposals. Gitschlag and Herczeg (1994) found that aerial surveys were more effective than surface surveys (i.e., from a ship) in locating sea turtles before oil platforms were removed. More studies like this are necessary to determine which mitigation measures are worth using.

Electromagnetic Fields

The specific cabling arrangements and thus the magnetic fields emitted from the arrangements to be used at U.S. facilities are not well characterized. Depending on the geometry of the cables, the EMF produced may be different than cable arrangements at existing installations.

Better knowledge of the behavior responses elicited from sea turtles when they are exposed to levels of EMF from cables would help understand the consequences of such responses. Direct effects such as disruption of orientation and navigation may impact a population of sea turtles, whereas indirect effects (e.g., displacement of prey as a result of EMF) may impact sea turtles on a smaller scale, forcing individuals to forage in other locations.

A better understanding is needed on how sea turtles use magnetic fields for navigation and orientation. Studies show that sea turtles use the earth’s magnetic field for orientation and migration; however, other studies indicate that sea turtles have other signals for navigation when they are unable to use magnetic cues. Further studies of hatchlings, juveniles, and adult sea turtles would help determine how important magnetic fields are for movements.

Vessel Traffic and Lighting

Additional and more extensive controlled exposure experiments on behavioral reactions of sea turtles to vessel noise (i.e., determine species-dependent dose-and-response relations for noise from various vessel classes) would improve the ability to predict potential impacts of offshore wind parks.

The effects of brightly lit areas in the OCS on all life stages of sea turtles are not fully understood. Answers to the following questions would allow for better impact assessment: Do brightly lit areas in OCS waters affect hatchlings or juveniles foraging in surrounding waters? Do lighted construction areas attract sea turtles and cause additional mortality from predators?

Cumulative impacts from a wind park with hundreds of turbines over a large area may be different than single navigational buoys or platforms.

5.1.7 Flying Animals

Flying animals potentially affected by offshore wind parks include birds, bats, and certain types of insects such as butterflies (thus the broad category of Flying Animals). Most information on behavior and potential impacts is available for birds; information on bats is sparse; and information on insects is essentially nonexistent.

5.1.7.1 Potential Impacts

Birds

The current understanding of potential impacts of offshore wind projects on birds is based on the knowledge of the geographic distribution and behavior of certain species, past studies of land-based parks, and on directly documented and modeled avian impact analysis at existing offshore wind parks in Europe.

More than 200 species of birds regularly use or travel over the waters of the United States outer continental shelf (OCS). Any proposed wind project would have a preconstruction avian resource involving a subset of these species. The impact of a wind project on avian resources is defined as the realm of changes that occur to the preconstruction avian resource during and after wind project construction. Potential impacts to birds from offshore wind development involve two major categories: direct collision with turbine structures (rotor and support tower) or roto-produced wind turbulence and behavioral changes. The former simply means that wind turbines introduce a source of collision threat to bird populations using wind project areas. The latter means an indirect impact affecting bird population fitness through altering their preconstruction energy expenditure patterns. It involves a spectrum of species-specific attraction and avoidance behavior to various aspects of wind projects, which are summarized in table 5-11.

Table 5-11: Potential changes in bird behavior and resulting impacts from offshore wind projects.

Behavioral Change	Potential Avian Impact
Avoidance (lateral deflection)	Barrier to movement (migration, feeding flights), increased energy expenditure, reduced fitness, decrease in population, decreased collision risk
Avoidance (displacement)	Habitat loss, displacement from feeding grounds, reduced energy intake, increased energy expenditure, reduced fitness, decrease in population, decreased collision risk
Attraction (opportunistic)	Habitat gain, creation of new feeding grounds, creation of perch sites, increased energy intake, decreased energy expenditure, increased fitness, increased collision risk
Attraction (disorientation)	Disruption of normal migratory senses and behavior, increased energy expenditure, reduced fitness, increased collision risk

Avoidance behavior (lateral deflection) has been documented with seaducks (eiders and scoters) at offshore wind projects in Denmark and Sweden (see section 5.1.7.3). This occurs when a population of birds that normally would have flown over the preconstruction project area now flies around the developed wind project. The avoidance is triggered by a visual (and possibly auditory) response to the turbines. The significance of such impacts depends on the energetic consequences of the additional flight necessary to circumnavigate wind projects. While the additional energetic costs in the European studies have been calculated to be minimal, accrued impacts from multiple projects have the potential to be significant.

Avoidance behavior (displacement) has been documented for a variety of waterbird species at European offshore wind projects (see section 5.1.7.3). This occurs when a population of birds that normally would have fed in the preconstruction project area does not do so after the project is built. The significance of such impacts depends on whether birds can find suitable alternative feeding grounds. The European studies suggest that the effect of any particular small offshore wind project is likely to be minimal; however, accrued impacts from multiple projects have the potential to be significant.

Attraction behavior (opportunistic) has been documented for a variety of waterbird species in Europe (see section 5.1.7.3). The attraction is caused by new food sources (e.g., fish, invertebrates) inhabiting the developed project that did not inhabit the area before construction. The attraction also may be caused by perching opportunities offered by the service access platforms of the turbines or other platforms associated with the wind project. The benefit of the new food resource and perching sites potentially increases risk of collision with turbines.

Attraction behavior (disorientation) has been documented with certain types of artificial lighting that may be used for aviation or navigation obstruction lighting on turbines. It has also been documented with permanent lighting on oil platforms and boats (Russell, 2005). In this case, the attraction behavior very likely is caused by a disruption in the physiological senses birds use for navigation at night (Evans et al., 2007; Gauthreaux and Belser, 2006; Avery et al., 1980). The ensuing disorientation may cause birds to fly in the vicinity of the artificial light for extended periods of time. This results in unproductive energy expenditure and increased risk of collision with wind turbine structures. Attraction behavior (disorientation) also includes any deviations of migratory flight caused when landbirds investigate turbine structures for possible landing sites. Such behavior is potentially an unproductive increase in energy expenditure.

To assist in avian impact analysis for offshore wind projects in the United States, it is useful to divide birds into different groups that are likely to have similar behaviors. Birds are typically first divided into waterbirds (birds that are adapted to land on water and spend much of their time over water (seaducks, terns, gulls, loons, grebes, alcids, pelagic seabirds) and landbirds that are not adapted to make landings on water and do not regularly spend much time over water (waders such as herons, rails, shorebirds, raptors, migratory songbirds). Depending on the location of the wind project, waterbirds and landbirds can be divided into different groups. For consideration in the initial buildout of wind projects in the Gulf of Mexico and Atlantic regions, the following categories would be appropriate:

- Seaducks (e.g., eiders, scoters, long-tailed duck)
- Seabirds (pelagic species such as petrels, shearwaters)

- Other waterbirds (e.g., loons, grebes, cormorants, alcids, gannet)
- Terns and gulls
- Shorebirds (e.g., sandpipers, plovers)
- Night-migrating passerines (e.g., thrushes, warblers, sparrows)
- Other landbirds (e.g., herons, rails, swallows, diurnal migrant passerines)
- Raptors (eagles, hawks, falcons, owls)

Table 5-12 lists potential impacts to different avian species groups. The potential magnitude and significance of these impacts may vary greatly between wind project sites. Any specific wind project may have most of these general species groups plus specific subgroups or species that raise regional attention. For example, projects in the Gulf of Mexico may consider different species groups than those in the Atlantic. There are likely to be greater numbers of seaducks wintering off of the Atlantic than in the Gulf, but species such as blue-winged teal may be more common in the latter environment. Some likely impacts on avian resources resulting from offshore wind projects in the United States are described below.

Seaducks, Seabirds, Terns, Gulls, and Other Waterbirds

Impacts can be expected to be similar to those documented in Europe for these species. For seaducks this includes collision risk and disturbance patterns involving avoidance behavior. Impacts will involve loss of habitat, barrier effects, and problems associated with cumulative wind project development, all of which have energetic consequences for seaduck populations. For the other groups mentioned, the same concerns with seaducks may apply; however, for some species groups (e.g., gulls) the new habitat the wind project creates may produce new attraction behavior. Detailed population studies will be necessary to understand the ultimate impact of a wind project on these species.

Table 5-12: Potential impacts of offshore wind facilities on birds.

Species	Potential Impact
Seaducks	Collision hazard, displacement from feeding grounds, barrier to migration and feeding flights, cumulative impact of multiple wind parks
Seabirds	Collision hazard, displacement from feeding grounds, barrier to migration and feeding flights, cumulative impact of multiple wind parks
Terns and Gulls	Collision hazard, displacement from feeding grounds, creation of new feeding grounds, barrier to migration and feeding flights, cumulative impact of multiple wind parks
Other waterbirds (e.g., loons, grebes)	Collision hazard, displacement from feeding grounds, barrier to migration and feeding flights, cumulative impact of multiple wind parks
Shorebirds	Collision hazard
Night-migrating passerines (e.g., warblers, sparrows)	Collision hazard, disorientation from turbine obstruction lighting, use of service access platforms as rest stops
Other landbirds (e.g., herons, rails, swallows)	Collision hazard, use of service access platforms as rest stops
Raptors (hawks, owls, and falcons)	Collision hazard, may create new habitat for falcons

Night-migrating passerines

During their transits across the Gulf of Mexico and the western Atlantic, much of the migratory songbird migration will occur well above the height of wind turbines, and there will be no avian impacts. In strong headwinds or rainy weather migrant songbirds will be forced down to near sea level, and they will accumulate in potentially large numbers on the service access platforms of offshore turbine structures. Such scenarios were addressed to some extent in Russell (2005) regarding songbird stopover on oil platforms, and the overall impact for such events is difficult to assess (see section 5.1.7.5). While the turbine structure will provide a potential rest stop for weary migrants, the rest stop likely will not have any substantial food source for refueling. In heavy rains, birds that might eventually have succumbed and died at sea are provided a landing site where they can wait out the rain without exerting much energy. When the weather clears, they may continue their flight with less overall energy expenditure, thanks to the turbine structure.

In some cases it is possible that where passerines use the turbine structures as rest stops rather than continuing to fly, they could have made safe landfall without the stop. Such delay without being able to refuel might weaken them to the point where they are not capable of making landfall. Another complicating factor is the potential for turbine structures to harbor migrant falcons. The turbine structures would provide no cover for migrant passerines to hide, and they would be easy prey for falcons, introducing the possibility that more songbirds would become falcon prey because the turbine structures are present.

In headwind situations when such birds might be tempted to use turbines as a rest stop, they likely would be flying below turbine height, and therefore, they may not be at increased collision risk; this hypothesis needs to be verified through observational studies. It is surprising there are no accounts in literature of migrant passerines accumulating on the base of turbine structures in Europe, perhaps because most European projects have been built closer to shore.

After an offshore wind facility is constructed, the total impact on avian resources is calculated as the sum of species-specific consequences caused by project construction plus the ensuing direct effect caused by collision. The overall impact is measured as changes in population size. If seaducks that avoid feeding in offshore wind projects move on and find suitable feeding grounds elsewhere, but their population remains the same, then the impact of the wind park project may be viewed as minimal for seaducks. Even though the initial analysis shows a low impact, a specific wind project could still play a role in population decline through cumulative impacts if additional wind projects are later added. Terns, gulls, and cormorants may face some increased collision mortality from feeding close to wind turbines, but this may not affect their population if the fitness of the regional population is augmented by an increased prey base and roosting stations. Accurate and comprehensive avian monitoring programs, which are covered in section 5.1.7.2, will help in understanding the impact of wind projects on avian resources.

Bats

Potential impacts to bats involve collision risk (with rotor, support tower, or with rotor-produced wind turbulence) and expenditures of critical energy reserves in their investigation of potential rest stops or foraging opportunities. While bats are regularly documented in specific regions of the OCS of the United States, little is known about the context of their presence there—whether this is true migration behavior or a case of bats being unintentionally blown offshore.

Understanding this will be important for evaluating potential impacts to bats caused by offshore wind parks.

5.1.7.2 Results of Monitoring at Existing Wind Parks

Offshore Wind Parks

According to Fox et al. (2006) in their review of information needs to support environmental impact assessments (EIA) in Europe, four projects (Tuno Knob, Nysted, Horns Rev, and Kalmar Sound) have "provided good quality data" on the effects of wind parks on birds postconstruction. Table 5-13 describes the study objectives and types of surveys conducted for these and other offshore monitoring programs at European offshore wind parks. The results of the studies are discussed in the following paragraphs.

Tuno Knob Wind Park

A 3-year study on abundance and distribution of birds before (1994–1995) and after (1996–1997) construction and at reference sites was conducted at Tuno Knob (Guillemette et al., 1998; 1999). Common eiders (*Somateria mollissima*) declined by 75 percent and common scoters (*Melanitta nigra*) by more than 90 percent from the preconstruction baseline year compared to the postconstruction year. No decrease in eiders was observed at control sites during this same period. Scoters decreased at the wind park and the control site. Eider tolerance for how close they would fly or land from the turbines changed from 100 meters (m) preconstruction to 300 to 500 m postconstruction. There were no detectable effects on eider distribution and abundance when the turbines were operating (turbines switched on) or were motionless (turbines switched off).

During this same period, blue mussel (*Mytilus edulis*), a preferred prey species, declined markedly at the wind park, but not at the control site. The authors suggested that bivalve populations are "characterized by large inter-annual variation in recruitment" and that, even if there was a successful spatfall, the biomass of preferred prey size may have been low, or it was subject to high predation by other species (e.g., sea stars) that year.

Flocks of eiders were small during the study, and because their sensitivity to disturbance may increase with flock size, these results may not be applicable at other sites. Other study characteristics that affected the results were that surveys were limited to the winter season, species other than seaducks were not addressed, and the number of turbines at Tuno Knob is small (10).

Following the study on potential disturbance effects discussed above, a study on nocturnal flight activity of seaducks at Tuno Knob was conducted in 1998–1999 (Tulp et al., 1999). Major results of the 2-year study showed nocturnal flight activity of eiders and scoters within (turbines plus 500 m buffer) and near Tuno Knob, mostly within the feeding area and between feeding and resting areas. Nocturnal flight activity was 3 to 6 times higher on moonlit nights than dark nights; this intensity was comparable to activity observed during dusk. Also, more groups of eiders than expected flew outside the wind park than through the wind park, indicating that wind parks may be flight path barriers. Flight activity in the vicinity of the wind park was lower than 1,000 to 1,500 m away from the outer turbines, suggesting active avoidance.

Table 5-13: Monitoring studies conducted at offshore wind parks in Europe.

Wind Park	Survey Years/Citation	Survey Types	Objectives
Tuno Knob, Denmark: 10 turbines; online since 1995	1994–1997; Guillemette et al., 1998, 1999	Aerial and ground surveys at Tuno Knob and control site; benthic prey sampled annually	Establish and quantify short- and long-term effects of disturbance; sample prey to assess variation in food supply
Tuno Knob	1998–1999; Tulp et al., 1999	Radar: nocturnal and ship-based, visual observations: tower and ship-based	Determine the nature and intensity of nocturnal flight activity for eiders and scoters within and near the wind park
Nysted, Denmark: 72 turbines; online since 2004	1999–2005; Dong Energy and Vattenfall, 2006	Aerial surveys of staging and wintering birds; migration route mapping (radar, observation, GIS); Thermal Animal Detection System (TADS) at turbines	Determine abundance and distribution of key species; analyze migration routes pre- and postconstruction for changes in orientation, evidence of avoidance; record migrating birds approaching rotating blades of turbine (collision risk)
Horns Rev, Denmark: 80 turbines; online since 2002	1999–2005; Dong Energy and Vattenfall, 2006	Aerial and ship-based surveys; collision risk: video and radar observations	Determine abundance and distribution of key species; determine construction impacts; assess collision risk
Utgrunden and Yttre Stengrund, Kalmar Sound, Sweden: 12 turbines total; online since 2001	1999–2003; Pettersson, 2005	Field observations (optical rangefinder), military radar	Determine migratory paths and intensity; examine migratory and staging displacement due to wind parks (energetic costs); observe migration and assess collision risk in normal vs poor visibility
North Hoyle, U.K.: 30 turbines; online since 2003	2001–2004; National Wind Power, 2003	Boat surveys, marine radar, aerial surveys	Determine changes in bird use; determine whether turbines cause a barrier effect; assess distribution of common scoter (key species); record flight heights
Blyth, U.K.: 2 turbines offshore, 9 turbines on the breakwater; offshore online since 2000; onshore online since 1993	1991–2001; DTI, 2005	Corpse surveys on the beach, offshore watches (day and night), desk study, video monitoring	Estimate bird mortality, document changes in behavior
Scroby Sands, U.K.: 30 turbines; online since 2004	2003–2004; Perrow et al., 2006	Radio-telemetry on little terns	Assess the relative importance of tern habitat occupied by the wind park
Lely, Netherlands: 4 turbines; online since 1994	1995–1996; Percival, 2001	Radar tracking	Study nocturnal flight behavior of diving ducks approaching the wind park
Kentish Flats, U.K.: 30 turbines; online since 2005	2001–2005; Gill, Sales, and Beasley, 2006	Boat and aerial surveys	Assess distribution and abundance

Nysted Wind Park

An extensive avian monitoring program from 1999–2005 was developed for Nysted wind park in Denmark, which is located within a very important migration route for waterfowl, raptors, and passerines (Dong Energy and Vattenfall, 2006). The studies focused on pre- and postconstruction comparisons of abundance and distribution of key species, avoidance behavior, and collision risk.

Major results of the preconstruction baseline monitoring (1999–2002) showed that 20 percent of total waterfowl migration (90 percent of which were common eider) passed through the planned wind park area, and 10 percent of cormorants, eiders, and gulls passed through the planned wind park area within critical rotor height. Also, 24 to 48 percent of bird flocks passed the eastern edge of the planned wind park. Large social foraging flocks of cormorant (*Phalacrocorax carbo)*, which have a population in the area that is of international importance, may occur in the planned wind park area.

Postconstruction monitoring (2003–2005) results relevant to avoidance, collision risk, and attraction are discussed below. Physical habitat loss and gain were considered trivial at less than 4 percent of the total marine substrate in the wind park.

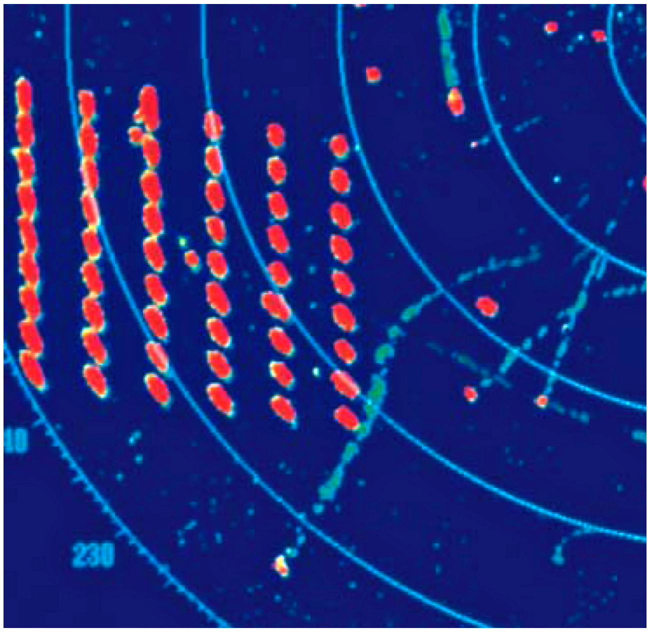
Postconstruction monitoring provided a robust demonstration of avoidance; 91 to 92 percent of birds passing through the study area avoided the wind park, as shown in figure 5-15. The data supported the hypothesis that increased lateral avoidance occurs postconstruction, and that deflection occurs close to the wind park, as shown in figure 5-14. Gradual and systematic modifications of flight routes were observed; modifications were more dramatic closest to the outermost turbines. Lateral deflection averaged 0.5 kilometer (km) at night and 1.5 km or greater during the day. Sometimes moderate reactions occurred 10 to 15 km outside the wind park. For eiders, minor flight adjustments were made at 3,000 m from the wind park, and they made marked changes in orientation at 1,000 m. Only 9 percent of flocks passed the eastern edge of the wind park postconstruction compared to 24 to 48 percent during the baseline studies. Extra energetic costs as a result of lateral deviation were considered negligible (0.5 to 0.7 percent).

There was a significant reduction in long-tailed duck (*Clangula hyemalis*) staging in the wind park postconstruction compared to the higher than average densities observed preconstruction. This was evidence of major displacement from former favored feeding areas.

A deterministic collision model estimated 68 eiders (0.94 birds per turbine per season) would collide in one autumn season (range of 3 to 484 individuals). TADS recorded one actual bird collision. The stochastic predictive collision model estimated that out of 235,000 passing birds, 0.018 to 0.020 percent would collide with turbines (41 to 48 individuals or 0.57 to 0.67 birds per turbine per season).

Although attraction behavior was observed for some species (e.g., some gulls, cormorants), there was little supporting evidence for significant changes in local abundance of any species in the vicinity of the wind park based on aerial survey data.

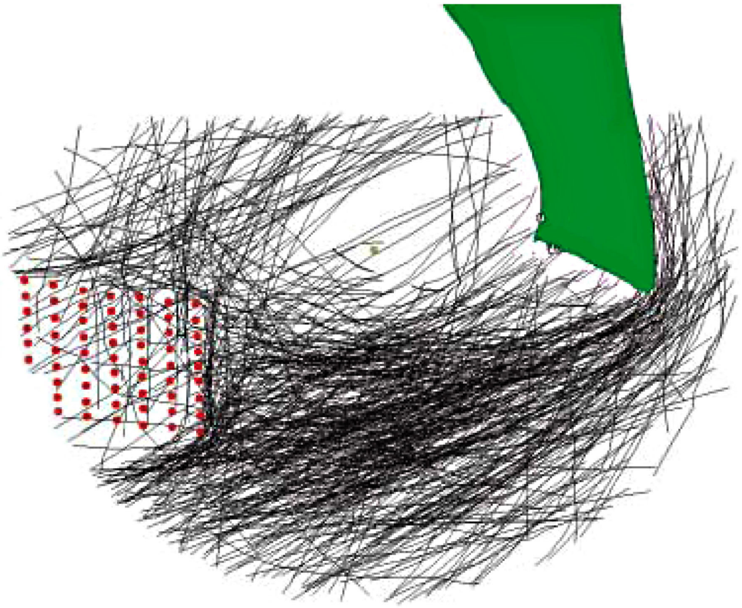
There was little evidence for or against avoidance and attraction behavior occurring during construction, but the results are based on a short survey period. The extent of avoidance is likely site- and species-specific. It must be emphasized that attraction and displacement results should



Note: Red echoes with green tails represent migrating waterbirds. Red echoes without tails indicate wind turbines.

Source: Desholm et al., 2006.

Figure 5-14: Echoes of migrating waterbirds in the vicinity of wind turbines at the Nysted wind park.



Note: Green area is land. Red dots indicate individual wind turbines. Black lines indicate migrating waterbird flocks. Green dot is the radar site.

Source: Kahlert et al., 2004.

Figure 5-15: Radar registrations from Nysted applied on a GIS platform.

be interpreted with caution because the data set is limited (e.g., small numbers of some species overall). The results may be applicable to other sites only on a very general level.

Another limitation of the study is that using TADS as the only method to measure actual collision rates was neither an economical nor practical option for estimating daily collisions at Nysted because of the small number of birds passing through the turbines.

Horns Rev Wind Park

A monitoring program for the Horns Rev wind park in Denmark was conducted from 1999–2006 (Dong Energy and Vattenfall, 2006). Changes in abundance and distribution of key species pre- and postconstruction were monitored, construction impacts were assessed, and collision risk was determined.

Relatively low numbers of birds were counted in Horns Rev and its surroundings out to 2 to 3 km during preconstruction baseline (1999–2001) monitoring. In the general area the only species recorded in significant numbers were divers, gannets (*Morus bassanus*), auks, gulls, terns, and scoters. Further monitoring focused on these species. Fewer birds were observed in the planned wind park area than in areas closer to shore.

Results of construction (2002) and postconstruction monitoring (2003–2005) relative to avoidance and collision risk are discussed below.

The Horns Rev studies indicated avoidance (displacement) and attraction trends. Divers and alcids avoided foraging and staging in the wind park during the construction phase; gulls were attracted to the area. For some species of gulls and terns there was an observed shift from preconstruction avoidance to postconstruction preference for the wind park area, but this change was statistically significant for only one species, little gull (*Larus minutus*) for the 2 km zone around the wind park. Several species (divers, scoters, seabirds) showed increased, but not statistically significant, avoidance of the wind park area and a 2- to 4-km buffer around the park postconstruction. Scoters showed a change in distribution within the study area in 2003–2004 compared to previous years.

The majority of migratory radar tracks showed lateral deflection around the wind park; of the more than 1,000 tracks recorded, only 7 percent showed no lateral deflection. Visual observations confirmed this behavioral response. Minor adjustments in orientation were observed 1 to 2 km from the wind park, and major reorientation was observed at 200 to 500 m. The average lateral deflection occurred closer to the turbines at night (0.5 km) than by day (1.5 km or greater). The few birds recorded flying between the turbines (gulls, terns) were observed at the edge of the wind park. Birds that entered the area adjusted their flight orientation to pass through in parallel with turbine rows, to avoid crossing several rows.

No collisions were observed. The high rate of avoidance and deflection probably kept the risk of collision low.

The authors state that the results of the monitoring are tentative because bird abundances were typically low and variable between surveys. Also, too few observations occurred during fog or precipitation, and the poor visibility prevented sufficient observance to assess avoidance response.

Utgrunden and Yttre Stengrund Wind Parks

Spring and fall migration studies from 1999 to 2003 were conducted in Kalmar Sound, Sweden, where Utgrunden and Yttre Stengrund wind parks are located (Pettersson, 2005). Several factors were examined including migratory paths and intensity, effects of displacement on migrating and staging birds, effects of poor visibility, and collision risk.

Eider migration paths were evenly distributed over the width of Kalmar Sound in spring 1999 before construction. In spring 2001, flight paths were displaced to the east following construction of Utgrunden. This pattern was more pronounced in 2002–2003 with the addition of Yttre Stengrund. Autumn migration was concentrated on the western side of the sound in 1999. This pattern did not change significantly postconstruction.

Lateral deflection occurred approximately 1 to 2 km from the wind parks in good visibility. Waterfowl appeared to detect the turbines under all conditions (at night and in poor visibility). To avoid the turbines, 15 percent of autumn flocks and 30 percent of spring flocks altered their flight paths. The extra energy expenditure was estimated to be 0.4 percent.

Staging waterfowl declined throughout the study period. Disturbances that could possibly lead to this include boat traffic, turbines, and changes in food supply.

During migration in Kalmar Sound, 73 percent of birds flew in daylight and good visibility; 5 percent during mist and fog in daytime; 22 percent during the night. During the Kalmar Sound study period, 1.5 million waterfowl were observed migrating through the sound, and no collisions were observed. Collision risk was estimated at 14 birds per year (1.2 birds per turbine per year). Fewer than 1 percent of flocks flew between or above turbines.

North Hoyle Wind Park

A baseline study was undertaken at North Hoyle from 2001–2002 (National Wind Power, 2003). Monitoring was conducted during (2003) and following (2004) turbine construction. Study objectives were to determine changes in bird use of the wind park, whether a barrier effect occurred, and to monitor scoter distribution.

Avoidance and attraction behavior was species-specific. Red-throated diver (*Gavia stellata*) and cormorant shifted their distribution toward the wind park during construction while shag (*Phalacrocorax aristotelis*) avoided the wind park during and after construction. Construction appeared to have very little effect on the distribution of common scoter. The analysis indicated that several species (terns, guillemots, auks) had a noneven distribution that did not change significantly after construction.

The monitoring data had several limitations. Flight height data had limited usefulness. Some species were present in low numbers; therefore, statistically it was not possible to assess changes in abundance. Also, an adequate assessment of a potential barrier effect was not possible during the study timeframe.

Blyth Wind Park

In Blyth Harbor nine turbines were erected along a harbor wall in 1992 and brought online in 1993. Two turbines were constructed offshore, and they have been operational since 2000. Major results from the onshore and offshore studies conducted from 1991–2001 including bird carcass collection from beaches, offshore watches, and video monitoring are discussed below (Still, Little, and Lawrence, 1996; DTI, 2006).

There was no evidence of significant long-term displacement of birds from their habitats (either feeding areas or flight routes). Temporary displacement of cormorants was observed. More seabirds were observed in the vicinity of the offshore turbines than the harbor turbines, although flight routes did not directly cross the offshore wind park.

The overall collision rate from 1991–1996 was less than 0.01 percent. During 10 years, 3,074 bird carcasses were collected; however, only 3 percent were directly attributed to collisions with turbines. Mortality events may have correlated with reduced visibility or poor weather conditions. Eider collision rates declined during the monitoring period, possibly because of adaptive behavior. Approximately 80 percent of observed flight activity was below rotor height; gulls were the primary species flying at rotor height and feeding between turbines.

Kentish Flats Wind Park

Preconstruction surveys conducted at Kentish Flats in 2001–2002 included the wind park location, a buffer zone, and a control area (GREP, 2002). Surveys were also conducted during construction (2002–2005) (Gill, Sales, and Beasley, 2006). No significant changes in abundance of bird populations were reported between the preconstruction and construction periods. The studies had limitations that included lack of data from the control area during the peak period for some sensitive species (e.g., divers), inconsistent sampling dates, and seasonal and interannual variation in numbers and distribution. Despite the lack of statistically significant differences, observational data suggested that red-throated divers and great and lesser black-backed gulls (*Larus marinus, Larus fuscus*) decreased in abundance, herring gulls (*Larus argentatus*) increased, and fewer common terns (*Sterna hirundo*) flew through the wind park site.

Scroby Sands Wind

Following preconstruction surveys at Scroby Sands from 1995 to 1999, Perrow et al. (2006) concluded that a large colony of little tern (*Sterna albifrons)*, the most important breeding site in the United Kingdom, was in proximity to the proposed wind park area, and a large percentage of birds in the colony were using the wind park area. Perrow et al. (2006) also conducted a radio-telemetry study on terns in 2003–2004. The major result this study showed was that with an active nest, birds occupied a range span of 4.6 km; failed nesters traveled up to 27 km in a single feeding bout. Therefore, the wind park was within the foraging range, but only a small proportion of terns were observed foraging in the area. Study limitations included few location fixes, a lack of multiyear data, and an inability to account for prey availability.

Lely Wind

Percival (2001) monitored the flight behavior of diving ducks at Lely, a four-turbine park built in the Netherlands in 1994, during the winters of 1995 and 1996. The main result this study showed was that ducks could adjust their flight behavior according to ambient light levels and fly around the turbines. Adjustments were made closer to the turbines on moonlit nights than during dark nights. Also, most birds passed around the outer turbines than between them.

Summary of Monitoring at Offshore Wind Parks

Most offshore studies focused on determining the significance of the following impacts: avoidance, attraction, and collision risk.

Impacts associated with avoidance include displacement of foraging and staging flocks from within the wind park area, and in most cases, a buffer area around the turbines. Displacement, or a change in abundance of staging birds postconstruction, was reported for Tuno Knob (eiders and scoters), Nysted (long-tailed ducks), Horns Rev (divers, alcids, scoters, seabirds), Yttre Stengrund and Utgrunden wind parks in Kalmar Sound (waterfowl), North Hoyle (shag), Blyth (cormorant), and Kentish Flats (divers and gulls) (Guillemette et al., 1998; Dong Energy and Vattenfall, 2006; Pettersson, 2005; National Wind Power, 2003; DTI, 2006; Gill, Sales, and Beasley, 2006).

The significance of displacement varied widely among studies. For example, at Blyth displacement of cormorants was considered temporary and there was “no evidence of significant long-term displacement” of other species from their habitats (DTI, 2006). At North Hoyle, several species were studied, but data analyses showed significant avoidance by only one species (National Wind Power, 2003). At Horns Rev, divers, scoters, and seabirds showed increased, but not statistically significant, avoidance of the wind park and a 2- to 4-km buffer postconstruction (Dong Energy and Vattenfall, 2006).

Declines in staging waterfowl were observed in Kalmar Sound and at Tuno Knob, but authors of both studies suggested that simultaneous declines in prey, disturbances from vessel traffic, or other natural variation also could be factors in the change in abundance (Guillemette et al., 1998; Pettersson, 2005). Only at Nysted did the authors suggest that the significant reduction in staging of long-tailed ducks was “evidence of major displacement from former feeding areas” caused by the wind park (Dong Energy and Vattenfall, 2006).

All studies carried cautions about extrapolating the results and applying them to other wind parks and other species, often because only a few species were studied during certain seasons. While data from most wind parks did not result in unequivocal evidence of permanent displacement of staging and foraging populations, wind parks that may be situated in important waterfowl high-use areas, particularly for seaducks, should consider displacement of these species a potentially significant impact. Kaiser et al. (2006) used a model to determine the potential cumulative effects of avoidance by feeding and staging waterfowl, based on the potential for multiple wind parks to be erected in Liverpool Bay, United Kingdom, which is discussed in the next section.

Studies on avoidance behavior for migrating flocks typically focused on measuring lateral deflection around the outermost turbines. Changes in orientation and avoidance of turbines were reported for Tuno Knob (1 to 1.5 km from turbines), Nysted (0.5 to 3 km from turbines, and sometimes moderate adjustments were observed 10 to 15 km away), Horns Rev (0.2 to 1.5 km), Kalmar Sound (1 to 2 km), and Lely (Tulp et al., 1999; Dong Energy and Vattenfall, 2006; Pettersson, 2005; Percival, 2001). Extra energetic costs as a result of lateral deviation were calculated and considered to be negligible at Nysted (0.5 to 0.7 percent) and Kalmar Sound (0.4 percent). In addition, at Nysted a decreased percentage of area migrant flocks crossed the eastern edge of the wind park postconstruction (9 percent compared to 24 to 48 percent preconstruction); and at Horns Rev, a very low percentage of flocks crossed through the wind park (7 percent of 1,000 flocks). In Kalmar Sound, 15 to 30 percent of migrants altered their paths postconstruction, and less than 1 percent flew through the parks. In contrast to the mixed results reported on displacement of staging birds, all studies that monitored lateral deflection of migrating flocks reported active avoidance of turbines.

Lateral deflection around turbines is potentially significant because it relates to avoidance, but it also demonstrates how flight adjustments may effectively lower collision risk. Also studied at Tuno Knob, Nysted, Horns Rev, and Kalmar Sound was how the effect of reduced visibility caused by nocturnal flight or flight during fog or poor weather related to increased collision risk (Tulp et al., 1999; Dong Energy and Vattenfall, 2006; Pettersson, 2005). The researchers concluded that flight adjustments often were made closer to the edge of the wind park at night or in poor conditions than during the day or in clear weather, and that flight intensity was often reduced during poor visibility. The researchers did not conclude that collision risk increases under these circumstances.

Collisions were monitored for Nysted (1 bird), Horns Rev (0 birds), Kalmar Sound (0 birds), and Blyth (86 birds) (Dong Energy and Vattenfall, 2006; Pettersson, 2005; DTI, 2006). Because nine Blyth turbines are on a breakwater, and two are only 1 km from shore, it was possible to more accurately assess actual collision rates by carcass collection on the beach than at some of the other offshore wind parks where either a single TADS unit was used on a turbine, or observation, video, or radar were used to assess collision frequency. At Blyth the collision rate was found to be minimal (0.01 percent) over a 5-year period with some species appearing to habituate to the turbines because the total numbers of collisions decreased over time. The models used to determine collision risk at Nysted and Kalmar Sound are discussed in the next section.

Attraction was observed for some species at Nysted (gulls and cormorants), Horns Rev (gulls and terns), and North Hoyle (divers and cormorants) (Dong Energy and Vattenfall, 2006; National Wind Power, 2003). The most often reported species to show attraction postconstruction were the more gregarious species (gulls, terns, cormorants). Significant attraction was noted only for little gull at Nysted and red-throated diver and cormorant at North Hoyle.

Onshore Wind Parks

Birds

Several comprehensive reviews on effects of wind parks on birds including data compiled from onshore studies are available (Langston and Pullan, 2003; Percival, 2001; Erickson et al., 2001; Erickson et al., 2002). The usefulness of extrapolating monitoring results from past offshore studies in Europe and the United Kingdom to current and future offshore sites in the United States is questionable because of factors such as differences in species studied, habitats, number of turbines, and size of turbines. Results from onshore studies may be even less applicable to offshore wind development in the OCS. For that reason, the following paragraphs give a brief synthesis of major results from onshore and coastal studies. The focus is on studies that examined disturbance effects and collision risk.

Disturbance effects on birds, primarily habitat displacement, resulting from the presence of onshore wind parks differ by species, season, and site. Reduction or absence of bird use has been documented at a range of distances from onshore turbines, with 600 to 800 m representing the high end of the range (Percival, 2001; Langston and Pullan, 2003). While Drewitt and Langston (2006) and Langston and Pullan (2003) report that 600 m is “widely accepted as the maximum reliably recorded distance” for displacement, Percival (2001) suggests that “several [studies] that have shown such relatively long-distance effects were flawed in that they did not take into account confounding factors that could have resulted in the apparent disturbance, including changes in human disturbance and habitat differences." Another criticism of onshore disturbance data is that "few studies are conclusive in their findings, often because of a lack of well-designed studies both before and after construction of the wind farm" (BirdLife, 2002). Disturbance in the form of lateral deflection and avoidance of turbines was observed at some sites, and reactions occurred 100 to 500 m from the outermost turbines (Langston and Pullan, 2003).

In general, collision rates have been reported as low or negligible at the majority of onshore and coastal wind parks studied (Langston and Pullan, 2003; Percival, 2001; Erickson, 2002; Drewitt and Langston, 2006). Average collision rates per turbine range widely—from 0.01 to 23 bird collisions annually (Drewitt and Langston, 2006). While no significant bird population declines have been reported at coastal sites, certain sites report "relatively high numbers of collisions," such as three study sites in Flanders, Belgium, where the average yearly collision rate ranged from 4 to 23 birds per turbine (Everaert and Steinen, 2006), representing the high end of the range of collision rates cited by Drewitt and Langston (2006). Also, species of conservation concern or species in sensitive life stages may be impacted, as was notable at several sites in the United States and Europe. The mean number of terns from a local breeding colony killed by turbines on a breakwater in Belgium in 2004 and 2005 was 6.7 birds per turbine per year and 11.2 birds per turbine per year, respectively (Everaert and Stienen, 2006). At Altamont Pass, CA, the collision rate was 0.06 birds per turbine per year, a low rate; but with 7,000 turbines and the presence of raptors, particularly golden eagle (*Aquila chrysaeotos*), high numbers of birds were affected (Orloff and Flannery, 1992). A 90-turbine park in Tarifa, Spain, had a collision rate of 0.34 birds per turbine per year; large numbers of griffon vultures (*Gyps fulvus*), a sensitive species, were affected.

Several of the collision studies discussed above have limitations (Langston and Pullan, 2003). For example, in many cases rates of collision were based on corpses collected, and the numbers were not adjusted for scavenging and other forms of loss. Also, corpse searches often overlooked passerines and other small birds. Also, most onshore and coastal parks have small turbines in tight clusters, which differ from offshore wind parks.

Contributions of U.S. onshore wind studies to the understanding of the effect on avian resources is limited because avian mortality has been studied at only three onshore wind projects with modern wind turbines east of the Mississippi River (i.e., Howe et al., 2002; Kerns and Kerlinger 2004; Nicholson 2003).

Bats

Mortality monitoring at terrestrial wind projects in the United States has indicated unexpectedly high numbers of bat fatalities at some projects during fall migration (Kunz, 2004). Available evidence from studies in Minnesota, Wyoming, Wisconsin, and Colorado suggests that resident populations (foraging and breeding bats) were not involved in these fatality events (Johnson, 2004). In contrast, resident bats were equally as susceptible to mortality as migrating bats at wind parks in Sweden (Ahlen, 2003). Mortality rates for bats at some wind projects in eastern North America (e.g., Buffalo Ridge, MN; Mountaineer, WV) are more than an order of magnitude greater than that for birds (Johnson, 2004). Because night migrating birds greatly outnumber migratory bats in the eastern United States, wind turbines appear to have a different and more deadly mechanism of mortality for bats than birds. Whether or not bats rely on echolocation during migration has been examined with conflicting results, but "generally, evidence suggests that bats depend on vision rather than echolocation for long-distance orientation" (Johnson, 2004). A recent study found the first evidence that at least one species of bat may use magnetoreception for long distance navigation (Holland et al., 2006).

Preliminary studies of bat interactions at terrestrial turbine structures indicate that attraction behavior to turbine structures may be involved (T. Kunz, pers. comm., 2006), which could account for the higher bat kills versus birds at wind projects in the United States. Data from wind parks in Iowa and Sweden contradict this premise, although in the Swedish study, the bats appeared to be attracted to flying insects around the turbines rather than to the turbines themselves (Koford et al., 2004; Ahlen, 2003). Artificially lit turbines did not appear to attract bats at a higher frequency than unlit turbines in Minnesota, Wyoming, Oregon, and Washington (Johnson, 2004).

5.1.7.3 Current Models Used to Determine Impacts

Birds

Potential impacts to birds during the environmental assessment phase of an offshore wind park project are evaluated using the following general approach in Europe (Casella Stanger, 2002; DTI, 2006; AMEC, 2002; Fox et al., 2006; GREP, 2002):

1. Assess the species composition, abundance, spatial and temporal distribution, and migratory patterns of birds in the vicinity of the wind park.
2. Assess the avoidance response such as whether there are disruptions in flight paths and if the wind park acts as a barrier to movement.
3. Assess the potential for disturbance including displacement and habitat loss of staging or feeding populations.
4. Assess collision risk.
5. Determine the significance of potential impacts.

Where practical, the before-after control-impact (BACI) design should be used for impact determination (Anderson et al., 1999). Collecting data at reference areas and using the same protocols pre- and postconstruction for acceptable time periods (e.g., 3 years baseline) can limit how certain variables such as changes in abundance over time or between areas affect study conclusions. The following paragraphs discuss assessment techniques and models.

1. Assess the species composition, abundance, spatial and temporal distribution, and migratory patterns of birds in the vicinity of the wind park.

A comprehensive review of existing baseline data and relevant literature is conducted before starting a monitoring program (AMEC, 2002; GREP, 2002). Data likely exists on species ranges, temporal use of the area for breeding, molting, staging, and wintering, and general migration patterns (Fox et al., 2006). In addition to variability in spatial and temporal use of an area between seasons and years, significant stochastic population variation may take place over one or more decades. Therefore, the review of existing data should include an assessment of long-term patterns, if feasible. A site-specific assessment of species composition and abundance in construction, impact, and reference areas is then undertaken. Field surveys may include aerial, boat, land, or tower-based observations and radar to document flight tracks. Camphuysen et al. (2004) provides a review of recommended survey and monitoring methods.

An assessment of the conservation status of the species and populations involved and the conservation status of protected land and water in the vicinity of the development is conducted to prioritize species for further monitoring. For example, in the Lynn Offshore Wind Farm EIA, the necessity for impact assessment on individual species was based on conservation status, proven or probable collision sensitivity, or known disturbance sensitivity, mostly based on literature review, and whether or not each species occurred in significant numbers, which was based on survey data (AMEC, 2002).

2. Assess the avoidance response such as whether there are disruptions in flight paths and if the wind park acts as a barrier to movement.

Pre- and postconstruction radar studies on flight volume, direction, and tracks are used to quantify the level of avoidance so that additional energetic costs as a result of the presence of the wind park can be calculated (Desholm and Kahlert, 2005). These studies were conducted at several operational wind parks including Nysted, Horns Rev, Yttre Stengrund, and Utgrunden (Dong et al., 2006; Pettersson, 2005). Qualitative assessments of avoidance typically are based on species ecology and avoidance data collected from other wind parks, and they tend not to be as robust as those using real, site-specific data. As technologies advance, particularly in the field of remote sensing, it may be possible to use "radar and thermal imaging equipment to construct frequency distributions of individual bird and flock trajectories (identified to species during day and night) in three-dimensional space through a defined corridor of air space in and around the proposed offshore wind farm before its construction" (Fox et al., 2006). Gathering rigorous data such as would be required for this method would make pre- and postconstruction comparisons possible. It would also allow for analyses of various weather conditions that may affect flight paths.

3. Assess the potential for disturbance, including displacement and habitat loss of staging or feeding populations.

An assessment of habitat loss due to disturbance and avoidance of birds from a preferred feeding or staging area should be based on several years of data (at least 3 baseline years) to account for annual variation in abundance and distribution (Camphuysen et al., 2004). Aerial surveys and spatial modeling are used to compare distribution and abundance pre- and postconstruction (Fox et al., 2006). Multiple years of postconstruction monitoring makes it possible to take annual variation into account when assessing displacement and habituation.

Quantifying the effects (e.g., energetic costs, increased mortality rates, lowered breeding success) of such displacement at the population level may be possible for some species. If data are collected on the feeding ecology of a species and the behavioral implications of altering its preferred feeding habits, construction of individuals-based, spatially explicit population models to test for the effects of habitat loss are possible (Fox et al., 2006). An interesting study was conducted between 2001–2004 in Liverpool Bay, United Kingdom, where several proposed and current wind parks are located (Burbo Bank, North Hoyle, Rhyl Flats, Gwynt-y-Mor, and Shell Flat). The purpose of the study was to predict the displacement of common scoter from benthic feeding areas (Kaiser et al., 2006). The researchers created a behavioral ecology model based on literature, aerial, ship-based, and benthic surveys and tidal modeling to predict changes in overwintering mortality of scoters in Liverpool Bay resulting from displacement from preferred feeding habitats. Because Liverpool Bay includes several existing and proposed wind parks, cumulative effects of displacement were also examined.

4. Assess collision risk.

Collision risk has been assessed a number of different ways with various qualitative and quantitative models. For the Burbo project, Casella Stanger (2002) suggested two approaches in the EIA. The quantitative model the authors described was the Scottish Natural Heritage (SNH) model (also known as the "Band Model" or "Collision Risk Model" (CRM)) that required data input including the numbers of birds flying through the wind park area, flight height, and the geometry and rotation of the blades (Scottish Natural Heritage, 2000). The original version of this model assumed no avoidance behavior. The authors of the Burbo EIA considered the necessary data gathering impractical for an offshore wind park. They opted to take a qualitative approach based on the proportion of observations within turbine flight height. No avoidance action was assumed.

Two approaches were undertaken for the Lynn Offshore EIA (AMEC, 2002). The empirical approach involved extrapolating data collected from other wind parks on turbine characteristics, flight height, direction, speed, and bird size. Using this approach, the predicted average collision rate was 1.23 collision mortalities per turbine per year. The theoretical approach was based on the two-stage SNH model. In stage 1, the probability of a bird flying through the rotor swept area and the probability of collision was factored into the model; avoidance was factored into the calculation in stage 2. Using the SNH model, the worst-case collision risk estimate was 0.02 birds per turbine per year.

Two models were used to determine collision risk at Nysted; the predictive model, based on literature, estimated that an average of 68 eiders would collide with turbines in one season (0.94 birds per turbine per season). The stochastic model used parameters from radar, TADS, and 1,000 iterations of the model, and predicted 41 to 48 individuals (0.018 to 0.020 percent of total passing; 0.57 to 0.67 birds per turbine per season) would collide with turbines during fall migration (Dong Energy and Vattenfall, 2006). Collision risk, using radar data, was estimated at 14 birds per year in Kalmar Sound (1.2 birds per turbine per year). Collision risk was considered to be negligible compared to the large number of birds potentially passing (hundreds of thousands) at these sites.

For future EIAs, Fox et al. (2006) suggested using a deterministic probability model corrected for avoidance. Data collected using radar should include rates of flight movements through the proposed area, flight altitudes and trajectories, and the volume of movement over a range of conditions (Kahlert et al., 2004). Chamberlain et al. (2006) discussed the use of the CRM (Band et al., 2005) adjusted for avoidance behavior. Avoidance rates currently available in the literature are limited, and extrapolating past data to predict avoidance at future wind parks is problematic because factors such as the species studied, surrounding environment, weather at the time of the surveys, number of turbines, vary greatly by site. In addition, the avoidance rates used in the CRM can have large effects on predicted mortality rates (Chamberlain et al., 2006). Experts generally agree that avoidance rates need to be calculated based on site-specific data over a variety of conditions (e.g., different weather, in darkness) to accurately assess collision. This is discussed in the section on information needs.

To test the validity of predictive models, it is necessary to monitor actual collision rates using technologies such as TADS (Desholm et al., 2006). Another new technology that has recently been tested in Europe is the WT-Bird System (Wiggelinkhuizen et al., 2006). This system is suitable for continuous remote operation at onshore and offshore wind parks. It makes species identification possible, and it can detect and register collisions using video, audio, acceleration sensors, and signal processing capabilities. These data can then be incorporated into models that assess long-term, postconstruction mortality for different populations. After these data sets are available, potential cumulative impacts of multiple offshore wind parks in a flyway can be assessed (Fox et al., 2006). Because long-term postconstruction data for offshore wind parks is lacking, this topic is discussed further in the section on information needs.

5. Determine the significance of potential impacts.

Examples of matrices used to determine significance for birds are shown in several EIAs (AMEC, 2002; Casella Stanger, 2002). The criteria used to evaluate the impact and rank the significance of the impact are fairly generic across resource groups. Tables 5-8 and 5-9 in Section 5.1.5.3 (marine mammals) provide examples of sets of criteria used for the Horns Rev 2 offshore wind park EIA (Skov et al., 2006).

Disturbance during construction, displacement from feeding areas, flight line disruption, and collision risk were assessed for EIAs. No significant impacts were predicted for the Lynn offshore site; medium significance for a single species of diver was predicted for the Burbo offshore site (AMEC, 2002; Casella Stanger, 2002).

In the Burbo EIA, Casella Stanger (2002) assessed the potential cumulative impacts of proposed and operating wind parks (Burbo, Rhyl Flats, North Hoyle, and Shell Flat) in Liverpool Bay. The methodology used to determine cumulative effects of disturbance was to calculate the percentage of total survey observations within the four wind parks and 2 and 4 km buffers around each. Because a large percentage (36 percent) of common scoters (a species of European importance) was observed within and around Shell Flats, the significance of cumulative effects was considered to be very high for this species. Effects on red-throated divers were considered to be medium at all four sites; therefore, the cumulative effect for this species was also considered to be very high.

To be able quantify potential cumulative impacts, particularly those related to increased energetic costs because of avoidance and displacement, "modeling of overall annual energy budgets to assess the effects on fitness and ultimately the potential for impacts at the population level" should be considered, and the parameters necessary to run the models need to be collected during surveys (Fox et al., 2006).

Bats

Specific impact models for bats have not been developed, but proposed monitoring programs and impact assessment protocols have been suggested, mostly in terms of onshore wind parks (Kunz, 2004). Monitoring studies would focus on identifying species and estimating population trends and demographic, habitat, and environmental variables. Key variables that may be used to develop a collision model include flight altitude and relationship of bat position from the turbine (bearing and distance), species identification and assessment of physical condition, insect activity at turbines, moon phase, moon light intensity, cloud cover, air temperature, precipitation, wind speed, and wind direction (Kunz, 2004). Survey methods geared mostly toward onshore sites include acoustic recordings, spotlighting, night vision imaging, infrared thermal imaging, radar imaging, ultrasonic detection, and insect (prey) sampling (potentially using sticky traps) (Kunz, 2004).

One report noted that two bats were positively identified during one fall season by using TADS at Nysted, Denmark, wind project (Dong Energy and Vattenfall, 2006). All evidence suggests that bird targets will far outnumber bat targets over the OCS; therefore, radar will be an ineffective study method for bats. Based on the limited results of monitoring studies to date, automated thermal imaging will be the most effective method for studying bat activity night and day, while video and observational data may be collected during the day. These methods also will allow bat attraction and avoidance behavior to be studied and potentially to document actual collisions. Observational models similar to those used for birds will incorporate bat passage rates, any evidence of avoidance or attraction behavior, and any documented collision rates.

5.1.7.4 Proposed Mitigation Measures—Flying Animals

Mitigation measures to reduce identified impacts to birds from offshore wind projects in Europe have evolved as the study of impacts has progressed. Because of the novelty of offshore wind projects, the impact on avian resources was largely unknown during the earlier projects, and as late as 2002 (Warwick Energy, Ltd., 2002), a stated mitigation measure for impacts on birds was simply to study avian impact through pre- and postconstruction studies. Now this course is formally built into the EIA process, and usually it is not cited as a mitigation measure. For most smaller offshore projects in Europe, avian impacts were seen to be minimal, and no specific mitigation measures were stipulated, although avian studies were part of these project’s EIAs.

The most common mitigation measures in Europe have been attributed to project sitings in areas known for low bird usage and project construction timed to minimize local bird disturbance. Aspects of turbine design and project layout have been proposed to mitigate the impact on the avian population. The following paragraphs discuss basic mitigation measures for flying animals in general, although it is important to note that, because so little is known regarding offshore habitat use by bats, these measures may not be applicable to all species. Also, certain mitigation measures that were developed for onshore wind farms may not directly translate to offshore locations.

Project Siting

The first mitigation measures to protect birds at offshore wind projects in Europe were part of Government legislative actions to determine which offshore resources could be developed for wind energy. Many factors were taken into consideration for designating such areas, but among these were locations of ecological preserves including those designated “Important Bird Areas.” Such measures were first implemented in Denmark with the Offshore Wind Turbine Action Plan for Danish Waters (The Offshore Wind-Farm Working Group, 1997). This plan, established with public input, laid the regulatory framework for offshore wind energy development in Denmark. Ultimately, 15 possible areas were designated for offshore wind development (four prime and eleven supplemental sites). Similar special offshore wind development areas have been legislated by the United Kingdom and Germany.

The second stage of mitigation involving project siting occurred when alternative development sites are proposed and evaluated. Standard European procedure for wind developers is to consider alternative sites in wind energy proposals. Public input and comment also provide opportunities for developing detailed information on the relative risks to birds among alternative sites. The Cape Wind project in the United States considered alternative sites through a public scoping process, and all sites were evaluated according to their potential effect on birds.

Construction Timing

One commonly proposed European mitigation measure for offshore wind projects to reduce impacts on avian populations is the timing of project construction, particularly the timing of piling installation. For example, in the Kentish Flats project EIA, it was proposed that pile driving not occur during the main period when divers (i.e., loons) were wintering in the area or that pile driving not occur if a specified number of divers were within 400 m. Another example is specifying the timing of onshore cabling operations to avoid disturbing important roosts for wintering wading birds.

Turbine Design

In preliminary avian risk assessments for terrestrial wind energy projects in the United States, it is not uncommon to find that use of tubular towers and slower rotation speeds are stated as means to mitigate impacts on the avian population. The Altamont Pass wind project documented the benefit of the tubular design over lattice towers and slower rotor speed over older wind turbine designs with higher speeds. The tubular towers reduced perching locations, and therefore, the theoretical risk of bird collisions. Larger tubular towers and slower rotor speed designs are preferred for offshore wind projects, and accordingly, no European projects consider this design as a mitigation measure.

Service access platforms of current offshore turbine designs do offer potential roost sites for birds. In the European EIAs reviewed, no mitigation measures were proposed to reduce perching sites on the wind turbine service access platforms. The Cape Wind Final Environmental Impact Report (FEIR) proposed to use wires above potential service access platform roost locations. This proposal was in response to concerns that terns and other waterbirds would be at increased collision risk if they had any perch sites on the turbine structure.

Based on recent research on bird attraction to lights, European and United States wind projects have proposed using flashing aviation and navigation obstruction lighting as a mitigation measure to prevent attraction of certain bird species.

Turbine Layout

Aligning the layout of a turbine field so that the longer leg of the turbine project is parallel to the primary direction of bird (especially waterbird) movement (migration or feeding flights) has been proposed in Europe (Birdlife, 2002). During the Cape Wind public scoping period for the EIR, 12 different designs for turbine layout were proposed.

Turbine Operation

Shutting off turbines during periods of intense migration or in associated specific weather conditions has been proposed in United States and Mexican onshore wind projects, and it has been proposed as a potential mitigation measure for offshore wind projects in Europe (Birdlife, 2002; Everaert and Stienen, 2006).

5.1.7.5 Information Needs—Flying Animals

Offshore wind park construction potentially could directly affect flying animals (birds, bats, and insects) through mortal collisions and indirectly through alteration of migratory and foraging habits. Three major information needs are apparent. One is knowledge of flying animal distribution, movements, and behavior in the specific regions of likely offshore wind energy development. A second is an understanding of the mechanism underlying the attraction or deterrence of flying animals to offshore turbines (individual and projects) as well as an assessment of the direct and indirect impacts of those reactions. A third is the fact that no matter how much is known about these first two topics, there will always be a need for knowledge of how offshore commercial wind projects affect flying animals and a means to accurately account for or estimate collision mortality. No established method exists to account for mortal collisions of flying animals with offshore turbine structures, although several new mortality assessment methods are in development. The following paragraphs discuss these potential impacts and summarize existing information and needs for additional research.

Geographic Distribution, Abundance, and Behavior of Birds

Basic ranges and seasonality of most species are known for the OCS. For any specific alternative energy project site, consultation with regional experts will produce lists of the species that are likely to regularly occur in the area and their temporal usage patterns. What is generally lacking is detailed information on abundance patterns and behavior of most species. There are a number of other fairly detailed regional studies for specific species groups. There are also general studies covering larger regions, for example, studies that analyze coastal weather radar data showing offshore landbird migration patterns. The following discussion on existing baseline studies in the United States by region is primarily limited to those studies highlighted by resource experts interviewed during the data collection process for this literature synthesis. The researchers who authored the studies are the most qualified scientists to evaluate the adequacy of existing data and its relevance to assessing potential impacts from offshore wind farm development.

Existing information
Northeast Atlantic Region—Data exist from shipboard surveys conducted by Manomet Bird Observatory between 1978 and 1982 along the North Atlantic coast. Shipboard surveys provide accurate data on behavior and food habits within a 300-m viewing area. Surveys cannot be conducted on large ships in shallow water (e.g., shoals) where some species tend to concentrate (Forsell, 2005). The most recent pelagic bird surveys conducted in the Gulf of Maine were in 1983 and included 26 months of observation on 61 cruises (Powers, 1983). Quantitative studies were conducted between 2001 and 2004 in Nantucket Sound, the proposed location for the Cape Wind Energy Project (Cape Wind Associates, 2004).

Information on avian abundance, seasonal occurrence, and types and species of birds that use the waters off Long Island is relatively well known; the information is based mostly on observations from shore. Few systematic surveys have been conducted, and little quantitative and behavioral information is available on species likely to occur 4 to 8 km offshore in the proposed location of the LIOWP Offshore Wind Energy Project (Kerlinger and Curry, 2002). As of 2005, U.S. Fish and Wildlife Service (USFWS) were in the process of conducting surveys off Long Island, including systematic winter surveys of shoals and pelagic cruises (Forsell, D., pers. comm., 2006).

Historic radar studies of nocturnal migration for coastal regions of Massachusetts from the early 1960s and 1970s revealed large landbird movements over the OCS. The data were for altitudes above 150 m, but complex seasonal patterns were noted. A radar study associated with the Cape Wind Energy Project covered a limited area in Nantucket Sound for 30 days in spring and 30 days in fall of 2002, and 60 days in fall 2005 and 45 days in spring 2006. This study used marine radar with resolution close to the water surface. A similar radar study is underway for the LIOWP Offshore Wind Energy Project.

Mid-Atlantic Region—From 2001 to 2003 USFWS conducted aerial surveys of waterbirds up to 22 km offshore from northern New Jersey to the Virginia-North Carolina border including Delaware Bay and the coastal bays. The goal was to determine the overall distribution and abundance of wintering waterbirds in the area and characterize the distribution and abundance of birds over sandy shoal areas designated by MMS. These data are adequate for identifying broad geographic distribution of birds and identifying areas where birds concentrate. This was a winter study, and additional surveys would be necessary to describe bird use in other seasons (Forsell, 2004).

The potential project area of the New Jersey Offshore Wind Energy Project extends from Sandy Hook to Delaware Bay out to a water depth of 30 m and 32 km from shore. Little is known about avian behavior, abundance, use, and seasonal occurrence in the waters between 1.6 and 16 km offshore of the New Jersey coast because few systematic surveys have been conducted in this area. Most of what is known on abundance, seasonal presence, foraging methods, migration flight, and height of foraging birds was gathered from literature, personal knowledge, various databases (e.g., Christmas Bird Counts), and interviews for the purpose of conducting the New Jersey Offshore Wind Energy Feasibility Study (Atlantic Renewable Energy Corporation and AWS Scientific, 2004). Current knowledge of the New Jersey Offshore study area includes locations of high bird use areas such as Cape May to Cape Henlopen, Sandy Hook, the mouth of the Raritan Bay, and waters inshore of 2.4 km (Kerlinger and Curry, 2002).

Long range tracking radar with a range of 100 km was used at Wallops Island, VA, to document large nocturnal bird movements departing the coastline and heading offshore in a southeasterly direction (Williams et al., 1977). The data suggest this is the case for much of the mid-Atlantic, although the flights documented were largely above 150 m (above current wind turbine heights). Offshore flights of landbirds regularly are documented by observers in boats, but they have not been studied systematically.

Gulf of Mexico Region—Two proposed wind parks were announced in 2006 off the coast of Texas near Galveston (Wind Energy Systems Technologies) and Padre Island (Superior Renewable Energy) in State waters. Avian surveys began December 2006 for the Galveston site.

Three seabird surveys were conducted during pelagic cruises in the northern Gulf of Mexico during 1996–1997 (Davis, Evans, and Wursig, 2000). Information was documented on species distribution and seasonal use of different regions of the Gulf as they relate to hydrographic environments and specific habitat variables.

Aerial surveys of marine birds were conducted in the Gulf of Mexico and southeast Atlantic from 1980 to 1981 on the distribution, abundance, and ecology of 69 bird taxa within 111 km of the coast (Fritts et al., 1983). Information on the seasonal distribution and abundance of 102 species of marine birds that occur off the southeastern Atlantic and in the Gulf of Mexico has been synthesized and mapped (Clapp et al., 1982a; Clapp et al., 1982b; Clapp et al., 1983).

The Migration Over the Gulf project highlighted which species are trans-Gulf migrants, specific migration routes, seasonal and diel timing, and how weather patterns relate to abundance and timing of migrants (Russell, 2005). This study used human observers on oil platforms and Next Generation Radar (NEXRAD) radar.

Additional studies have been performed using NEXRAD or older weather radar stations to study bird migration over the northernmost portion of the Gulf of Mexico (Russell, 2005). These studies were concentrated in the northwestern Gulf and generally studied migration well above 150 m (above current wind turbine height).

Pacific Region—Although there have been no geographic studies related to wind parks offshore of the Pacific Coast, extensive research has been conducted on marine birds through research programs for MMS, NOAA, and other entities since the mid-1970s. A few examples are described below.

Three-year studies were conducted in the Southern California Bight (1975–1978) and Northern and Central California (1980–1983) from the coast to 175 km offshore. Data on population status, distribution, seasonality, and ecology were collected. At least 102 species of seabirds numbering 6.5 million annually may occur offshore of California. Important nesting and offshore use areas (including the OCS) were documented (Bonnell et al., 1981; Dohl et al., 1983). At-sea seabird surveys were conducted over the period 1975–2001 and compiled into the Marine Mammal and Seabird Computer Database Analysis System (Bonnell and Ford, 2001).

NOAA National Centers for Coastal Ocean Science (NCCOS) compiled and analyzed multiple aerial and ship-based at-sea data sets from 1980 to 2001 with assistance from local researchers and resource managers to create a biogeographic assessment of North and Central California (NOAA NCCOS, 2003). Expert workshops were held to create a GIS-based map of seabird use of the nearshore and offshore environment from Point Reyes to Point Conception, CA (Research Planning, Inc., 2005).

Information Needs

There is a lack of baseline data on general distribution and abundance by species group including on-water and in-air movements and behavior during migration, wintering, foraging, and staging that are necessary to accurately assess the risk to bird populations in most areas. The following paragraphs summarize information needs.

Data are limited on waterbird (e.g., seaduck) use of shoals and key ecological areas (e.g., mouths of bays, swales), and these areas are likely to be considered for wind parks. The density of scoters on mid-Atlantic shoals was an order of magnitude higher than off shoals during surveys conducted within 12 nautical miles of shore from 2001 to 2003 (Forsell, 2005). Because shoals may be used for sand mining and other purposes, cumulative effects of use of these habitats should be considered. Scoters appear to be declining in the Atlantic Flyway; therefore, any potential impacts to these species cause concern (Sea Duck Joint Venture, 2003).

Little is known about the presence, movements, flight behavior, and foraging behavior of pelagic seabirds (northern gannet, shearwaters, and storm-petrels) and terns. Seasonal and geographic gaps for Atlantic coastal and marine waterbird data likely exist for over 50 percent of the region. In their Draft Waterbird Conservation Plan for 2006-2010, the Mid-Atlantic/New England/Maritimes Region (MANEM) Waterbird Working Group discussed the paucity of pelagic data that exist, and state that survey data for this region are 25 or more years old. Species they would like to see targeted through ship-board surveys include shearwaters, gulls, terns, jaegers, fulmars, storm-petrels, gannets, guillemots, puffins, and murres. (MANEM Waterbird Working Group, 2006). More information should be gathered on loons, grebes, and alcids during migration and winter (Kerlinger and Curry, 2002).

Offshore raptor migration is poorly understood (Atlantic Renewable Energy Corporation and AWS Scientific, Inc., 2004). Because raptors may be more susceptible to colliding with wind turbines than other birds (typically while in pursuit of prey), and several raptor species are listed as state or federally endangered, information such as foraging range, habits, migratory distance offshore, and flight height should be examined (Anderson et al., 2000; Orloff and Flannery, 1992, 1996).

Little is known about how far offshore night migrating songbirds and shorebirds fly, how often they move, and how high they fly along the East Coast (Atlantic Renewable Energy Corporation and AWS Scientific, Inc., 2004; Kerlinger and Curry, 2002).

Federally threatened and endangered species (e.g., roseate tern, a federally endangered species, and piping plover, a federally threatened species) occur throughout potential project areas. Studies should be designed to examine numbers of birds, foraging behavior, migration, and the likelihood of impacts (Atlantic Renewable Energy Corporation and AWS Scientific, Inc., 2004; Kerlinger and Curry, 2002).

Information on nocturnal compared to diurnal movement of seaducks, passerines, and other species during migration and foraging is not well understood (Atlantic Renewable Energy Corporation and AWS Scientific, Inc., 2004; Kerlinger and Curry, 2002).

Migration is profoundly influenced by weather (Russell, 2005). Shutting down turbines directly in migration paths during peak movement has been shown to be very successful in reducing collisions (Richardson, 1988; Keil, 2005). Further study and analysis on weather patterns related to bird migration in potential offshore wind park locations are recommended.

Understanding ecological linkages and habitat usage by different guilds provides insight into how different species are using the environment. Basic information on the food habits of different species is generally known (e.g., plankton feeders, pelagic feeders, benthic feeders). These data should be analyzed with population and distribution data to determine concentration areas, flyways, temporal patterns of use, and behavioral reasons for using an area (Forsell, 2005).

Based on the specific information needs per bird species group described above, it is possible to highlight some key research objectives:

- Define flyways including distance from shore, density of birds within various migratory corridors, and timing of spring and fall migration.
- Determine flight height including understanding inter- and intraspecies variability.
- Understand diurnal and nocturnal movements.
- Understand foraging and wintering use of offshore habitats.
- Define potential use of offshore areas by threatened and endangered species.
- Identify temporal patterns.
- Improve baseline data on distribution and abundance of all species groups in offshore habitats.
- Analyze the effects of weather on migratory and other movements.

To achieve these research objectives, regional assessments over broad geographic areas should be conducted before starting the site selection process (Forsell, D., pers. comm., 2006; Keil, 2005; Fox et al., 2006; Camphuysen et al., 2004). Because the regions covered by this analysis are so large (e.g., the Atlantic, the Gulf of Mexico), refinement of priority regions for offshore wind development is necessary to better define the scale, cost, and suggested area covered by these regional studies. Information on timing and species occurrences in a flyway is often gathered at land-based migration watches (e.g., Avalon Sea Watch in New Jersey) (Kerlinger and Curry, 2002). There is a need for surveys that focus on pelagic species and verifying migratory corridors offshore.

An integrated study program would consist of both ship-based and aerial surveys (Camphuysen et al., 2004). Benefits of ship-based surveys include more accurate species identification, the ability to collect multiple parameters and information on distribution and abundance including flight height, flight direction, flocking behavior, nocturnal and diurnal flight (possibly using night vision or radar onboard) as well as physical and biologic oceanographic data. Benefits of aerial surveys include coverage of a large area quickly, the ability to access shallow areas, and less disturbance to some species. Aerial surveys are more cost-effective than ship-based surveys; and therefore, conducting marine mammal surveys concurrently while at sea may be a money-saving option. In addition, direct visual observations from fixed platforms may be useful in obtaining some migration information, and remote techniques such as radar and infrared-based technologies, may be used to plot migration trajectories before construction (Russell, 2005; Atlantic Renewable Energy, Corporation and AWS Scientific, Inc., 2004; Kerlinger and Curry, 2002; Desholm et al., 2006).

Recommended ship-based and aerial survey methodologies are described in a detailed report developed to help assess the effect of United Kingdom offshore wind parks on seabirds to help standardize at-sea census techniques (Camphuysen et al., 2004). Species composition in the survey regions may influence survey methods; and therefore, known information needs to be compiled for an area of survey interest during the planning phase. Expert working groups in the United States should evaluate data sets from the last several decades, particularly shipboard surveys from the 1970s and 1980s, the time period when most of the data on offshore distribution and abundance of waterbirds were collected (Forsell, 2005). Existing waterbird shipboard and aerial data sets should be compiled and incorporated into a GIS (Forsell, pers.

comm., 2006). In addition, these expert groups should be encouraged to develop and review standardized methodologies for baseline data collection, assessment of effects, and appropriate monitoring programs (Percival, 2001). One recommendation was to model new surveys to be conducted in Atlantic, Gulf of Mexico, and Pacific waters after the intensive Outer Continental Shelf Environmental Assessment Program surveys conducted in Alaska in the late 1970s and early 1980s (Forsell, D. pers. comm., 2006).

As much as 3 years of survey data would be useful in understanding key stopover, wintering, migration, and foraging locations. Even within a relatively small (on a regional scale) potential project area, it is possible to have extensive use by migrating and foraging birds in some portions of the area, and much less use in other portions (Kerlinger and Curry, 2002; Keil, 2005). In areas where systematic regional surveys have been conducted in certain seasons (e.g., aerial surveys over mid-Atlantic shoals in winter), these surveys could be expanded to include all months for at least 3 years to account for variability between years and other factors (Forsell, pers. comm., 2006; Kerlinger and Curry, 2002; Keil, 2005). In some cases, even 3 years may not be sufficient if major weather events (e.g., the presence or lack of sea ice in cold weather climates, El Niño year) may affect distribution and timing. Because spatial and temporal occurrences of waterbirds may be highly variable, reviewing literature and existing data over several decades to examine long-term use patterns and fluctuations will be essential. In addition, detailed monitoring studies over a 2- to 3-year period within potential projects areas (which are defined as much smaller areas than those covered by regional assessments) are recommended (Keil, 2005). Survey protocols need to be consistent in order to compare distribution and abundance pre- and postconstruction.

Attraction and Avoidance Behavior of Birds to Offshore Turbines

Understanding bird attraction and avoidance behavior to offshore turbines is important for ultimately understanding the impact of wind projects in their environments. Beyond simply documenting attraction and avoidance behavior, it is important to understand the mechanisms causing the behavior. For example, why do lights attract or deter birds? Why do some species of seabirds fly around turbines? Understanding the mechanism potentially will enable more bird-friendly wind project design involving aspects such as navigation obstruction lighting and the geometry of turbine arrays.

Existing Information

A number of excellent European studies have focused on documenting wind project avoidance behavior of seaducks and seabirds (see section 5.1.7.2), but little information exists on why these behaviors occur. Other than general radar portrayal of avian migration patterns, there are no offshore wind project studies on attraction or avoidance behavior that include migratory landbirds, including raptors. Aggregation behavior of migratory landbirds, including raptors, has been documented at offshore oil platforms and boats (Russell, 2005).

Information Needs

It is unknown if offshore turbine structures will cause migratory landbird aggregation because of their attraction to aviation and marine navigation lighting (Evans et al., 2007) or use of the turbine structures as rest stops.

Recent research at terrestrial locations indicates that flashing lights do not induce aggregations of migratory landbirds (Evans et al., 2007; Gauthreaux and Belser, 2006); however, it cannot be assumed this also will be the case offshore. Landbirds may exhibit different kinds of behavior to lights offshore (e.g., they may associate lights with land; they may react to lights reflecting off the water surface).

Cumulative effects of avoidance behavior and displacement as a result of offshore wind parks acting as barriers to movement are not well understood in Europe, and have not been studied in the United States.

For offshore wind development in the United States, studies geared toward documenting and understanding attraction and deterrence behavior for all these species groups will be essential. Most of these studies will need to occur postconstruction. For seabirds and seaducks, it will be important to first conduct preconstruction surveys on the usage patterns of these species at a prospective wind site so that any changes that occur postconstruction can be evaluated. Using a rigorous BACI study design is a desirable method for gathering necessary data for comparisons pre- and postconstruction (Anderson et al., 1999).

According to Fox et al. (2006), “there is a very clear and urgent need to gather extensive and better quality data on [site] specific avoidance rates of different bird species to turbines to enable effective parameterization of bird avoidance rates to incorporate into collision risk modeling.” Several authors including Chamberlain et al. (2006) reiterated that a lack of real data for key parameters necessary to quantify avoidance behavior makes it difficult to test the validity of predictive models.

Pre- and postconstruction studies would provide the basis to determine whether turbine aviation and navigation lights will cause aggregation of migrant landbirds. A conjunction of acoustic, radar, and other methods (e.g., Evans et al., 2007; Gauthreaux and Belser, 2006) could be used to evaluate bird response to standard turbine obstruction lighting. A test facility such as an offshore meteorological tower could be fitted with standard turbine lighting. During monitoring of avian activity, repeated on-off tests of the lighting (e.g., Evans et al., 2007) could be used to deduce whether the light causes bird aggregation. Offshore control sites with and without permanent lighting known to cause bird aggregation could be used for reference. Conducting the study at two sites in different regions simultaneously would speed data acquisition. Demonstration that the standard combination of aviation and marine navigation lights on turbines does not induce migratory landbird aggregation would greatly relieve concerns for potential impact of offshore wind energy for this species group.

The postconstruction monitoring protocol for birds likely will involve acoustic, radar, and thermal imaging; therefore, testing these three methodologies together would be useful in the preconstruction period to work out technical issues before postconstruction studies begin. The USFWS Communications Tower Working Group was formed in 1999 to address the problem of bird mortality at communications towers; the issue of bird attraction to aviation lighting is a primary research area. The group comprises many top bird migration experts in the United States.

The effectiveness of current models and the thoroughness of data being collected for model input affect how scientists understand the cumulative effects of multiple wind parks on avoidance behavior (barrier effect), displacement, and local impacts that affect population levels (Fox et al., 2006). Researchers in the United States should discuss and agree on standard approaches to impact modeling and consider improvements in data collection and parameters used.

Mortality and Collision Risk Assessment for Birds

An important component of the impact offshore turbines have is the number of birds that collide with turbine structures (rotor, support tower) or that are injured by rotor-produced wind turbulence. Flying animal strikes at inland projects can be assessed in ground surveys; this is not possible for offshore wind projects. In most cases collision victims fall in the water. Two new offshore mortality assessment methodologies are being developed in Europe, and evaluation of one is just beginning in the United States. All methodologies need further testing and documentation.

Existing Information

No offshore mortality studies that quantify actual avian mortality exist. Section 5.1.7.3 describes collision risk models at European offshore wind projects.

Information Needs

Promising tools to help evaluate mortality at offshore wind energy facilities may exist in the development of devices for automatically detecting flying animal collisions with turbine structures. In Europe, such research is proceeding along two lines. One involves acoustic and accelerometer devices for detecting collisions at turbine structures with triggered video documentation of the events providing verification (Verhoef et al., 2004; Wiggelinkhuizen et al., 2006). The second involves automated detection of flying animal targets near turbines using an automated thermal target detection system (Desholm et al., 2006). Both systems are under development and more research is needed. Currently, the necessary equipment is expensive to purchase and costly to operate and “there remains a need for a cheap equipment solution that provides time-specific records of avian collision on an extensive scale…” (Desholm et al., 2006).

Acoustic monitoring alone has been used to document bird strikes at communications towers in the United States (Evans, 2000). Preliminary experimentation of the acoustic technique at a single turbine in a Wisconsin wind project has revealed potential for automatic acoustic strike loggers at wind projects (Howe et al., 2002; Evans, pers. comm., 2007). Detailed work documenting the acoustic signatures of strike indicator sounds is necessary, but this method offers the potential for an automated collision strike system that would be less expensive than the systems under development in Europe. A study on the potential of automatic acoustic registration of flying animal strikes will be occurring at the Maple Ridge wind energy facility in New York State during fall 2007 (Watson, pers. comm., 2007). In addition to documenting collision sounds, vocalizations of flying birds in the vicinity of the turbine structures will be logged and identified to species to aid risk assessment. If this study shows that acoustic strike logging is effective, additional studies on this methodology likely will be necessary at terrestrial wind projects before offshore projects could be fitted with such devices as part of postconstruction impact studies.

A detection method using accelerometer devices was developed recently in California to detect avian collisions with power lines by sensing collision vibrations (California Energy Commission, 2004). Application of this methodology has been proposed for wind turbines (Pandey et al., 2006). Similar to the acoustic strike detection method, accelerometer devices could be operated remotely on turbines and the strike data could be transmitted digitally for analysis. Potentially every turbine in a wind project could be monitored to provide more accurate collision reporting.

Geographic Distribution, Abundance, and Behavior of Bats

Existing Information

Fairly compelling, although mostly anecdotal, evidence exists indicating offshore habitat use by tree bats. The evidence is based on occurrence on islands, sometimes consistently over multiple years and decades, landings aboard ships, and offshore observations (Arnett, E., pers. comm., 2006; Cryan, P. pers. comm., 2006). The majority of observations occurred during autumn migration. Expected migratory corridors include onshore (e.g., ridge tops and open plains) and offshore (coastal regions) habitats (Kunz, 2004). Patterns in bat mortality at land-based wind parks suggest migration of most bat species killed by turbines, and peak mortality tends to coincide with periods of migratory activity (Cryan, P., pers. comm., 2006; Johnson, 2004; Kunz, 2004; Morrison, 2006).

Information Needs

Information is inadequate on bat migration (Energetics Inc., 2004; Johnson, 2004; Kunz, 2004). The primary information need at this time is understanding the extent and context to which bats fly offshore. Topics that require further research include migration patterns, migratory corridors, how migration is affected by weather, flight altitude and characteristics, group size, feeding behavior, and temporal variation in bat activity levels.

Rigorous data are lacking to elucidate patterns of mortality in relation to factors such as location and weather (Energetics, Inc., 2004). Existing data should be compiled and analyzed (Energetics, Inc., 2004). Information is also lacking on whether turbines attract or concentrate flying insects (prey items) (Kunz, 2004).

Defining research priorities is difficult because so little is known about bats in regard to offshore wind development. Given the opportunity, experts in the field may be able to use visual techniques (e.g., visual spotlighting), thermal imaging, radar, and radio-telemetry to better understand how the offshore environment is used. A potential issue is the small number of animals; results might not provide enough information to accurately define migratory corridors. A workshop involving key national researchers is merited, as interest in conducting studies is high (Cryan, P., pers. comm., 2006). Also, offshore research planned for birds should include a bat observation component.

Attraction and Avoidance Behavior of Bats to Offshore Turbines

Bat attraction and avoidance behavior has been studied most successfully at inland sites in the United States with thermal imaging methods (Kunz, T., pers. comm., 2006). Similar methodology has been used in Europe (e.g., Desholm et al., 2006). Such study could occur simultaneously with bird attraction and avoidance studies.

Kunz (2004) and Ahlen (2003) discussed several hypotheses on how and why bats are killed (mostly related to attraction or an inability to avoid obstacles) that could be tested. The following is a list of possible hypotheses applicable to offshore wind parks:

- Sensory failure may cause migrating and feeding bats to fail to visually or acoustically [using echolocation] detect wind turbines.
- Bats may perceive turbines as a roost attraction similar to roost trees.

- Bats may have an acoustic attraction to the low frequency sounds emitted by some wind turbine blades.
- Migrating and foraging bats may be drawn to high concentrations of prey and insects and then become entrapped in the wake of the vortex or collide with the turbine.
- Tree bats may use tall obstacles as staging areas for mating (Cryan and Brown, in press).
- Migrating bats may experience reduced maneuverability because their body mass and wind loading lessen their ability to avoid wind turbines.
- Bats may be killed by rapid decompression while encountering the turbulence associated with rotating turbines.
- Bats may be attracted to lights associated with the wind park, and this hypothesis has been tested on lighted and unlighted turbines (see section 5.1.7.2), but the hypothesis needs further evaluation.

An expert workshop could provide a forum to discuss how to pursue testing these hypotheses. Potential research that may be applicable to birds on attraction and avoidance behavior may also be applicable to bats.

Geographic Distribution, Abundance, and Behavior of Insects

Little is known about insect presence and behavior in the OCS of the United States, and what impact it might have on offshore wind energy development. The Gulf Coast region is the most important region for consideration because a number of species of butterflies, moths, and dragonflies are believed to regularly cross portions of the Gulf of Mexico. The most detailed study on the matter is the Migration Over the Gulf Project (Russell, 2005) in which observations of insect presence on oil platforms in the northern Gulf were documented. So little is known about the potential impacts to insects, top insect experts would need to convene a workshop to determine a course of action to evaluate potential impacts and research recommendations.

5.2 Wave Technologies

Proposed wave energy technologies for the OCS are described in Section 3.2. Most of the current designs consist of floating structures that are held in position by anchors and floats. However, technologies could be developed that would be mounted on seabed foundations. Only demonstration devices have been deployed as of early 2007. It is difficult to evaluate the potential impacts of wave energy technologies because the devices are still under development and prototype testing, and thus are likely to be modified to improve performance.

Three environmental impact assessments were reviewed for the following test projects: 1) the six wave buoys to be deployed 1.1 kilometers (km) offshore of the Marine Corps Base at Kaneohe, Hawai'i (Department of the Navy, 2003); 2) the four AquaBuOYs to be deployed 5.9 km off Makah Bay, Washington (AquaEnergy, Ltd., 2006); and 3) the Wave Hub project located 25 km off the south west coast of England (Halcrow Group Ltd., 2006a). The Wave Hub project is essentially a “plug-in” that will be available for a range of wave energy devices. All of the environmental impact statements noted that there was much uncertainty in their analysis because of the lack of actual monitoring data.

Several generic assessments of the potential environmental impacts have been completed. Entec UK Ltd. (2003) published a generic environmental scoping study for the Pelamis wave device. Hagerman and Bedard (2004) published a summary of the environmental issues of wave energy technologies in the United States. ABPmer (2005) published a similar summary of potential nature conservation and landscape impacts of wave, tidal, and wind energy development in the Welsh territorial waters. WaveNet (2003) published a summary of the potential environmental impacts of wave energy in Europe and made recommendations to minimize the impacts and conduct studies to address information needs.

The European Marine Energy Center (EMEC, 2005) developed guidance for wave and tidal energy developers interested in testing their marine energy conversion devices at the offshore facilities at EMEC. They identified the types of impacts that might be caused by various types of wave energy technologies (listed in table 5-14), and the issues that developers were required to address in their application to EMEC. This guidance also included evaluation criteria for ranking the magnitude of ecological effects, socioeconomic effects, and stakeholder concerns as major, moderate, minor, negligible, no interaction, or positive. A summary impact matrix was provided as a tool for presenting the results of the environmental assessment of the proposed test project.

With such limited information on the likely designs and no actual studies on environmental impacts, the following sections on potential impacts are necessarily general in nature and based largely on extrapolation from other types of marine installations.

Table 5-14: Ecological and socio-economic impacts to be considered in environmental assessment of wave energy projects (EMEC, 2005).

Issue	What should be considered/Why is it important?
Ecological issues	
1. Ecological energy balances and flows	Consequence of energy extraction and physical presence of devices in the sea should be assessed, e.g. changes in vertical mixing, may lead to changes in offshore and coastal habitats/features and subsequent effects to biological communities (see 7).
2. Disturbance to seabed habitats	Anchoring, mooring/foundation installation, operation, and maintenance equipment, and other seabed disturbances can lead to disturbance/destruction of seabed habitats.
3. Disturbance to water masses	The scale and implications of changes to such factors as nutrients, temperature, light levels, turbidity (suspended sediments), surface waves and current patterns should be considered.
4. Shoreline disturbance	Activities that have the potential to cause change to the coastline such as erosion/deposition and change in character, either directly or indirectly should be considered.
5. Disturbance of landward areas	Onshore activities should avoid onshore habitats important from a conservation perspective and minimize the loss of natural habitat.
6. Behavioral changes in wildlife	Test activities have the potential to affect the distribution of wildlife. The potential influence of activities and facilities on wildlife, in particular those protected by European Directives and national legislation (also see issue 7) should be considered.

Table 5-14: Ecological and socio-economic impacts to be considered in environmental assessment of wave energy projects (EMEC, 2005).

7. Impacts on conservation areas/protected species	Any interference with designated conservation areas and protected species, of international, national and local significance should be considered.
8. Contamination of water, seabed and wildlife (including fish stocks)	Contamination may result from effluent discharge, chemical discharge/leaching/leaks, oil discharge leaks, sewage discharge, dumping of waste. All potential sources, planned or accidental should be considered.
9. Wildlife entanglement, entrapment and collision	The potential for damage and entrapment of wildlife, in particular marine invertebrates, fish, mammals and birds, should be addressed in relation to structure, operation, season, and location. Impacts may include entanglement or collision with any blades/rotors, jamming in joints, and entrapment.
10. Underwater sound, light and vibration	Test devices and associated activities are likely to produce sound, light and other disturbances that may disturb and affect the behavior or the well being of marine life. Although the exact cause and effect relationships can be difficult to determine, there is interest in this issue from regulators and stakeholders.
11. Airborne sound, light and other nuisances	Airborne sound, light and other nuisances can affect wildlife (potentially offshore, coastal and onshore) and impinge on coastal resident communities and recreational activities.
12. Electromagnetic and electrical effects	Some organisms e.g. elasmobranch fish (sharks, rays and skates), are particularly sensitive to electric and electromagnetic fields generated from electric cables.
13. Greenhouse gas emissions	Consideration should be given to potential greenhouse gas emissions e.g. from fuel use.
Socio-economic issues	
14. Visual and landscape impacts	Devices visible from the coast and at sea may affect the landscape qualities of particular views. Factors (within navigational requirements) that help structures blend in with or enhance the landscape are important. This can include color, orientation, structural design, and materials. Consider visibility distance of lights and ensure compliance with Northern Lighthouse Bard requirements and recommendations.
15. Local air quality issues	Any emissions of combusted or vented gases have the potential to reduce air quality.
16. Interference with communication systems	Some device to shore communications could interfere with normal shipping communications.
17. Waste minimization and disposal	All efforts should be made to minimize waste. Ensure suitable storage, transport and disposal for all waste streams. Some wastes will be able to follow existing waste disposal routes, others may not.
18. Navigation/sea user interference	The presence of devices and their mooring systems has the potential to interfere with vessels and other sea users, e.g. fisheries. Although test berths will generally be avoided by such activities, they are not exclusion zones and therefore such impacts need to be considered.

5.2.1 Physical Processes

The potential impacts on physical processes largely depend on the physical nature of the installed devices–namely floating with anchors versus mounted on the seafloor, and their ability to change the shape/direction of the wave itself.

5.2.1.1 Currents and Tides

The potential impacts on currents and tides due to wave energy extraction devices are very similar to the impacts from wind parks because they are related to modification of the flow velocity and direction, and the increased turbulence. The impacts of these modified currents include changed mixing properties in the nearfield, modified sediment transport in the nearfield and farfield, and the potentially reduced capability of neighboring areas to generate power from currents. Modified wave-current interaction can also result in a modified wave climate, which will be further discussed in the next section. The presence of the structures themselves may modify tidal currents on the OCS, leading to the same nearfield impacts as modifying the main currents themselves. Changes to major ocean currents (such as the Gulf Stream) are farfield and extreme farfield impacts with reaches well beyond the continental United States; namely that those changes may affect the climate of North America as well as other continents.

Due to the uncertainty of the technologies and designs that will be chosen for future utility-scale projects, and the absence of major installations and associated monitoring data, quantifying the potential for reduction or modification to the currents is difficult. Nonetheless, the Makah Bay Project in the United States measured currents near their proposed site and concluded that there would be no modification to currents and waves (AquaEnergy, Ltd., 2006). However, the statement was made without reference to physical evidence or predictive modeling. In contrast, the Wave Hub project in the United Kingdom commissioned numerical modeling of the currents and tides. Modeling indicated a local reduction in current velocities of up to 0.8 meters per second (m/s), while simultaneously an increase in velocities elsewhere on the order of 0.6 m/s was found. The changes were all in the nearfield and changes in the farfield were negligible (Halcrow Group Ltd., 2006b).

It may be assumed that the floating structures would influence currents less than fixed or bottom-mounted structures, as a portion of the water column will still convey water.

Mitigation approaches include adequate siting to avoid locations with a particular sensitivity to altered currents, and the selection of technologies that minimize the impact to currents. The WaveNet report recommends the analysis of local currents in the pre-planning phase (WaveNet, 2003). In conjunction with the initial placements, monitoring and in situ testing to determine the spatial extents of the impacted currents, and to quantify the changes will provide data to justify future mitigation decisions.

5.2.1.2 Waves

The potential impacts upon the local wave climate have necessarily been studied as part of product development and site selection for wave energy conversion devices, as it influences the spacing and placement options of the devices themselves.

Modification of wave climate would result from wave-structure interactions (diffraction, reflection, breaking, and sheltering), and wave-current interactions caused by a modified current regime (likely less than the wave-structure components). Because the wave energy conversion devices have a significantly reduced above-water component compared with wind parks, the potential for reduced wind-wave generation capacities is much less significant than with offshore wind parks, and is likely negligible. In the nearfield, potential impacts include reduced energy available to wave energy conversion devices, changed navigational conditions, wave loads on adjacent structures, and sediment transport under waves. In the farfield, the modified wave climate could affect the recreational potential of nearby shorelines (e.g., surfing and swimming beaches), sediment transport along adjacent shorelines (possibly leading to changed shoreline erosion and deposition patterns and rates), and reduced capacity for neighboring areas to implement wave energy conversion devices. Fixed, or bottom-mounted devices are expected to have a greater impact on the wave climates than devices that are floating with anchors (WaveNet, 2003).

Unlike offshore wind parks, analysis of the impacts on the wave climate has been included in the environmental assessments for proposed offshore wave applications. Halcrow Group Ltd. (2006b) conducted significant numerical modeling in conjunction with the Wave Hub project. Halcrow Group Ltd. estimated between 3 and 13% reduction in wave heights at the shoreline, depending on the wave conditions. AquaEnergy, Ltd. (2006) suggested that there would be no impact on the local wave climate for the Makah Bay project, but did not reference any modeling or other predictive approaches.

As with the currents and tides portion, mitigation approaches are generally started during pre-project planning and include adequate siting to avoid locations with a particular sensitivity to modified wave climates (popular surfing beaches, shorelines in sensitive littoral cells), and the selection of technologies that have less impact, or allow storm waves to pass over the structures. The Wave Hub project consulted with community groups that could be concerned with a reduction in wave heights (in their case, it was local surfing groups), using this information to help mitigate the concerns of the community toward reduced wave heights (Halcrow Group Ltd., 2006a). In conjunction with the initial placements, monitoring and in situ testing to determine the spatial extents of the impacted wave climate will provide data to inform future mitigation decisions.

5.2.1.3 Sediment Transport

The impacts to sediment transport from wave energy conversion devices is similar to the impacts caused by offshore wind parks, however, the various types of wave technologies would result in different impacts.

Changes to waves and currents drive the changes to sediment transport. In the nearfield, the impacts are seen as local and global scour. Scour is of greater concern with bottom-mounted devices, because erosion of supporting sediments may lead to structural failure. Anchored floating devices may still experience local scour around anchor elements, chains, and even under the floating body if the installation depth is shallow relative to the draught of the conversion device. Scour may also be an issue around cables and cable trenches, particularly in the transition between rocky and soft sediment habitats.

In the farfield, the primary potential impacts are changes in seabed topographic features, littoral zone limits, and transport rates. The regional impacts in the farfield could result in widespread erosion or deposition in areas where the said process was not previously occurring. This could impact intakes and outfalls, beaches and other recreational areas, navigation channels, and shoreline vegetation. Further concerns include loss of habitat, exposure and re-suspension of contaminated sediments, damage to archaeological sites, and damage to existing infrastructure installed on or below the seabed.

With the Makah Bay project, it was determined that scour would occur during storm events, but that there would be no significant impact on the adjacent shoreline due to the small size of the project and distance from the shoreline (AquaEnergy, Ltd., 2006). Numerical modeling was conducted to determine the near and farfield impacts on sediment transport. The results indicated that the modified wave climate would not influence the nearfield sediment transport due to the installation depth. Also, there would be minimal accretion along the adjacent shoreline, since the structures were oriented such that the flow properties near the shoreline would not be changed significantly (Halcrow Group Ltd., 2006b).

In general, mitigating impacts to sediment transport from wave energy conversion devices is identical to mitigating the impacts in the case of an offshore wind park. Notable pre-project mitigation measures include siting and selection of appropriate technology, baseline surveys, predictive scour models, and assessment of the impact of a modified wave and current regime on the recession and longshore transport at adjacent shorelines. The Wave Hub project proposed trenching cables in water depths less than 20 m, and trenching them to depths between 2 and 5 m (Halcrow Group Ltd, 2006b) in order to mitigate the impacts of scour and changes to beach morphology. During construction, monitoring and observation of suspended sediments, scour development, and good construction practices (such as not leaving temporary anchors on the seabed) may be employed. Post-construction mitigation may be accomplished with bathymetric surveys as part of a morphological monitoring program, as has been done for the offshore wind parks at Scroby Sands (CEFAS, 2006) and Kentish Flats (Emu Ltd., 2005, 2006), and in the farfield at a sand feature in the lee of the Nysted offshore wind park (Elsam Engineering and Energi E2, 2005).

5.2.2 Benthic Resources

Impacts from the construction and operation of offshore wave energy installations include bottom disturbances from: the mooring system (e.g., anchors, rock bolts, and the sweep of anchor chains along the bottom), anchoring of construction and maintenance vessels, units that are attached to the seafloor to gather the power from the devices and feed it to the transmission cable, use of antifouling coatings and cleaning of marine fouling growth, and laying of cable. Potential impacts from electromagnetic fields will be similar to those described for offshore wind parks, with the exception that often the cable cannot be buried but is attached to the seafloor.

The four wave energy converter buoys off Hawai'i have anchor base plates and weights that are rock-bolted to the seafloor. The installation also includes anchors for mooring clumps and one equipment canister for every two buoys that is also anchored to the seafloor. The transmission cable to shore will be rock-bolted to the seafloor or encased in a protective split pipe, depending on seafloor conditions. Divers will direct the actual cable route to avoid vertical relief and live coral. In the Environmental Assessment (Department of the Navy, 2003), it was determined that there would be no significant impacts to benthic resources because the small footprint of the anchor systems and areas of high coral coverage were to be avoided, both at the buoy site and along the cable route.

For the demonstration installation of four AquaBuOYs off Makah Bay, Washington, the original anchoring system that used heavy chains and concrete anchors was modified to reduce the footprint of impact to the seafloor from chain sweep (AquaEnergy, Ltd., 2006). The revised mooring system consists of four vertical load anchors per buoy. The transmission cable will be anchored to the seafloor except where it crosses nearshore sediments and eelgrass beds; installation in these areas will be done by horizontal direction drilling. Anchoring of construction and maintenance vessels could also affect benthic habitats.

Halcrow Group Ltd. (2006a) determined that the potential impacts to the sediment regime at the Wave Hub in England would be small and would have no discernable effect on benthic communities. Wave energy installations require water depths of at least 30 m, and deeper water depths are preferred to ensure that the seabed does not diminish the wave energy. The mooring devices are not likely to cause scour at these depths, thus impacts to benthic resources from changes in sediment regimes are not likely to be significant.

The potential impacts of electromagnetic fields from the cable to benthic communities are generally stated in environmental impact assessments as unknown, but likely to be low because of the very low magnetic fields the cables generate. There are few studies, and very few species have been studied.

Marine fouling of wave energy devices is of particular concern because of the rapid and heavy growth of fouling organisms on submerged structures. According to the Seventh Report on Wind and Tidal Energy of the United Kingdom House of Commons Select Committee on Science and Technology (2000), "The area that appears to pose some of the largest problems for wave and tidal devices is that of encrustation..." Unlike wind farms, fouling communities will have to be prevented or removed to reduce corrosion and fatigue and maintain efficiency of most types of wave energy devices. Interestingly, one developer reported that some devices would be stabilized by the added mass (Resolve, Inc., 2006). There are currently only three options to deal with marine fouling: use of antifouling coatings, in situ cleaning using high pressure jet spray by divers or remotely operated vehicles, and removal of the device from the water surface for cleaning on site or onshore and reapplication of antifouling coatings.

Antifouling coatings can reduce the frequency of maintenance by the slow release of a biocide at the surface. Most products have been developed for the shipping industry and rely on the movement of water to accomplish the self-polishing that exposes a new layer of the coating (which would be different for moored facilities). Historically antifouling coatings used tri-butyl tin or copper as the biocide. Because these coatings work through the slow release of the biocide and they have to be re-applied after several years, there could be concern about the long-term accumulation of these persistent compounds from large arrays. The impacts of tri-butyl tin on marine organisms in ports and harbors have been well documented; it has been banned in the United States, and international conventions have been proposed to phase out the use of tri-butyl tin (Champ and Pugh, 1987; Champ, 2000). There are research efforts to develop less toxic antifouling coatings; however, commercially available products are not likely to be available for years. For the demonstration buoys off Makah Bay, the developer will test different types of antifouling coatings to determine their effectiveness, as part of an agreement with the Olympic Coast National Marine Sanctuary (AquaEnergy, Ltd., 2006).

There are no monitoring studies of the actual impacts to benthic resources at past demonstration or pilot wave energy installations; however, baseline studies have been conducted or are proposed at planned project sites. The types of studies are similar to those conducted at offshore wind project sites.

No new models have been developed for assessing impacts to benthic resources related to wave energy projects. Techniques to assess impacts of wave energy projects will likely be adapted from models being used to assess wind power impacts.

Proposed mitigation measures related to benthic resources in the few published environmental assessments are listed below (AquaEnergy, Ltd., 2006; WaveNet, 2003; Entec UK Ltd., 2003; Halcrow Group Ltd., 2006a):

- Route the cable to avoid sensitive substrates such as live coral, productive rocky habitat.
- Use horizontal directional drilling methods for the cable route through sensitive habitats such as seagrass beds.
- Use dynamic positioning to reduce the need for using anchors in sensitive areas.
- Use soft start-up of pile driving so that benthic species can move away from the source of disturbance.
- Design the mooring systems to minimize the anchor scale, footprint on the seafloor, and the chain/cable sweep of the seafloor.
- Avoid kelp beds.

5.2.3 Fishery Resources

There is little information in the existing literature about the potential impacts of wave energy installations on fish resources. Potential impacts can be drawn from the appropriate studies of wind parks and include habitat disturbance, sound, electromagnetic fields (EMF), artificial reef effects, and changes in fishing pressures. The response of fishes to sound generated from construction and operations at a wave energy installation is not currently known because the engineering design and installation methods are not certain at this time.

The preliminary Draft Environmental Assessment of the Makah Bay project (AquaEnergy, Ltd., 2006) provided only the broadest treatment of potential fish impacts and discussed the potential for habitat disturbance, concluding no significant impacts would occur. A general discussion of environmental issues for the wave energy technologies for the United States (Hagerman and Bedard, 2004) did not address impacts on fishes, but rather considered fishes only in the context of a space-use conflict. The Wave Hub project conducted a baseline fisheries survey with specifications for methods and sampling sites (Halcrow Group Ltd., 2006c). The baseline methods were developed in consultation with the commercial fishery interests of the area (Halcrow Group Ltd., 2006d). The results show the need for sampling over a longer time period because the project results were only a snapshot of the development site. WaveDragon (2006) produced a generic matrix of proposed considerations for an environmental impact analysis.

It is likely that the wave energy installations will be anchored on hard bottom, a more sensitive habitat than soft sediments, and could affect essential fish habitat and Habitat Areas of Particular Concern. The transmission cable cannot be buried in hard bottom areas, creating concerns for those species that have EMF sensitivities. The report on the effect of electromagnetic electrical fields on fish by Gill et al. (2005) is very comprehensive, and the issues would be the same as discussed for wind parks. Salmon are a very important species in the Pacific Northwest and have demonstrated the ability to use magnetic fields in migration (Taylor, 1986).

Another wave energy concern is that the devices and mooring systems will develop fouling communities, and some designs will require treatment with toxicants and/or cleaning. Tri-butyl tin has toxic effects on many marine and estuarine organisms, and specifically different life stages of fishes (Bryan and Gibbes, 1991). The effects include masculinization of genetically female flounder, *Plaralichthys olivaceus*, (Shimsaki et al., 2003) and bioaccumulation negatively affecting microstructural and enzyme functions in the liver (Holm, Norrgren, and Linden, 1991). Resultant damage at all life stages was demonstrated in uptake and elimination experiments with fish yolk-sac-larvae (Fent and Hunn, 1993). More recently, mutagenic effects have been shown in fish exposed to tri-butyl tin (Ferraro et al., 2004). The magnitude of the response of aquatic organisms to tri-butyl tin has prompted a series of regulatory recommendations on its use (Champ, 2000).

Some of the devices that use overtopping as part of their process might entrain fishes, primarily embryos and larvae, that live at the surface of the ocean. Current forms of overtopping technologies include the Wave Dragon (Christensen et al., 2006) and the Mighty Whale (Osawa and Miyazaki, 2004). There is little information to evaluate the impact of entrainment in these devices on fish populations. A brief mention of the effect of overtopping and its role in entrainment is that there will be a “trash rag” covering the total reservoir, “preventing fish and mammal access to the reservoir and turbine system” (Christensen et al., 2006). Christensen et al., (2006) also state that “Fish smaller than the openings in the trash rag will pass through the operating turbines.” This phenomenon has been a major source of mortality in all hydropower projects globally. It appears that “a turbine with a slow turning (300 rotations per minute) propeller” is their concept of mitigation for the entrainment process.

A critical point is that the fish community population is dynamic, and an understanding of the variability of the biota when calculations are made is required. As an example, Lough and Manning (2000) reported on the entrainment of cod and haddock fish larvae in an oceanic tidal front in a band that was 10 to 20 km wide. If such a tidal front passed over a wave energy installation, which could happen over a short period, it could have significant potential for entrainment of a large number of fish larvae. It should be possible to calculate the volumes of water entering the system of overtopping wave energy devices. Data obtained with plankton and neuston nets collected at the proposed project site would yield the numbers of specific organisms per volume of water. The results would help clarify if the entrainment represents a significant effect and possible cumulative effects.

Although structure-specific information on wave energy devices varies by device, it is likely that they will function as fish aggregation devices or fish attraction devices (FADs). The terms fish attraction devices and fish aggregation devices are considered synonymous for the purposes of this report. No matter whether wave energy devices are horizontal or vertical physical structures, the fact is that they will attract fishes and function as FADs. Thus, they will also attract fishermen.

The utility of FADs to attract fishes goes back to the beginning of recorded history, and they have received significant attention more recently. The placement of FADs is encouraged to develop fisheries by governments and agencies on a global scale (Roullot, Venkatasami, and Soondron, 1988; Naeem and Latheefa, 1994; Anderson and Gates, 1996; Gates, Cusack, and Watt, 1996; Gates, Preston, and Chapman, 1998; Venkatasami and Sheik Mamode, 1996; Chapman et al., 2005). Placement of FADs for commercial fishing on skipjack, bigeye tuna, and yellowfin tuna has occurred at such a high level in the Gulf of Guinea that it is considered the major cause of reductions in the populations of these species, putting them very close to an overfished and overfishing state (ICCAT, 2006); their use is now regulated. The point is that FADs are extremely effective in concentrating fishes and making them susceptible to harvest.

How FADs function is still a point of discussion. Castro, Santiago, and Santana-Ortega (2001) reviewed the literature and developed a general theory on the process. The content of their literature cited is very comprehensive and useful. The most general theory is that fishes use floating materials to protect themselves at various life stages. They are also used as feeding stations by predators such as tuna (Marsac and Cayre, 1998) who move systematically among a FAD deployment. Albacore are a major fishery for the Pacific coast and albacore have been consistently reported to occupy FADs in the Mediterranean Sea and Indian Ocean where they have been deliberately constructed (Roullot, Venkatasami, and Soondron, 1988; Naeem and Latheefa, 1994; Gates, Cusack, and Watt, 1996; Gates, Preston, and Chapman, 1998; Venkatasami and Sheik Mamode, 1996; Deudero et al., 1999; Massuti, Morales-Nin, and Deudero, 1999). Many other fishes and recreational and commercial fishermen also utilize FADs (Addis et al., 2006). It is important to know how economically important species such as albacore, rockfish, salmon, and other fishes will interact with floating wave energy devices. Important issues include: the time frame for establishment of the fish community, the temporal and spatial dimensions of the fish community, and the population structure of the community (Dempster, 2005; Addis et al., 2006). Perhaps the most important assessment will be the evaluation of the wave energy parks as habitat under the ecosystem-based fishery management requirements of the Magnuson-Stevens Fishery Conservation and Management Act (2007).

Because of the stage of development of the projects, there are no complete impact assessment models for wave energy projects; most projects have adapted approaches from the impact assessment models developed for the wind parks. However, it is likely the wave energy devices will be sited in areas where the essential fish habitat is more sensitive to disturbance. Fishes that live in such habitats are more resident than fish communities over soft sediments. A possible model for defining adverse environmental impact has been developed by Bailey and Bulleit (2002). The process considers the facility's physical location, design, and operation as well as the local biology. The approach considers effects on the affected fish and shellfish populations and the benefits of any necessary best technology alternatives and modifications to protect populations in a cost-effective manner.

A demonstration project can provide information to estimate impacts of fullscale development and appropriate mitigation measures for wave energy systems. Only a few mitigation measures have been suggested for fishery resources and they primarily address the issue of space use conflicts between user groups.

Mitigation measures for potential impacts to fishes at existing demonstration projects focus mostly on proper siting to avoid sensitive areas. At the Makah Bay site, the project design was modified to consist of a closed-loop hydraulic pump system to avoid entrainment, and the anchoring system was modified to reduce its benthic footprint (AquaEnergy, Ltd., 2006). They propose to use specialized anchors to reduce the impact on the benthic habitat, and the transmission cable will be on the surface in rocky areas and buried under soft sediments. The exposed cable will be subject to colonization by invertebrates and might act as an artificial reef. The Wave Net (2003) report specifically recommends mitigation measures such as protection of the cable (by trenching, if possible) and prohibition against fishing in the area of the park and around the cable.

5.2.4 Marine Mammals

Potential impacts to marine mammals associated with construction and operation of offshore wave energy installations are similar to those impacts discussed for offshore wind technologies. The potential impacts are listed below (Hagerman and Bedard, 2004; Department of the Navy, 2003; Halcrow Group Ltd., 2006a; AquaEnergy, Ltd., 2006):

- Creation of artificial haul-out sites for pinnipeds
- Alteration of habitat
- Disruption of coastal migratory patterns in whales
- Avoidance, displacement, or behavioral changes from noise generated from construction activities and operation
- Entanglement or entrapment of marine mammals in offshore wave structures
- Avoidance or disorientation as a result of electromagnetic fields

An offshore wave energy installation could serve as an artificial haulout site if the device has low freeboard, allowing seals and seal lions to use the structures as part of their natural habitat (Hagerman and Bedard, 2004). Additional haulout sites represent a potential concern as they may result in increased pinniped populations over what would occur under natural conditions. This, in turn, may cause changes to the overall community. The Makah Bay offshore energy pilot project has structures designed with a conical shape that will prohibit the hauling out of pinnipeds onto the structures (AquaEnergy, Ltd., 2006).

The alteration of habitat from the construction of the mooring system, anchoring of construction and maintenance vessels, and laying of cable may cause temporary displacement of prey species in the area. This may cause temporary displacement of marine mammals that forage in the area. There are no studies that evaluate the effect of habitat alteration on marine mammals; however, the environmental assessment on the Makah Bay offshore energy structure indicated that the impacts would be localized and short-term (AquaEnergy, Ltd., 2006). The alteration of habitat with the addition of submarine structures may be beneficial, as it provides more surface area for the colonization of algae and invertebrates on the underwater structures. The additional prey may attract fish, and in turn, marine mammals (Hagerman and Bedard, 2004).

Depending on the location of wave energy installations, the structures may disrupt the coastal migration patterns for some whale species. Hagerman and Bedard (2004) evaluated offshore wave energies in relation to gray whale migrations off the U.S. west coast. The gray whale is observed using waters within 2.8 km of the shoreline for migration, and it was determined that any structures present more than 4 km offshore would not impact the migration of this species. However, any construction activities (e.g., maintenance vessels, seafloor surveys, laying of cable) occurring within 2.8 km of the shoreline may impact gray whale migration during specific times of the year.

Sound from wave structures is of potential concern because of the sensitive hearing capabilities of marine mammals. Sound is generated by two different activities in the project area: construction activities (e.g., installation of the moorings using hydraulic drills to drill holes in rocky substrates); and operations (e.g., continuous sounds during the operation of the wave generator) (Department of the Navy, 2003). The drilling would cause the most intense noise, however, it will be a short-term impact. The environmental assessment for the wave energy pilot in Kaneohe, Hawai'i stated that frequencies of the drill used during construction activities could range from 15 hertz (Hz) to over 39,000 Hz (Department of the Navy, 2003). A study on sound generated from rock drills recorded sound pressure levels ranging from about 120 dB Ref 1 μPa to nearly 170 dB Ref 1 μPa at 2 m from the operating drill (Department of the Navy, 2003). Pinnipeds and cetaceans can sense sounds in the frequency range of the sound produced by the hydraulic drills. However, these levels are below the National Marine Fisheries Service recommended sound levels for seismic surveys of 180 dB for cetaceans and 190 dB for pinnipeds (Federal Register 68, No. 71, April 14, 2003). The rock socket drilling at the North Hoyle wind park produced a strong fundamental component at 125 Hz, and harmonics up to 1 kHz, but source level and transmission loss were not obtained. Tonal components of the drilling were likely identifiable by marine mammals at ranges of up to 7 km (Npower renewables, Ltd., 2005).

There are currently no studies that assess the impacts of sound from underwater drills on the behavior of marine mammals. Impacts likely would be similar in nature to the impacts from pile driving, although to a lesser degree. At the wave energy pilot in Kaneohe, Hawai'i, the Department of the Navy (2003) indicated that the sound would likely not alter the behaviors of marine mammals in the area due to the short and intermittent nature of the sound produced by drilling. The intensity of submarine sound produced by construction activities will be specific to the location of the site and the anchoring systems used. Further research is necessary to determine what the actual impacts of drilling sound will have on marine mammals.

Acoustical data on the sounds produced during normal operations of wave energy technologies are not available, although it has been compared as "light" to "normal" density shipping noise (range between 75–80 dB) (Hagerman and Bedard, 2004; Department of the Navy, 2003). Sounds from wave energy installations are expected to increase in proportion to the ambient background sound associated with surface wave conditions, thus minimizing the effect of increased operational sound during high wave events (Hagerman and Bedard, 2004). Sound levels from a hose pump and pressurized water hitting the turbine in the PowerBuoy system are expected to be well below the ambient sound of the ocean (AquaEnergy, Ltd., 2006).

Offshore wave energy structures may present a risk for marine mammals to become entangled or entrapped in the structure. Cetaceans may be attracted to the buoy site by their natural curiosity, but most buoys can be designed so that the threat of entrapment to marine animals is minimal (Sound & Sea Technology in Department of the Navy, 2003). Entanglements in the cables could also cause an impact. As part of the environmental assessment for the Kaneohe, Hawai'i project, Department of the Navy (2003) conducted a review of the literature and surveyed cable industry representatives to assess the risk of marine mammal entanglement with submarine cables. They found no reports of entanglements in submarine cables since 1960, which they attributed to technological advancements in cable manufacturing and installation. The Kaneohe, Hawai'i wave energy test project has a cable design with a single or double armor configuration and one or two layers of steel wires and a synthetic coating (Department of the Navy, 2003). The cable is intended to be torque-balanced and prohibits the formation of loops. It will also be installed with enough slack so that it will lay flat along the seafloor without suspensions. Monitoring for potential entrapment was proposed during project operation.

As with offshore wind technologies, impacts from EMF generated from the transmission cables may have adverse effects on marine mammals. Some marine mammals use the earth's magnetic field for orientation and migration, and the EMF generated from cables may interfere with natural cues. The potential for disturbance from OCS alternative energy structures may/may not be significant but few studies have been done to determine possible impacts (Gill et al., 2005). The Wave Hub proposed off the south west coast of England would have an EMF of 24 kV, which is insignificant compared to background magnetic fields (Halcrow Group Ltd., 2006a). Sound & Sea Technology (Department of the Navy, 2003) determined that it was likely that marine mammals can sense the magnetic emissions from the transmission cable at the Hawai'i project site, but it was impossible to confidently predict how marine mammals would respond. As stated for wind technologies, there is very little information regarding the sensitivities of marine animals to EMF.

There are no monitoring studies of the actual impacts to marine mammals at demonstration or pilot wave energy installations. The South West of England Regional Development Agency conducted baseline studies and proposed some monitoring for the Wave Hub project to determine impacts of sound on marine mammals (Halcrow Group Ltd., 2006a). Projects involve monitoring marine mammal activity in parallel with sound monitoring of construction and operational activities. A baseline sound survey will also be necessary against which the effects of the wave energy installations can be assessed.

No new approaches or models have been developed for assessing marine mammal impacts related to wave energy projects. The techniques used in the environmental assessments discussed above are based on studies of similar construction or operational activities, often citing studies conducted at existing wind parks.

Proposed mitigation measures for marine mammals listed in environmental assessments include (AquaEnergy, Ltd., 2006; WaveNet, 2003; Hagerman and Bedard, 2004; Department of the Navy, 2003):

Design Considerations

- Buoys should have a ready egress path located at the bottom of the buoy for animals to easily escape.

- Buoys should be designed to include a heavy duty plastic conical attachment to be placed over the above-water portion of the buoy to prevent marine mammal haulout.
- Projects should be designed with adequate distance between buoys and their anchoring systems to allow marine mammals to pass between individual units.
- Cables should be armored with steel wires and an external jacket over the wires to be as highly resistant to damage as possible.

Construction

- Construction activities should avoid sensitive time periods for marine mammal species (e.g., breeding, migration).
- Undersea cables should be laid with enough tension to allow the cable to contour to the seafloor without suspensions or loops.
- Divers should inspect cables once in place.
- Mooring lines and anchor chains should be pulled taut during installation to minimize the risk of entanglement.

Operation

- Structures should be examined for entrapped marine mammals as part of the monitoring plan.
- Cables should not occupy any unique feeding, breeding, or birthing areas.

5.2.5 Sea Turtles

Potential impacts to sea turtles from offshore wave energy installations include (Hagerman and Bedard, 2004; Department of the Navy, 2003):

- Alteration of habitat
- Avoidance, displacement, or behavioral changes from sound generated from construction and operation activities
- Entanglement or entrapment of sea turtles within offshore wave structures
- Avoidance or disorientation as a result of electromagnetic fields

Alteration of habitat may impact sea turtles beneficially as the colonization of algae and invertebrates on submarine structures could act as an artificial reef. Sea turtles may forage on the fouling communities (Hagerman and Bedard, 2004). However, reductions in wave energy may also potentially alter the structure of nearshore communities, favoring some benthic species over others, thus changing the type of prey available for sea turtles. The degree of impact will vary by location and project type.

Sound from wave energy installations may be a concern; however, the hearing capabilities of sea turtles are not as sensitive as those of marine mammals. The Department of the Navy (2003) reported that, during construction activities involving drilling similar to that which may occur for the wave energy installation at Kaneohe, Hawai'i, sea turtles were attracted to the activity. The attraction may have been caused by the benthic biota that were stirred up by the drilling. The Department of the Navy (2003) suggested that these observations indicate that the intensity of sound produced by the drilling activity may not be sufficient to cause behavioral changes in sea turtles.

Entrapment of sea turtles is a potential impact at wave energy installations. The buoy structure proposed in the pilot program in Kaneohe, Hawai'i was designed so that the top of the buoy is closed and the bottom is open allowing for ingress and egress through only one end (Department of the Navy, 2003). A sea turtle could become disoriented, but it is unlikely that the animal could not find its way out of the buoy (Department of the Navy, 2003). Monitoring for potential entrapment was proposed during project operation.

Disorientation from EMF produced by submarine cables may be more significant for sea turtles than for marine mammals. As discussed in more detail in section 5.1.5 on wind technology impacts, sea turtles use magnetic cues for navigation, orientation, and migration. EMF generated from the cables may confuse or disorient animals relying on magnetic cues, however, there is little information regarding the sensitivity of sea turtles to EMF. Sound & Sea Technology (in Department of the Navy, 2003) determined that it was likely that sea turtles could sense the magnetic emissions from the transmission cable at the Hawai'i project site, but it was impossible to confidently predict how they would respond.

There are no monitoring studies of the actual impacts to sea turtles at previous demonstration or pilot wave energy installations. No new approaches or models have been developed for assessing sea turtle impacts related to wave energy projects.

Proposed mitigation measures for sea turtles are discussed in the documents referenced above (Hagerman and Bedard, 2004; Department of the Navy, 2003). The mitigation measures listed below are similar to the mitigation measures proposed for marine mammals.

Construction

- Mooring lines and anchor chains should be pulled taut during installation to minimize the risk of entanglement.
- Undersea cables should be laid with enough tension to allow the cable to contour to the seafloor without suspensions or loops.
- Divers should inspect cables once in place.
- Cables should be armored with steel wires and have an external jacket over the wires to be as highly resistant to damage as possible.
- Construction activities should avoid sensitive time periods for sea turtles (e.g., breeding, migration).

Operation

- Interior of buoys should be free of obstructions, sharp edges, and corners, and allow an easy egress path for sea turtles that enter the buoy from the top opening.
- Examination of structures for entrapped sea turtles should be part of the monitoring plan.
- Buoys should have no horizontal surfaces that could provide resting habitat for sea turtles.

5.2.6 Birds

Potential impacts on birds associated with construction and operation of offshore wave energy installations include the following (Halcrow Group Ltd., 2006a; WaveNet, 2003; AquaEnergy, Ltd., 2006; Hagerman and Bedard, 2004):

- Disturbance to offshore and intertidal birds during construction and maintenance
- Enhancement of habitat and population size via attraction of prey species to artificial structures
- Physical obstruction to feeding areas
- Changes in physical/chemical habitat (e.g., sediment movement, water quality, loss of available water surface area during construction/operation)
- Attraction of seabirds to artificial roost/nest sites
- Entanglement
- Disturbance/disorientation of birds due to lighting at night
- A potential increase in pollution (e.g., leaking fluids from devices and/or oil spills caused by vessel collisions).

Potentially impacted species include waterbirds using the offshore and intertidal environment (see 5.1.7 for species groups). Most of the potential impacts are considered to be of low or very low risk to bird populations. Halcrow Group Ltd. (2006a) states, “given that proposed Wave Hub development is the first of its kind in the United Kingdom, the likely impacts will inevitably be subject to some uncertainty.”

Disturbance to birds during construction and maintenance would be caused by construction noise and vessel traffic, and is likely to be temporary and limited. The wave energy installation is likely to attract fishes and shellfish. If fishing exclusion zones are put in place, attraction of birds is even more likely. For these reasons, it is important for the design to minimize the potential for entanglement and to limit roosting sites (WaveNet, 2003). Alternatively, larger populations of birds may be able to exist than under natural conditions, potentially considered to be a positive impact, depending on the species involved and how the overall community structure may be altered (Hagerman and Bedard, 2004). Habitat changes may cause indirect impacts, such as changes in water quality, changes in the hydrophysical or sediment regime, and changes in benthic communities. These changes could potentially impact prey species and foraging behaviors (Entec UK, Ltd., 2003; Halcrow Group Ltd., 2006a).

There are no monitoring studies of the actual impacts to birds at demonstration or pilot wave energy installations. The South West of England Regional Development Agency conducted baseline studies and proposed some monitoring for the Wave Hub project (Halcrow Group Ltd., 2006a). The monitoring program will be similar to those proposed for offshore wind projects, including the Before-After-Control-Impact (BACI) methodology and techniques suggested by Camphuysen et al. (2004) for identifying distribution and abundance of birds in the wave power development area.

No specific models have been developed for assessing bird impacts related to wave energy projects. Techniques to assess population level and cumulative effects of wave energy projects will likely be adapted from models being used to assess wind power impacts.

Proposed mitigation measures related to birds in the few available published environmental assessments are listed below, though the effectiveness of these proposed measures is unknown (AquaEnergy, Ltd., 2006; WaveNet, 2003; Entec UK Ltd. 2003; Halcrow Group Ltd., 2006a):

- Designing a closed-loop system to prevent any marine life from entering pressurized water flow
- Designing buoys with conical attachments to deter seabird roosting
- Identifying and avoiding sensitive areas for siting
- Avoiding construction during sensitive time periods (breeding, migration)
- Minimizing sound levels
- Using non-toxic/non-polluting substances for anti-fouling and maintenance
- Using nighttime lighting only when required for safety and navigational purposes

5.2.7 Information Needs – Wave Energy

Many of the information needs for wave energy installations are similar to those described in Section 5.1 for offshore wind. In this section, emphasis is on those information needs that are somewhat unique or focused for offshore wave energy technologies.

5.2.7.1 Physical Processes

In situ testing and monitoring focused on understanding how wave energy devices modify the wave climate is a critical information need. Since the devices are still under development and have not been installed, no data have been collected. For example, Halcrow Group Ltd. (2006b) made estimates of wave transmission on the basis of previous research completed for floating breakwaters. While this is a valuable contribution to the Wave Hub project, approaches that are not specific to wave energy conversion devices should be validated through in situ testing and monitoring at pilot project locations in addition to physical modeling. Although many of the wave energy devices are proprietary, regulatory agencies and developers should endeavor to publicly release the results of such studies to aid in evaluating potential impacts for various devices.

Physical data related to shoreline change caused by modified wave climates and similar modeling results should also be collected. Elsam Engineering and Energi E2 (2005) used satellite imagery to determine impacts on shoreline change as a result of the modified wave climate caused by the Nysted offshore wind park. This type of study should be completed for existing wind parks and at pilot sites for wave energy extraction devices to better understand the impact of the modified wave climate on shorelines in the vicinity of such projects. Future projects could use this dataset to validate numerical models used in determining shoreline impacts at proposed sites.

As with the offshore wind park installations, guidance is needed on how to determine acceptable limits for changes to the wave, current, or sediment transport climates caused by wave energy conversion devices.

5.2.7.2 Benthic Resources

Impacts to benthic resources are likely to be small, site-specific, and best addressed during the project planning phase. Studies of the potential amounts, fate, and effects of antifouling coatings released from wave energy devices, particularly as new products are developed, would provide the basis for impact assessment. There are two pathways of potential concern: 1) direct release of biocides from the surfaces treated with antifouling coatings; and 2) transfer of contaminants to marine fouling organisms that are then released to the environment during in-water cleaning. Because wave energy installations will be in high-energy environments, the fate of released biocides will require modeling of transport and fate processes.

5.2.7.3 Fishery Resources

Information needs for baseline fishery studies are similar to those described in the section on wind parks. Information needs of the environmental impact of wave energy installations on fishes are discussed below.

The potential for impact on fishes from disturbance to hard bottom habitats is significantly greater than disturbance of soft substrates (NRC, 2002). The response of the fish community to hard bottom disturbance from anchoring and chain swing in a wave energy project area is a critical factor in evaluating potential impacts.

Another critical issue is the amount of entrainment of fishes associated with each type of wave energy technology. Site-specific information on the species of fishes and the temporal and spatial distribution of the life stages of the species are necessary to address this issue, as well as information on the volume of water entrained.

There has been significant effort in Europe addressing the response of fishes to EMF from cables. There is not likely to be an effect from the small-scale prototype wave energy systems. However, if the systems go to full operational level, it will be necessary to determine the EMF levels from inter-array and transmission cables that are not buried. The responses of the resident species to the EMF should be investigated.

It is clear that the wave energy devices will function as FADs. The response of the fish community in terms of structure, and daily, seasonal, temporal, and spatial dynamics should be investigated.

The space-use conflict issue could be significant with the commercial and recreational fishing community and the environmental interests (Blyth et al., 2004; Crowder et al., 2006). The positive and negative attributes of treating wave energy project areas as Habitat Areas of Particular Concern and fishing exclusion areas must be considered. Alternatively, it would be possible to recognize the site as a FAD, and accept the reality of recreational and commercial utilization.

5.2.7.4 Marine Mammals

Site-specific seasonal distribution and abundance studies for species of marine mammals are necessary to determine impacts at proposed wave energy installation sites (see Section 5.1.5.5). Further studies of the hearing capabilities for cetaceans and pinnipeds, as was discussed for wind technologies, would improve the ability to determine potential impacts. Well-designed monitoring studies will be necessary to provide conclusive evidence of behavioral changes due to sound, EMF, or predator-prey relationships at wave energy installations on the OCS. Baseline studies will be necessary to determine background sound levels in the site-specific location of a proposed project. An evaluation of the wave energy structure should be conducted to determine the best arrangement to prohibit the avoidance of whales during migrations. A monitoring study of the wave energy installations, once in operation, will provide data for entanglement and entrapment occurrences.

5.2.7.5 Sea Turtles

Site-specific seasonal distribution and abundance studies for sea turtle species are necessary to determine impacts at proposed wave energy installation sites (see Section 5.1.9.5). The effects of EMF for hatchling, juvenile, and adult sea turtles are poorly understood, as was discussed for wind technologies. Monitoring studies that assess entrapment occurrences in wave energy buoys and structures will need to occur after the wave energy installations are in operation.

5.2.7.6 Birds

Information needs regarding distribution and seasonal presence of birds, bats, and insects are similar to those described for offshore wind power (see Section 5.1.7.5). More data on attraction of birds to structures, both as roosting/nesting habitats, and for foraging, due to a potential increase in prey abundance would improve the ability to assess risks. Disturbance/habitat loss related to wave energy construction and operation should be examined. Attraction to artificial lighting in the context of wave energy structures (e.g., height and intensity of lighted features) should be studied. Monitoring of installations will provide information on the actual risk of entanglement and measures needed to reduce those risks.

5.3 Ocean Current Technologies

Ocean current technologies for the outer continental shelf (OCS) are only in the development or prototype stage where single devices are deployed or planned for installation at isolated testing sites, as discussed in section 3.3. Some of the pilot projects for tidal current energy extraction use technologies that could be modified for use in the OCS; however, these projects have not generated actual data on the types and magnitudes of potential effects. The potential environmental impacts are based on the following assumptions about the design for ocean current devices likely to be deployed in demonstration and pilot projects in the next 5 to 7 years:

- Horizontal axis turbines, with rotor blades up to 20 meters (m) in diameter, most likely would be bottom mounted on the seafloor using monopiles, although cables and anchors could be used. The rotor blades will turn at 10 to 20 revolutions per minute (rpm). Rotational speeds at the turbine tip may reach 13 m per second (m/s) (Fraenkel, 2006).

- Open center turbines would be anchored using twin monopiles or tethered with cables. The tip speed is about 6 m/s (H. Williams in Resolve, Inc., 2006, p. 12).
- Pilot projects in the OCS could include components that are above the water surface or are completely submerged. Existing designs for tidal current projects near shore and in shallow water have above-water components to facilitate maintenance. Other designs have no above-water components.

As summarized by Elcock (2006), proposed projects will be conducted in phases, with phase 1 usually consisting of a single prototype unit, phase 2 consisting of build-out to 8 to 20 units, and phase 3 consisting of further expansion of the site. Horizontal axis turbines would be installed at a density of 3 per square kilometer (km^2).

No environmental impact documents for ocean current energy projects were available for review. Some assessments have been done for tidal current pilot projects; however, the technologies are so new that the discussion of potential impacts is often very general (e.g., Devine Tarbell & Associates, Inc., 2006).

In 2002, Verdant Power began field studies of horizontal axis turbines using tidal currents in the East River in New York Harbor. During the permitting process for expanded tests, the following topics were the focus of the comments provided by review agencies, stakeholder groups, and private citizens (J. Gibson in Resolve, Inc. 2006, p. 57–58):

- Rare, threatened, and endangered species
- Water quality (turbidity, potential toxins)
- Recreational resources and commercial fishermen
- Navigation and security
- Temperature changes
- Leaking oils and fluids
- Toxicity of antifouling measures
- Demobilization plan
- Aquatic birds
- Hydrodynamic and hydraulic impacts
- Historical and cultural resources
- Wetland impacts
- Aesthetic impacts
- Bottom scour
- Fishery impacts

Similar concerns would be raised for offshore ocean current technologies, with the addition of marine mammals and sea turtles. More habitats are available offshore, so some of the potential impacts have lower levels of concern (e.g., fish migration up a river rather than along the continental shelf).

The European Marine Energy Center (EMEC) (2005) developed guidance on conducting an environmental impact assessment (EIA) for wave and tidal energy developers interested in testing their marine energy conversion devices at the offshore facilities at EMEC. It identified the mechanisms by which impacts might occur during testing (see table 5-14), and thus, the issues that developers had to address in their application to EMEC. This guidance also included criteria by which the magnitude of ecological effects, socioeconomic effects, and stakeholder concerns could be evaluated as major, moderate, minor, negligible, no interaction, or positive. Listed below are the criteria proposed to evaluating ecological effects:

- *Major:* Degradation to the quality or availability of habitats and/or wildlife with recovery taking more than 2 years.
- *Moderate:* Change in habitats or species beyond natural variability with recovery potentially within 2 years.
- *Minor*: Change in habitats or species which can be seen and measured but is at the same scale as natural variability.
- *Negligible*: Changes in habitats or species within scope of existing variability and difficult to measure or observe.
- *Positive*: An enhancement of ecosystem or popular parameter.

A summary impact matrix was provided as a tool for presenting the results of the environmental assessment of the proposed test project.

Scott Wilson Ltd. and Downie (2003) included tidal energy technologies in their review of the potential natural heritage impacts from a Scottish perspective. They discussed concerns with antifouling paints, sound, cables and the associated electromagnetic fields (EMFs), and diving birds. ABPmer (2005) published a similar summary of potential nature conservation and landscape impacts of wave, tidal, and wind energy development in Welsh territorial waters.

With such limited information on the likely designs and no actual studies on environmental impacts, the following sections on potential impacts are necessarily general and based largely on extrapolation from other types of marine installations.

5.3.1 Physical Processes

The potential impacts on physical processes caused by the installation of current energy extraction devices largely depend on the physical nature of the installed devices, namely if they are floating with anchors rather than mounted on the seafloor and whether they have above-water components. The impacts also depend on the nature of the downstream current profile. As these technologies become more mature, the relative importance of these potential impacts will become more certain.

5.3.1.1 Currents and Tides

Potential impacts to currents and tides resulting from current energy technology include modification to flow velocity and directions, increased turbulence, and extraction of energy from the current stream itself. Following is a list of potential impacts to currents and tides resulting from current energy extraction devices:

Nearfield impacts

- Changed mixing properties
- Modified sediment transport
- Reduced capacity for current energy extraction
- Potentially modified wave climate resulting from wave-current interactions

Farfield impacts

- Modified sediment transport on nearby shorelines
- Reduced current energy extraction potential
- Changes to major ocean currents such as the Gulf Stream (with potential impacts in the extreme farfield)

The nearfield impacts generally depend on modifications to the current profile and properties themselves (e.g., turbulence, thermal stratification). For example, increased turbulence can result in changes to local and global scour, plus changing the mixing properties of the area. A change in the current profile is of particular interest to project developers because of the need to determine such factors as spacing of units. As a result, currents have been studied for two pilot projects—one in the East River in New York, and one in Scotland. For the pilot tidal energy project in New York (Resolve Inc., 2006), the measurements have been taken but the results have not yet been published. Full-scale in situ testing has been done in conjunction with the pilot Stingray tidal energy project at Yell Sound in Scotland (The Engineering Business Ltd., 2005). In this case, upstream and downstream current velocity measurements were taken using acoustic doppler current profilers, and the results have been published. Although the study concluded that not enough data were collected to make firm conclusions, some significant reductions in the current velocities (from 2 m/s to 1.5 m/s) were observed between the nonoperational and operational cases. The Engineering Business Ltd. (2005) also concluded that better understanding of the wake effects would be required before park planning and implementation could be undertaken. Changes to current directions were not presented.

Farfield impacts of modified currents on nearby shorelines could include the development of erosion or depositional hot spots because even slightly modified waves or currents can create significant changes to longshore sediment transport rates (Benedet et al., 2006).

Ocean current energy conversion approaches most likely to cause disruption would be current energy extraction devices because they actually remove energy from the current stream. While the potential for utility-scale deployments of these devices to modify major ocean currents is unknown, the impacts of modifying these currents could be severe, albeit in the extreme farfield. Their regional and global impacts on climate are conceptually well understood. Scientists believe that changes to ocean currents can instigate abrupt climate change (NRC, 2002), which likely would result in severe hardships on economies and societies around the world (Arnell et al., 2005). These changes may be caused by natural fluctuations, or they may be accelerated through influences such as global warming (Broecker, 1997).

Mitigating the impacts on currents themselves would include site selection studies so that modified currents do not occur in an area significantly sensitive to a changed current and postconstruction monitoring at pilot sites, as is being done with the Verdant Power pilot project in New York (Resolve Inc., 2006).

5.3.1.2 Waves

Modification to a wave climate itself comes as a result of wave-structure interactions (e.g., diffraction, reflection, breaking, sheltering, and wave-current interactions caused by a modified current regime). Wave-structure interactions will be more significant for current energy extraction devices with above-water components or foundations. Current energy conversion devices have a significantly reduced above-water component compared with wind parks, thus the potential for reduced wind-wave generation capacities is likely negligible. Significant nearfield impacts include changed navigational conditions, modified wave loads on adjacent structures, and sediment transport under waves. Farfield impacts include a modified wave climate that could affect recreational potential and sediment transport along adjacent shorelines (possibly leading to changed shoreline recession rates), and reduced capacity for neighboring areas to implement wave energy conversion devices.

In the few locations worldwide where current extraction devices have been installed, very little effort toward mitigation of wave impacts has been expended. For proposed projects, mitigation measures would be similar to those presented for wind and wave energy extraction devices. This includes adequate siting to avoid locations with a particular sensitivity to modified wave climates (e.g., popular surfing beaches, shorelines in sensitive littoral cells), the selection of generation technologies that have a lesser impact on the wave climate, and postconstruction monitoring.

5.3.1.3 Sediment Transport

Changes to waves and currents influence changes to sediment transport. In the nearfield, potential impacts include local and global scour or sedimentation. Bottom-mounted devices are more likely to generate scour problems because erosion of supporting sediments may lead to structural failure; however, anchored and cabled devices may still experience local scour around anchor elements, chains, and even under the device body if the installation depth is shallow relative to the draught of the conversion device. Scour is also an issue around cables, and cable trenches. Furthermore, these devices have the potential to produce significant wake effects, which may lead to scour pits developing away from the immediate vicinity of the device itself (although still within the nearfield). Sedimentation is also possible with these devices because the slowed currents would allow sediments to settle that previously may have remained suspended. This sedimentation could make maintenance and monitoring more difficult, as well as potentially cover productive benthic communities and fish habitat.

In the farfield, the primary impacts are changes in seabed topographic features, littoral zone limits, and transport rates. Regional impacts in the farfield could result in erosion or deposition in areas where the process was not previously occurring. This can impact intakes and outfalls, beaches and other recreational areas, navigation channels, and shoreline vegetation. Further concerns include loss of habitat, exposure and resuspension of contaminated sediments where they exist, damage to archaeological sites, and damage to existing infrastructure installed on or below the seabed.

Mitigation measures would be similar to those proposed for an offshore wind park or wave energy conversion project.

5.3.2 Benthic Resources

Construction and operation of offshore ocean current energy installations can cause the following impacts to benthic resources:

Construction

- Bottom disturbances from installation of foundations or anchoring systems and anchoring of construction and maintenance vessels
- Sediment disturbance and suspension during installation of foundations or anchoring systems
- Sound during pile driving or drilling
- Habitat loss from foundations and units attached to the seafloor to gather the power and feed it to the transmission cable to shore
- Habitat disturbance during cable laying
- Introduction of hard substrates
- Habitat disturbance resulting from scour

Operation

- Operational sound and vibration
- Introduction of contaminants from use of antifouling coatings and cleaning of marine fouling growth
- Introduction of different communities from fouling growth on monopiles and scour protection around the foundation or anchoring systems

Potential impacts from electromagnetic fields are similar to those described for offshore wind park projects, with the additional possibility of the cable being buried or not, depending on the site characteristics. Most potential impacts to benthic resources are similar to those discussed in section 5.1.3; therefore, only those with special significance for ocean current technologies are discussed below.

Operational sound and vibration from the turbines would be unique to each design, but little is known about the potential levels of impact. Cavitation noise may be of concern, but cavitation also reduces efficiency and increases mechanical damage, thus studies are being conducted to develop models to allow blade optimization analyses to reduce or eliminate cavitation (e.g., Bahaj et al., 2007).

Marine fouling of ocean current energy devices is of concern because of the rapid and heavy growth of fouling organisms on submerged structures. Fouling communities will need to be prevented or removed to reduce corrosion and fatigue and maintain efficiency of most types of ocean energy devices. According to the Seventh Report on Wind and Tidal Energy of the United Kingdom House of Commons Select Committee on Science and Technology (2000), "The area that appears to pose some of the largest problems for wave and tidal devices is that of encrustation...". There are currently only three options to deal with marine fouling: (1) use of antifouling coatings, (2) in-situ cleaning using high pressure jet spray by divers or remotely operated vehicles, and (3) removal of the device from the water surface for cleaning onsite or onshore and reapplication of antifouling coatings.

Antifouling coatings can reduce the frequency of maintenance through slow release of a biocide at the surface. Most products have been developed for the shipping industry, and they rely on the movement of water to accomplish the self-polishing that exposes a new layer of the coating (which would be different for moored facilities). Because these coatings work through the slow release of the biocide and they need to be re-applied after several years, there could be concern about the long-term accumulation of these persistent compounds from large arrays. The impacts of biocides such as tributyl tin on marine organisms in ports and harbors have been well documented; tributyl tin has been banned in the United States since 1980 and international conventions have been proposed to phase out the use of tributyl tin (Champ and Pugh, 1987; Champ, 2000). There are research efforts to develop less toxic antifouling coatings; however, commercially available products are not likely to be available for years.

No monitoring results are available for the actual impacts to benthic resources at existing ocean or tidal current installations, but baseline studies have been conducted or are proposed at planned project sites. The types of benthic studies would be similar to those conducted at offshore wind and wave project sites.

No new models have been developed for assessing impacts to benthic resources related to ocean current projects. Techniques to assess impacts of ocean current projects likely will be adapted from models being used to assess wind power impacts. Potential mitigation measures for benthic resources would be similar to those discussed for wind and wave technologies.

5.3.3 Fishery Resources

Following is a list of potential impacts to fishery resources from ocean current installations:

Construction activities

- Habitat disturbance or loss from foundations, moorings, anchors, and cable laying
- Sound associated with pile driving and drilling

Operations activities

- Introduction of artificial hard substrates
- Scour impacts on benthic habitats
- EMF effects on sensitive species

- Collisions with moving parts
- Changes in water flow and pressures

The greatest problem in addressing impacts directly related to ocean current technologies and evaluating them is a lack of data. Thus, it is necessary and relevant to look at analogous systems such as turbines in traditional hydropower in dams and in tidal systems that have more data and experience (Bihlmayer, 2006).

A detailed review of available information from the proposed ocean current projects yields only the most preliminary information. There is a great deal of speculation about the ecological impact of these systems, and the material is rife with unsupported assumptions (e.g., O'Donnell, 2005). Environmental assessments for the few proposed tidal current projects that mention potential impacts on fishes present only general information (Triton Consultants, Ltd. 2002; Hoover, 2005; Fraenkel, 2006).

The executive summary for a report of a workshop on hydrokinetic and wave energy technologies highlights a development obstacle as follows: "Many of the environmental impact questions that must be addressed in order to permit even a demonstration project cannot be answered without deploying the devices and monitoring the impacts. Although the technologies themselves appear to have fewer impacts than more conventional energy technologies, the prospect of deploying these devices in already-stressed environments requires strict scrutiny from the point of views of resource managers" (Resolve, Inc., 2006).

Marine fouling concerns will be similar to those discussed in section 5.2.3.

Some data are available from experiences with turbine systems in tidal power. Usachev, Shpolyanskii, and Istorik (2004) report commercial fishes of up to 25 cm in length (99 percent) of a school successfully passed through a ladder and the low-head wheel of a bulb-type turbine unit with a diameter of 3.3 m and rotation speed of 72 rpm. The authors assume that fishes can pass a turbine with a wheel diameter of 5.3 to 10 m with no problems. Fraenkel (2006) reviewed tidal current technologies and contrasts the impact of a ship propeller on water with that of a turbine blade. He states that the risks of harming wildlife are small, but he believes an independent monitoring project is necessary to understand the risks and benefits.

An existing prototype tidal current project is the Verdant Power field study of the horizontal axis turbines in the East River in New York. A case study analysis of the Verdant Power project lists topics of specific fishery concerns (Gibson, 2006):

- Strike probability
- Sheer stress and turbulence
- Impingement and entrainment
- Cavitation and pressure changes
- Increased predation
- Migration patterns
- Subsampling compared to continuous sampling

These same concerns will need to be addressed for all offshore ocean current technologies.

Verdant Power addressed the fish community issues by establishing a baseline and ongoing monitoring project to assess fishery resources using four hydroacoustic monitoring studies to establish a predevelopment baseline (Gibson, 2006). The plan is to install two of the six units and conduct hydroacoustic monitoring 24 hours a day for 2 months, followed by recovery of the fish for study. After data analysis, and if the agency approves the project, Verdant Power will deploy four more units. Results are not yet available.

The environmental impact assessment guidance by EMEC (2005) is a comprehensive analysis of potential impacts, and it provides excellent guidance for developers. A table on ecological issues and the environmental assessment plan in the report contain useful information presented coherently.

The impact of ocean current projects on fishery resources has not generated new models for assessing impact. Probably prototypes and early projects will adopt methods and mitigation proposals used by offshore wind park projects.

5.3.4 Marine Mammals

The following is a list of potential impacts to marine mammals from ocean current installations:

Construction activities

- Sounds from geophysical surveys, transport vessels, cable installation, and placement of mooring pilings (e.g., pile-driving or drilling)
- Habitat disturbance or loss from foundations, moorings, anchors, and cable laying
- Disturbance and collision risks from construction vessels

Operational activities

- Collisions with rotating turbines and service vessels
- Entanglement in the underwater structure
- Sounds from mechanical operations and maintenance vessels
- EMF effects from cables
- Habitat disturbance or loss from underwater structures

Many of the potential impacts to marine mammals are similar to those discussed for offshore wind parks; therefore, only those that are of particular significance to ocean current technologies are discussed below.

Construction of ocean current installations may generate sound from the use of hand tools and machinery such as air compressors as well as sound produced by work boats. These sounds may result in temporary avoidance of an area by marine mammals, but the sounds are not likely to cause long-term impacts or physical injury. Geophysical surveys used during site characterizations and pile driving or drilling to anchor ocean current installations would produce high-intensity pulses that are of concern for marine mammals, as discussed in section 5.1.5.

Impacts could range from minor to severe depending on an animal's distance from the activity and timing and location of the activity (e.g., during seasonal migrations, in calving areas).

Underwater sound from the rotation of drive gear and electrical generators will be emitted during operation of ocean current structures. Mechanical sound would be continuous, but it is expected to be of low intensity. If marine mammals permanently avoid areas that contain ocean current structures because of the continuous sound, it could lead to abandonment of feeding or mating grounds. Very little information is available on sound levels produced by ocean current structures. Fraenkel (2006) reported that underwater acoustic measurements taken at the Seaflow project in the United Kingdom indicated that sound levels and frequencies were unlikely to disturb marine animals, but no values were provided for review or validation.

Turbine collision is a potential concern for marine mammals. Animals passing through a horizontal-axis turbine may be struck by one of the blades and cause injury or death. According to Fraenkel (2006), animals entrained in the flow of water passing through the turbine would tend to be swept between the rotor blades rather than into the blades, thus avoiding injury. It is unknown if marine mammals actually would avoid underwater structures or if cetaceans in the pursuit of prey would inadvertently swim into the path of a turbine and become injured.

Entanglement in mooring lines used to attach the turbines to the ocean floor may also be a potential impact for marine mammals. Smaller dolphins and pinnipeds are expected to easily move around mooring lines, but larger whales have more difficulty navigating around mooring cables, and they may be more prone to an entanglement. The spacing of turbines in an area will be particularly important to ensure safe passage of marine mammals through areas that house ocean current installations.

There are no monitoring studies of the potential impacts to marine mammals at pilot projects for tidal current energy installations. A suggested monitoring program likely will be similar to those proposed for offshore wind projects including the before-after control-impact (BACI) methodology and techniques for a site that has been selected. Fraenkel (2006) suggested monitoring the attraction of marine mammals to turbines in addition to basic distribution and abundance studies. Scott Wilson Ltd. and Downie (2003) suggest examining the following aspects of a location that may be selected for ocean current installations:

- Species in the area
- Number, distribution, and location of sightings
- Known routes and movements in or though the site
- Relative importance of the site to each species
- Specific uses of the site including temporal use (e.g., haulout sites, pupping sites, feeding and breeding grounds)

No specific models to evaluate impacts of ocean current projects on marine mammals have been developed. EMEC (2005) developed impact matrices and criteria for assessing the significance of ecological effects for European developers of ocean current technologies. Models used to determine impacts to marine mammals from offshore wind parks may also be used to evaluate impacts from ocean current installations.

Potential mitigation measures for avoiding impacts to marine mammals include: (1) coordination with resource agencies (e.g., National Marine Fisheries Service) to avoid selecting locations in sensitive habitats (e.g., mating or feeding sites, pupping sites), (2) scheduling high sound-level activities (e.g., geophysical surveys, pile driving) for times of least sensitivity for marine mammals (e.g., avoiding migration periods), and (3) using pingers or seal-scaring devices to reduce entanglements or collisions with turbines or mooring cables (Fisher and Tregenza, 2003). Several of the mitigation measures proposed for offshore wind park technologies, especially during construction activities, may also apply for ocean current installations. Evaluating the effectiveness of the measures will be necessary before their use in ocean current installations.

5.3.5 Sea Turtles

Following is a list of potential impacts to sea turtles from ocean current installations:

Construction activities

- Sound from geophysical surveys, transport vessels, cable installation, and placement of mooring pilings (e.g., pile driving or drilling)
- Habitat disturbance or loss from foundations, moorings, anchors, and cable laying
- Disturbance and collision risks from service vessels
- Light pollution from work boats and construction areas

Operational activities

- Migration disruption
- Collision with rotating turbines
- Sound from mechanical operations and maintenance vessels
- EMF effects from cables
- Habitat disturbance or loss from underwater structures

Many of the potential impacts listed above are similar to those discussed for offshore wind parks; therefore, only those that are of special significance to ocean current technologies are discussed below.

It is unknown how the migrations of sea turtles may be affected by ocean current installations. Sea turtle hatchlings rely on the same ocean currents to transport them out to the ocean that the turbines are targeting. Hatchlings may be especially sensitive because they are thought to rely on ocean currents to transport them to pelagic nursery habitats (Luschi et al., 2003). More information is needed to determine the possible impact on hatchlings during this vulnerable life stage.

Light pollution may impact hatchlings as well. Hatchlings are known to be attracted to light (Witherington and Martin, 1996), and they may orient to lighted work boats, construction areas, or lights placed on the ocean current structure for marine safety instead of to the open ocean. Attraction to lights around the installation also may result in hatchling mortality because predators (e.g., birds, fish) are also attracted to lighted areas (Witherington and Martin, 1996).

Sea turtles are at risk of collision with the turbines and entanglement in the mooring cables. Sea turtles passing through the turbines may be injured or killed after being struck by a rotating blade; however, it is not known whether sea turtles would avoid working turbines. The tip speed of the turbine could reach speeds of 10 to 12 m/s (Fraenkel, 2006). Considering that juvenile and adult sea turtles are relatively slow swimmers, they may not be able to react quickly enough to avoid contact. Installations that are located between nesting beaches and offshore pelagic nurseries may be more at risk for turtle collisions, especially facilities with a large number of turbines.

The characteristics of operational sound from ocean current devices are not known enough to evaluate potential impact to sea turtles. Furthermore, not enough is known about sea turtle hearing capabilities to fully understand the potential effects. Studies of the response of sea turtles to different sounds is discussed in section 5.1.6.

Sea turtles may be affected by the EMF produced by cables between turbines and from turbines to shore. Several studies have shown that sea turtles use the earth's magnetic field for orientation and migration (Irwin and Lohmann, 2003; Lohmann and Lohmann, 1994). EMF from transmission may interfere with a sea turtle's natural ability to sense the earth's magnetic field and potentially hinder their movements. Further studies are needed to understand the impact of EMF on sea turtle movements.

There are no monitoring studies of actual impacts to sea turtles at pilot projects for tidal current energy extraction. Monitoring programs will be needed after sites are selected for ocean current installations.

No models have been created to evaluate impacts of ocean current installations on sea turtles. Models probably will be adopted from offshore wind park projects and altered for use with ocean current technology. The matrix developed by EMEC (2005) may be used as a guide to assess the significance of ecological effects as described earlier for marine mammals.

Potential mitigation measures for avoiding impacts to sea turtles include: (1) avoid locating ocean current installations offshore of known nesting beaches or coastal foraging and nursery habitats, (2) schedule high noise-level activities (e.g., geophysical surveys, pile-driving) for times of least sensitivity for marine mammals (e.g., nesting periods), and (3) avoid unnecessary lighting. Short-term, temporary, and transient lighting should be used on vessels, and deck lights should be downshielded to prevent upward illumination, which could cause illumination of surrounding waters. Several of the mitigation measures proposed for offshore wind parks may also apply to the ocean current installations.

5.3.6 Birds

Bird species potentially impacted during the construction and operation of offshore ocean current energy installations include waterbirds using the offshore zone, where the turbine structures are placed, and species in the intertidal environment, where cables and onshore infrastructure are located. See 5.1.7.1 for species groups in these habitats.

The nature and magnitude of impacts from ocean current technology are currently unknown (EMEC, 2005; Scott Wilson Ltd. and Downie, 2003). Following is a list of the most likely impacts to birds:

- Underwater collisions with turbines and mooring structures
- Disturbance and displacement during construction and operational activities as a result of noise and vessel traffic
- Entanglement and entrapment with cables and other structures
- Disturbance and disorientation of birds because of lighting at night
- Injury from releases of hazardous materials

Species most likely to be affected by collisions or entrapment involving underwater turbines are diving ducks, cormorants, and seabirds (e.g., gannets, auks, terns). Diving birds have been reported at depths of 3 to 200 m (Prince, Huin, and Weimerskirch, 1994; Croll et al., 1992); turbines most likely will be located at depths less than 20 m. Fraenkel (2006) considered the overall underwater collision risk to be low or potentially nonexistent; birds will avoid the rotors or dodge the blades if they pass through because of their agility and sensory awareness that are common traits in these species. Impacts to birds from disturbance and displacement resulting from noise and vessel traffic, entanglement and entrapment, and potential pollution risks are discussed in section 5.2.7 and are expected to be low. Species potentially affected by lighting are covered in detail in section 5.1.7.

There are no monitoring results of the actual impacts to birds at pilot projects for tidal current energy extraction. Suggested monitoring programs likely will be similar to those proposed for offshore wind projects including the BACI methodology and techniques suggested by Camphuysen et al. (2004) for identifying distribution and abundance of birds in the tidal current development area. Fraenkel (2006) suggested monitoring attraction of sensitive species (e.g., seabirds, marine mammals) to the turbines in addition to basic distribution and abundance studies.

No specific models have been developed for assessing bird impacts related to ocean current projects, including no mortality assessment methodologies. Techniques to assess population level and cumulative effects likely will be adapted from models being used to assess wind power impacts. EMEC (2005) developed a general framework for impact assessment in its EIA guidance document for European developers of wave and tidal test sites, including impact matrices and criteria for assessing the significance of ecological effects.

The few published documents (Fraenkel, 2006) that have proposed mitigation measures related to birds include the following possibilities:

- Avoid siting the facility, cable paths, and vessel routes in important bird areas.
- Time construction and other sound-generating activities outside of nesting periods.
- Use antiperching or other deterrent devices (noisemakers) to deter birds from the above-water structures.
- Use appropriately colored or lighted structures underwater to deter birds.
- Adjust underwater sound to an appropriate level.

The necessity and effectiveness of these measures is unknown prior to any monitoring.

5.3.7 Information Needs—Ocean Current

Many of the information needs for ocean current installations are similar to those described in section 5.1 for offshore wind and section 5.2 for wave energy. In this section, emphasis is placed on information needs that are somewhat unique or focused mainly on ocean current technologies.

5.3.7.1 Physical Processes

Given the uncertainty with how these technologies will develop over the next 5 to 7 years, determining specific magnitudes of impacts is difficult. The most likely approach to understanding the nearfield impacts to currents and waves will require physical modeling or in situ testing. The in situ testing done in conjunction with the Stingray tidal project was useful, but it was concluded that insufficient data were available to draw firm conclusions (The Engineering Business Ltd., 2005). Similar types of testing should be conducted with various devices that are more specific to the conditions present on the OCS of the United States.

As mentioned by The Engineering Business Ltd (2005), a better understanding of the wake effects of these devices is needed. This most likely would be accomplished through physical modeling and in situ testing at pilot project locations. A better understanding of the wake could be used for scour studies to better determine the potential of these structures to generate scour pits away from the structures themselves.

Establishing the degree of impacts on neighboring shorelines should be undertaken as a combination of numerical modeling to estimate how sediment transport rates may change and monitoring shoreline morphology rates using satellite and aerial photography.

Fully understanding the farfield impacts of a modified major ocean current will require reasonable estimates of the current energy removed from the system (through physical modeling or in situ testing at pilot sites), and then using these results as inputs to a global climate model.

As with the other technologies, there is no relevant guidance on how to determine acceptable limits for changes to the wave, current, or sediment transport climates caused by current energy extraction devices.

5.3.7.2 Benthic Resources

Impacts to benthic resources are likely to be small and site-specific. The best method to mitigate impacts to benthic resources is to address possibilities during the site selection process. The potential amounts, fate, and effects of antifouling coatings released from wave energy devices, particularly as new products are developed, are not well characterized. Because ocean current installations will be placed in environments with steady one-directional currents, modeling of transport and fate processes should be readily feasible.

Cavitation noise needs better characterization to better assess potential impacts to benthic resources within the array.

5.3.7.3 Fishery Resources

Potential impacts to fishes that are unique to ocean current systems are collisions with moving parts and changes in water flow and pressures. Developers are working to reduce the turbine speeds to make them more fish friendly; research is needed to determine the speeds at different key locations in each turbine design that may cause injury to selected indicator fish species. Studies are also needed to determine if turbine designs for OCS installation will affect water flow and pressures in ways that could affect fish. Studies of fish impacts from hydroturbines on dams should provide a basis for design of such studies. Other information needs such as impacts from sound, EMF, introduction of hard substrates, and habitat disturbance could be extrapolated from studies of wind and wave installations because they are progressing ahead of ocean current installations.

5.3.7.4 Marine Mammals

The need for distribution and abundance studies as discussed in wind technologies also applies to ocean current technologies. More information is needed on the level of sound created during the operation of the underwater turbines and the effect the continuous sound may have on different species. Data are also needed on the attraction of marine mammals to underwater turbine structures and the collision risks associated with structures, especially among different age groups within a species. Further evaluation of the spacing of wind turbines is needed to determine possible impacts to marine mammals traveling through the area.

5.3.7.5 Sea Turtles

The distribution and abundance studies discussed for offshore wind power are also needed for ocean current technologies. Further information is needed to evaluate the potential collision risk for sea turtles in the vicinity of the underwater turbines, especially in areas where hatchlings will be present (e.g., near nesting beaches) and use currents to travel offshore. More data are also needed on whether sea turtles would avoid or approach operating turbines.

5.3.7.6 Birds

Some of the information needs on distribution and seasonal presence of birds are similar to those described for offshore wind power. More data on attraction of birds to underwater and above-water structures, both as roosting and nesting habitats and as collision risks would provide the basis for more informed assessments. Disturbance and habitat loss impacts related to ocean current energy construction and operation should be examined. Attraction to artificial lighting in the context of ocean current energy structures (e.g., height and intensity of lighted features above water and underwater lighting) should be studied. Monitoring of actual installations will provide information on the actual risk of entanglement and entrapment and measures needed to reduce those risks.

6. Summary

The objectives of this study were to identify, collect, evaluate, and synthesize existing information on potential impacts of offshore alternative energy activities on the outer continental shelf (OCS) for the following topics:

- Current offshore energy technologies and future trends
- How public acceptance of existing projects was or was not achieved
- Summaries of the results of monitoring studies at existing projects
- Potential direct, indirect, and cumulative environmental impacts of offshore energy technologies
- Previously used mitigation measures that could avoid, minimize, rectify, eliminate, or compensate for environmental impacts
- Current physical and numerical models designed to determine environmental impacts
- Information needs to address gaps in our current understanding of environmental impacts

Most available literature is based on assessments or studies of existing or planned offshore wind parks in Europe. There are a few prototype or demonstration projects for wave energy devices and tidal current systems for deployment nearshore, but there are no full-scale installations currently. While existing literature provided valuable information on the potential magnitude of impacts for environmental resources in the project areas, more information is needed to address environmental assessment of alternative energy projects in the offshore waters of the United States. These information needs are described in detail for the broad resource categories of physical processes, benthic resources, fishery resources, marine mammals, sea turtles, and flying animals (birds, bats, and flying insects) at the end of each section on wind, wave, and ocean current technologies. The lists of information needs for each resource are comprehensive, and they cover a wide range of types of studies and priorities. The information needs can be divided into the following five general categories:

1. Finer-grained data on the distribution and life history for key species in each regional ecosystem; environmental assessments for specific projects need more detailed data on benthic habitats and multiyear studies of seasonal abundance and distribution of key species of each resource.
2. Development of better field data collection methods for baseline studies and postconstruction monitoring surveys to improve the confidence of impact detection; study of highly mobile species in offshore areas is particularly difficult, requiring new approaches and technologies.
3. Focused laboratory studies to determine thresholds for potential effects resulting from exposure to the types and levels of sound and electromagnetic fields likely to be generated by different types of alternative energy devices in full-scale installations.
4. Development of protocols for field studies on potential effects from exposure to sound, electromagnetic fields, and obstructions on the behavior and survival of key species of each resource of concern.

5. Development of guidelines to set acceptable limits of direct, indirect, and cumulative impacts resulting from the installation and operation of offshore alternative energy projects; guidelines are needed for all types of potential impacts such as changes to the hydrodynamic climate, erosion of adjacent shorelines, habitat loss and alteration, avoidance and attraction behavior, mortality, aesthetics, and lost use.

MMS has conducted preliminary analyses of the likely geographic locations where alternative energy development is most feasible based on existing and near-term technologies and physical factors such as wind speed, wave energy, and water depth. The scale of these analyses is very coarse, indicating wind parks in shallow water (less than 100 m in depth) along the Atlantic and Gulf of Mexico coasts, wave technologies along the Pacific coast, and ocean current technologies where the Gulf Stream passes close to Florida. Many of the resource concerns are associated with mobile and migratory species, and baseline studies in broad geographic areas are very expensive. To better identify and prioritize where studies of key resources should be conducted, MMS should conduct geospatial analyses to identify the most likely areas of OCS alternative energy development in the near term. These maps would then be used to identify where more detailed resource studies are needed.

As information is collected, the alternative energy and scientific communities would benefit from the initiation of a spatially and temporally referenced database. The ability to relate and connect various datasets both spatially and temporally is a powerful and efficient way to assess a site's appropriateness for alternative energy technology on a preliminary basis. Beyond the preliminary phases, it is useful in modeling and monitoring phases.

The ability to make these datasets open and available to the alternative energy and scientific communities through web portals and other internet resources makes for efficient collaboration and reduces the chance of duplicating research efforts. These efforts could be aligned with the efforts of the U.S. Geological Survey and the National Oceanic and Atmospheric Administration to provide more seamless datasets. Future permits could be made contingent on certain datasets being shared with permitting agencies – thus maximizing the reach of research efforts.

In June 2007, MMS is convening a workshop, "Workshop to Identify Alternative Energy Environmental Information Needs." This synthesis report will assist workshop participants in their efforts to evaluate the body of information currently available, identify data and knowledge needs in the information available about human and marine environments as they relate to alternative energy issues, and develop a prioritized list of environmental studies needed to fill the identified information needs.

7. References Cited

References for Section 3.1 – Wind Technology

Birklund, J. and Petersen, A.H. 2004. Development of the Fouling Community on Turbine Foundations and Scour Protections in Nysted Offshore Wind Farm, 2003. Energi E2 A/S.

BWEA (British Wind Energy Association). 2000. Noise from Wind Turbines. Internet Web site: www.bwea.com/pdf/noise.pdf. Accessed March 2007.

British Wind Energy Association. 2005. BWEA Briefing Sheet Offshore Wind.

British Wind Energy Association. 2006. Offshore Wind. Internet Web site: http://www.bwea.com/offshore/. Accessed February 2007.

Cape Wind Associates, LLC. 2007. Internet Web site: http://www.capewind.org. Accessed February 2007.

Dong Energy and Vattenfall. 2006. Review Report 2005: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms Environmental Impact Assessment and Monitoring. The Environmental Group of the Danish Offshore Wind Farm Demonstration Project.

Elsam Engineering A/S and Energi E2 A/S. 2005. Review Report 2004: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farm Environmental impact assessment and monitoring. The Environmental Group of Danish Offshore Wind Farm Demonstration Projects.

Elsamprojekt A/S. 2000. Horns Rev Offshore Wind Farm Environmental Impact Assessment: Summary of EIA Report. I/S Elsam.

General Electric. 2007. Wind Energy at GE. Internet Web site: http://www.gepower.com/businesses/ge_wind_energy/en/index.htm. Accessed February 2007.

Hay, Michael, pers. comm. 2007. British Wind Energy Association.

Ladenburg, J., 2006. Attitudes towards Wind Power Development in Denmark. Institute of Food and Resource Economics, Environmental Economics and Rural Development Division, The Royal Veterinary and Agriculture University, Copenhagen. 51 pp.

Leonhard, S.B., Pedersen, J., Moeslund, B., Spanggaard, G. 2006. Benthic Communities at Horns Rev Before, During and After Construction of Horns Rev Offshore Wind Farm: Final Report: Annual Report 2005. Vattenfall A/S.

LIOWP. 2007. Long Island Power Authority Offshore Wind Park Homepage. Internet Web site: http://www.lipower.org/cei/offshore.html. Accessed March 2007.

MMS (Minerals Management Service). 2006. Technology White Paper on Wind Energy Potential on the U.S. Outer Continental Shelf. Renewable Energy and Alternate Use Program. U.S. Department of the Interior.

Npower Renewables. 2006. North Hoyle Offshore Wind Farm. Internet Web site: http://www.natwindpower.co.uk/northhoyle/index.asp. Accessed February 2007.

Npower Renewables. 2007. Communication from Adrian Emanuel, Wind Operations Regional Manager, by email dated March 26, 2007.

RPS. 2005. Environmental Statement, Non-Technical Summary, London Array Limited, 2005.

The Scottish Office. 1994. Planning Advice Note, PAN 45, Annex A: Wind Power, A.27. Renewable Energy Technologies, Environment Department. 2H Victoria Quay, Edinburgh.

WEC (World Energy Council). 2001. Survey of Energy Resources: Wind Energy. Internet Web site: http://www.worldenergy.org/wec-geis/publications/reports/ser/wind/wind.asp. Accessed February 2007.

References for Section 3.2 – Wave Technology

Bedard, R., Hagerman, G., Previsic, M., Siddiqui, O., Thresher, R., and Ram, B. 2005. Final Summary Report: Project Definition Study – Offshore Wave Power Feasibility Demonstration Project. E21 EPRI Global WP 009 – US Rev 2.

Finavera Renewables. 2006. Wave Energy: Makah Bay. Internet Web site: http://finavera.com/wave/makah_bay. Accessed February 2007.

JAMSTEC. 1998. Wave Energy Research and Development at JAMSTEC. Internet Web site: http://www.jamstec.go.jp/jamstec/MTD/Whale. Accessed March 2007.

Ocean Power Delivery, Ltd. 2007. The Pelamis Wave Energy Converter. Internet Web site: http://www.oceanpd.com/Pelamis/default.html. Accessed February 2007.

Ocean Power Technologies. 2007. Technology. Projects. Internet Web site: http://www.oceanpowertechnologies.com. Accessed March 2007.

Scottish Executive, 2007. Internet Web site: http://www.scotland.gov.uk/News/Releases/2007/02/20091751. Accessed March 2007.

Thorpe, T.W. 1999. An Overview of Wave Energy Technologies: Status, Performance and Costs. Wave Power: Moving towards Commercial Viability, 30 November 1999:1–16.

Wave Dragon. 2005. Wave Dragon Homepage. Internet Web site: http://www.wavedragon.net/index.php?option=com_content&task=view&id=7&Itemid=7. Accessed February 2007.

References for Section 3.3 – Ocean Current Technology

ABP Marine Environmental Research Ltd. 2004. Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters. Countryside Council for Wales.

Blue Energy Canada, Inc. 2006. Blue Energy The Davis Hydro Turbine. Internet Web site: http://www.bluenergy.com/davishydroturbine.html/. Accessed February 2007.

Hammerfest Strøm A/S. 2007. Hammerfest Strøm Homepage. Internet Web site: http://www.e-tidevannsenergi.com/. Accessed February 2007.

IT Power. 2005. Development, Installation, and Testing of a Large-Scale Tidal Current Turbine. Report T/06/00210/00/REP, URN 05/1698. Internet Web site: http://www.dti.gov.uk/files/file18130.pdf?pubpdfdload=05%2F1698. Accessed April 2007.

Marine Current Turbines, Ltd. 2002. Marine Current Turbines Homepage. Internet Web site: http://www.marineturbines.com/background.htm. Accessed February 2007.

MMS (Minerals Management Service). 2006. Technology White Paper on Ocean Current Energy Potential on the U.S. Outer Continental Shelf. Renewable Energy and Alternate Use Program. U.S. Department of the Interior. Internet Web site: http://ocsenergy.anl.gov.

Open Hydro Group, Ltd. 2007. Open Hydro Homepage. Internet Web site: http://www.openhydro.com/. Accessed February 2007.

Triton Consultants Ltd. 2002. Green Energy Study for British Columbia. Phase 2: Mainland. Tidal Current Energy. Chapter 6: Technology Review. Prepared for BC Hydro, Engineering. Internet Web site: http://homepage.mac.com/max.larson/Triton/download/environment3928.pdf. Accessed March 27, 2007.

References for Section 3.4 – Solar Technologies

Broehl, J. 2007. A New Chapter Begins for Concentrated Solar Power. Internet Website. www.renewableenergyaccess.com/rea/new/printstory;jsessiionid=26237C3B052590. Accessed March 26, 2007.

U.S. Department of Energy Efficiency and Renewable Energy (EERE). 2006. Internet Website: http://www1.eere.energy.gov/solar/csp.html Accessed March 27, 2007.

Kanellos, M. 2007. Full Steam Ahead for Nevada Solar Project. News.com Website: http://news.com.com/full+steam+ahead+for+Nevada+solar+project/2100-11392_3-6166113.html. Accessed March 26, 2007.

MMS (Minerals Management Service). 2006. Technology White Paper on Solar Energy Potential on the U.S. Outer Continental Shelf. Renewable Energy and Alternate Use Program. U.S. Department of the Interior. Internet Web site: http://ocsenergy.anl.gov.

PowerLight. 2006. How solar works. Internet Web site: http://www.powerlight.com/solar/howitworks.php. Accessed November 15, 2006.

Renewable Energy UK. 2007. Renewable Energy UK website. http://www.reuk.co.uk/Worlds-Largest-Solar-Power-Plant.htm. Accessed March 26, 2007.

Solar Depot, Inc. 2006. Oroville Sewage Commission. Internet Web site: http://www.solardepot.com/testimo/Orroville_commercial.htm. Accessed February 2007.

Solar Energy Society of Canada Inc. (SESCI). 1997. Photovoltaic solar energy. Internet Web site: http://www.newenergy.org/sesci/publications/pamphlets/photovoltaic.html. Accessed November 16, 2006.

References for Section 3.5 – Hydrogen Technologies

MMS (Minerals Management Service). 2006. Technology White Paper on Generation of Hydrogen and Transportation and Transmission of Energy Generated on the U.S. Outer Continental Shelf to Onshore. Renewable Energy and Alternate Use Program. U.S. Department of the Interior.

References for Section 4 – Social, Economic, and Cultural Impacts of Offshore Energy

AMEC 2002. AMEC Wind Energy Lynn Offshore Environmental Impact Assessment. AMEC. 426 pp.

AquaEnergy, Ltd. 2006. Makah Bay Offshore Wave Energy Pilot Project: FERC Docket No. DI02-3-002: Preliminary Draft Environmental Assessment. FERC. 179 pp.

BMT Cordah Limited. 2003. Offshore Wind Energy Generation: Phase 1 Proposals and Environmental Report. Prepared for the UK Department of Trade and Industry. 224 pp.

BWEA (British Wind Energy Association). 2002. Best Practice Guidelines: Consultation for Offshore Wind Energy Developments.

Cape Wind Associates. 2007. Cape Wind Energy Project: Final Environmental Impact Report/Development of Regional Impact. 774 pp.

Coyle, A.M. 2007. Scroby Sands Stakeholder Dialogue, Presentation by Powergen. 1-16. Internet Web site: http://www.owen.eru.rl.ac.uk/documents/BWEA23/BWEA23_Coyle_ScrobySandsDialogue_presentation.pdf. Accessed April 2, 2007.

Danish Energy Authority. 2005. Copenhagen Strategy on Offshore Wind Power Development. European Policy Seminar on Offshore Wind Power. October 27, 2005.

Department of the Navy. 2003. Environmental Assessment Proposed Wave Energy Technology Project, Marine Corps Base Hawaii, Kaneohe Bay, Hawaii. Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. 300 pp.

Department of Trade and Industry, UK. 2005. Guidance on the Assessment of the Impact of Offshore Wind farms: Seascape and Visual Impact Report. DTI/Pub 8066/0.3k/11/05/NP. 127 pp.

Department of Trade and Industry. 2006. Consultation on Safety Zones. Implementing the Provisions of The Energy Act 2004 Relating to the Establishment of Safety Zones Around Offshore Renewable Energy Installations. Department of Trade and Industry, London. 45 pp.

Department of Trade and Industry, UK. 2007. Renewable Energy. Internet Web site: http://www.dti.gov.uk/energy/sources/renewables/index.html. Accessed April 2, 2007.

Dong Energy, Vattenfall, Danish Energy Authority, and the Danish Forest and Nature Agency. 2006. Danish Offshore Wind – Key Environmental Issues. November. 144 pp.

Elsam Engineering. 2004. Report on Horns Rev VHF Radio and Marine Radar. Prepared for Cape Wind Associates. Appendix 5-14B in the Cape Wind Project Draft Environmental Impact Statement. 9 pp.

Emu Ltd. 2002. Kentish Flats Environmental Statement. Report submitted to Global Renewable Energy Partners. Report No. 02/J/1/06/0394/0306. Kentish Flats Ltd.

ETSU for Department of Trade and Industry. 1996. The Working Group on Noise from Wind Turbines. Assessment and Rating of Noise from Wind Farms. ETSU-R-97. 153 pp. http://www.dti.gov.uk/energy/page21743.html. Accessed 3 March 2007.

Firestone, J., Kempton, W. and Krueger, A. 2007. Delaware Opinion on Offshore Wind Power – Interim Report. 16 pp.

Grady, D.O. and Cousino, K.A. 2004. Public Attitudes Toward Wind Energy in Coastal North Carolina: A Systematic Survey. Appalachian State University Energy Center and the North Carolina Energy Policy Council. February 26.

GREAT (Graveny Rural Environmental Action Team). 2007. G.R.E.A.T. News. Internet Web site: http://www.graveney-village.co.United Kingdom/greatnews_35076.html. Accessed February 5, 2007.

Gray, T., Haggett, C. and Bell, D. 2005. Offshore wind farms and commercial fisheries in the UK: A study in stakeholder consultation. Ethics Place and Environment 8(2):127-140.

Hagemann, E. and Jensen, P.C. 2005. Offshore Wind Power: Danish Experiences and Solutions. Danish Energy Authority.

Hagerman, G. and Bedard, R. 2004. Offshore Wave Power in the US: Environmental Issues. Global Energy Partners, LLC. E2I Global EPRI-007-US. 29 pp.

Halcrow Group Ltd. 2006. South West of England Regional Development Agency Wave Hub Environmental Statement. Sowton, Exeter. 268 pp.

Hill, M., Briggs, J., Minto, P., Bagnall, D., Foley, K. and Williams, A. 2001. Guide to Best Practice in Seascape Assessment. Maritime Ireland/Wales INTERREG Report No.5. Countryside Council for Wales, National University of Ireland, Dublin. 58 pp.

Kent Wildlife Trust. 2007. What is KWTs policy on the London Array and Windfarms? Internet Web site: www.kentwildlifetrust.org.United Kingdom. Accessed April 3, 2007.

Kuehn, S. 2005a. Sociological Investigation of the Reception of Nysted Offshore Wind farm, Annual Report 2004, ECON Analysis.

Kuehn, S. 2005b. Sociological Investigation of the Reception of Horns Rev and Nysted Offshore Wind farms In the Local Communities. Report No. 2005-044, ECON Analysis. 20 pp.

Ladenburg, J. 2006. Attitudes Towards Wind Power Development in Denmark. Institute of Food and Resource Economics, Denmark.

Ladenburg, J., Dubgaard, A., Martensen, L. and Tranberg, J. 2005. Economic Valuation of the Visual Externalities of Off-Shore Wind farms: Report No. 179. Food and Resource Economic Institute. The Royal Veterinary and Agriculture University, Copenhagen. 185 pp

Larsen, J.H.M., Soerensen, H.C., Christiansen, E., Naef, S. and Volund, P. 2005. Experiences from Middlegrunden 40 MW offshore wind farm. Copenhagen Offshore Wind 26-28 October 2005.

Lieberman Research Group. 2006. New Jersey Shore Opinions About Off-Shore Wind Turbines, Presentation to the New Jersey Commerce, Economic Growth & Tourism Commission and Brushfire, Inc. September 14.

Mackinson, S., Curtis, H., Brown, R., McTaggart, K., Taylor, N., Neville, S. and Rogers, S. 2006. A Report on the Perceptions of the Fishing Industry into the Potential Socioeconomic Impacts of Offshore Wind Energy Developments on their Work Patterns and Income. Sci. Ser. Tech Rep., CEFAS, Lowestoft 133:1-99.

McKay, J., Nides, J. and Vigil, D. (eds). 2002. Proceeding: Gulf of Mexico Fish and Fisheries: Bringing Together New and Recent Research, October 2000, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-004. 674 pp.

Mackinson, S., Curtis, H., Brown, R., McTaggart, K., Taylor, N., Neville, S. and Rogers, S. 2006. A Report on the Perceptions of the Fishing Industry into the Potential Socio-Economic Impacts of Offshore Wind Energy Developments on their Work Patterns and Income. Science Series Technical Report no. 133, CEFAS Lowestoft, 133: 99 pp.

Manwell, J.F. 2007. Hull Offshore Wind. Presentation by the Renewable Energy Research Laboratory of the University of Massachusetts. February 24.

Market Research Wales Ltd. 2002. Public Attitudes to Wind Energy in Wales. Prepared for Friends of the Earth Cymru. September. Internet Web site: http://www.foe.co.uk/resource/reports/attitude_wind_energy_wales.pdf. Accessed April 2, 2007.

Nedwell, J. and Howell, D. 2004. A Review of Offshore Windfarm Related Underwater Noise Sources. Collaborative Offshore Wind Energy Research into the Environment (COWRIE).

NOAA. 2006. Final Consolidated Highly Migratory Species Fishery Management Plan. National Oceanic and Atmospheric Administration, Highly Migratory Species Management Division, Silver Spring, MD. 934 pp.

NTIS. Petroleum Structures as Artificial Reefs: A Compendium. MMS. NTIS No. PB 90-114620/AS.

Olmstead, C. pers. comm. 2007. Cape Wind, Boston, MA.

Opinion Dynamics Corporation. 2002. Memorandum to Cape Wind Associates Regarding the Analysis of Voter Opinion Survey Results. October 3. Internet Web Site: http://www.capewind.org/downloads/public_opinion_survey.pdf. Accessed April 2, 2007.

Opinion Research Corporation. 2006. Massachusetts Renewables/Cape Wind Survey. Prepared for the Civil Society Institute. June 7, 2006.

Oregon Fishermen's Cable Committee. 2007. Internet website: http://www.ofcc.com/procedures.htm. Accessed on 11 March 2007.

Patterson, W.F., Cowan, J.H. and Shipp, R.L. 2004. Red Snapper Site Fidelity to, and Speed of Movement from, Artificial Reef Sites off Alabama in the Northern Gulf of Mexico. In McKay, J., Nides, J. and Vigil, D. (eds). Proceeding: Gulf of Mexico Fish and Fisheries: Bringing Together New and Recent Research, October 2000, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-004. Pp. 633-648.

Renewable Energy Research Laboratory. 2007. Wind Power on the Community Scale – Community Wind Case Study: Hull. University of Massachusetts. Internet Web Site: http://www.ceere.org/rerl/about_wind/RERL_Case_Study_Hull_Wind_One.pdf. Accessed April 2, 2007.

RSPB (Royal Society for the Protection of Birds). 2007. Save the Lewis Peatlands. Internet Web Site: http://www.rspb.org.uk/supporting/campaigns/lewis/index.asp. Accessed April 3, 2007.

RPS. 2005. Environmental Statement: Non-Technical Summary, London Array Limited. Shell Wind Energy, Farm Energy, Energi E2, and E.ON. June.

SAFMC. 2007c. Minutes of Amendments 13-14 for MPAs for Snapper-Grouper. Charleston, SC. Internet Web site: http://www.safmc.net/Library/SnapperGrouper/tabid/415/Default.aspx. Accessed 13 March 2007.

The Birdinsight. 2007. UK - RSPB Backs London Array Wind Farm. Internet Web site: http://thebirdinsight.com/forum/showthread.php?p=9919. Accessed April 3, 2007.

The Scottish Office. 1994. Planning Advice Note, PAN 45, Annex A: Wind Power, A.27. Renewable Energy Technologies, Environment Department. 2H Victoria Quay, Edinburgh.

University of Newcastle. 2002. Visual Assessment of Wind farms: Best Practice: Scottish Natural Heritage Commissioned Report No. F01AA303A. Scottish Natural Heritage. 79 pp.

UN (United Nations Economic Commission for Europe). 2005. Internet Web Site: www.unece.org/env/eia/sea_protocal.htm. Accessed April 2007.

Watson, G. pers. comm. 2007. Massachusetts Technology Collaborative, Boston, MA.

WaveNet. 2003. Results from the Work of the European Thematic Network on Wave Energy. ERK5-CT-1999-20001. 484 pp.

Wilson, C.A. 2006. The Effect of Depth, Location and Habitat Type on Relative Abundance and Species Composition of Fishes Associated with Petroleum Platforms and Sonnier Bank in the northern Gulf of Mexico. Completion Report Minerals Management Service Contract number: 1435-0001-30660-19947.

Wilson, C. A., Pierce, A. and Miller, M.W. 2003. Rigs and Reefs: a Comparison of the Fish Communities at Two Artificial Reefs, a Production Platform, and a Natural Reef in the northern Gulf of Mexico. Prepared by the Coastal Fisheries Institute, School of the Coast and Environment. Louisiana State University. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-009. 95 pp.

References for Section 5.1 – Wind Technologies

Carryer, R. and Deeming, K. 1998. Environmental risk for offshore windfarm developers: lessons from other industries. In Proceedings of the Twentieth BWEA Wind Energy Conference Wind Energy: Switch on to Wind Power. Professional Engineering Publishing Ltd., Bury St Edmonds, UK.

Dong Energy and Vattenfall. 2006. Review Report 2005: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind farms Environmental Impact Assessment and Monitoring. The Environmental Group. 150 pp.

Gill, A.B. 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. J. Applied Ecology 42:605-615.

Hiscock, K., Tyler-Walters, H. and Jones, H. 2002. High Level Environmental Screening Study for Offshore Wind Farm Developments: Marine Habitats and Species Project. Department of Trade and Industry New & Renewable Energy Programme, UK. 34 pp.

References for Section 5.1.2 – Physical Processes

Aalborg University. 2004. Scour Around Offshore Wind Turbine Foundations. Borkum Riffgrund. Report prepared for LICEngineering, November 2004.

Annandale, G.W. 2006. Scour Technology Mechanics and Engineering Practice. The McGraw-Hill Companies, Inc. New York, NY. ISBN 0-07-144057-7

Arnell N., Tompkins, E., Adger, N. and Delaney, K. 2005. Vulnerability to abrupt Climate Change in Europe. Tyndall Centre Technical Report 34. Report submitted to ESRC Environment and Human Behavior Programme. Project RES-221-25-0011

Benedet L., Stive, M., Hartog, W., Walstra, D. and Van Koningsveld, M. 2006. Effects of wave diffraction and initial bathymetric conditions on beach fill volume change predictions. In Proceedings of the International Conference on Coastal Engineering 2006, San Francisco CA, 2-8 September 2006.

Bos, K.J. and Verheij, H.J. 2002. Scour Protection Around Gravity Based Structures Using Small Size Rock. In Proceedings, First International Conference on Scour of Foundations. Texas A&M University, College Station, TX. November 2002. Pp 567-581.

Broecker, W.S. 1997. Thermohaline circulation, the Achilles' Heel of our climate system: Will man-made CO_2 upset the current balance? Science 278(5343):1582-1588.

Cape Wind Associates. 2007. Cape Wind Energy Project Final Environmental Impact Report. Submitted to Massachusetts Environmental Policy Act Office.

CEFAS. 2006. Scroby Sands Offshore Wind Farm Coastal Processes Monitoring. Final Report. Report prepared for The Department of Trade and Industry, UK. Contract Ref. No. AE0262.

Cooper, B. and Beiboer, F. 2002. Potential Effects of Offshore Wind Developments on Coastal Processes. Report Submitted to Department of Trade and Industry, UK. Report No. ETSU W/35/00596/00/REP.

DHI Water and Environment. 1999. Horns Rev Wind Power Plant: Environmental Impact Assessment of Hydrography. Report submitted to Elsamprojekt, November 1999. Project No. 50396-01.

DHI Water and Environment. 2006. Horns Rev 2 Offshore Wind Farm: Coastal Impact Assessment. Report prepared for ENERGI E2 A/S Project No. 53575.

Emu Ltd. 2002. Kentish Flats Environmental Statement. Report submitted to Global Renewable Energy Partners. Report No. 02/J/1/06/0394/0306. Kentish Flats Ltd.

Emu Ltd. 2005. Kentish Flats Offshore Windfarm Post-Construction Swath Survey 2 For Kentish Flats Ltd. Report No. 05/J/1/02/0869/0564: December 2005 Job No. J/1/02/0869. Kentish Flats Ltd.

Emu Ltd. 2006. Kentish Flats Offshore Windfarm Post-Construction Swath Survey 3 For Kentish Flats Ltd. Report No. 06/J/1/02/0942/0590: April 2006 Job No. J/1/02/0942. Kentish Flats Ltd.

ENERGI E2 A/S and Elsam Engineering A/S. 2004. Review Report 2004, The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms, Environmental Impact Assessment and Monitoring. Report prepared for The Environmental Committee of the Danish Offshore Wind Farm Demonstration Projects.

Fredsøe, J. and Deigaard, R. 1992. Mechanics of Coastal Sediment Transport. World Scientific Publishing Co. Pte. Ltd., Singapore. ISBN 981-02-0841-3.

Goda, Y. 1985. Random Seas and Design of Maritime Structures. University of Tokyo Press, Tokyo. ISBN 0-86008-369-1.

Halcrow Group Ltd. 2001. Proposed Scroby Sands Wind Farm, Analysis of bank morphology and predictions of future changes. Report prepared for PowerGen, UK, December 2001.

Halcrow Group Ltd. 2006. Wave Hub Environmental Statement. Report submitted to South West of England Development Agency, June 2006. 286 pp.

Høgedal, M. and Hald, T. 2005. Scour Assessment and Design for Scour for Monopile Foundations for Offshore Wind Turbines. Copenhagen Offshore Wind 2005, Copenhagen. 13 pp.

Kvitek, R., Leisten, T., Iampetro, P., Bretz, C. 2003. Santa Monica Bay Mapping Project: Final Report and GIS User's Guide. Seafloor Mapping Lab, California State University.

NRC (National Research Council). 2002. Abrupt Climate Change: Inevitable Surprises. National Academies Press. Washington, DC. 244 pp.

Offshore Center Danmark. 2006. Offshore Wind Turbines Situated in Areas with Strong Currents. Ramboll, Aalborg Universitet, Offshore Center Danmark Aalborg Universitet Esbjerg and A2SEA. 156 pp.

Partheniades, E. 1991. Handbook of Coastal and Ocean Engineering, Volume 3: Harbors, Navigational Channels, Estuaries and Environmental Effects. Gulf Publishing Co., Houston TX. Pp 767–984.

Sarpkaya, T. and Isaacson, M. 1981. Mechanics of Wave Forces on Offshore Structures. Van Nostrand Reinhold Company Inc. New York, NY. ISBN 0-442-25402-4.

Schwab, W.C., Thieler, E.R., Denny, J.F., Danforth, W.W. 2000. Seafloor Sediment Distribution Off Southern Long Island, New York: U.S. Geological Survey Open-File Report 00-243

Soulsby, R. 1997. Dynamics of Marine Sands. Thomas Telford Services Ltd. London. ISBN 0-7277-2584-X.

Sumer, B.M. and Fredsøe, J. 1997. Hydrodynamics Around Cylindrical Structures. World Scientific Publishing Co. Pte. Ltd., Singapore. ISBN 981-02-3056-7.

Sumer, B.M. and Fredsøe, J. 2002. The Mechanics of Scour in the Marine Environment. World Scientific Publishing Co. Pte. Ltd., Singapore. ISBN 981-02-4930-6.

U.S. Geological Survey. 2006. National Seafloor Mapping and Benthic Habitat Studies. Internet Web site:: http://walrus.wr.usgs.gov/research/projects/nearshorehab.html. Project #: 99380LD.0.0 Accessed 31 May 2007.

Van Rijn, L. 1993. Principles of sediment transport in rivers, estuaries and coastal seas. Aqua Publications, Amsterdam. ISBN 90-800356-2-9.

Whitehouse, R. 1998. Scour at Marine Structures. Thomas Telford Publications. ISBN 0 7277 2655 2.

Williams, S.J., Reid. J.M. and Manheim. F.T., 2003, A bibliography of selected references to U.S. marine sand and gravel mineral resources, U.S. Geological Survey Open-File Report 03-300

References for Section 5.1.3 – Benthic Resources

AMEC 2002. AMEC Wind Energy Lynn Offshore Environmental Impact Assessment. AMEC. 426 pp.

AMEC. 2005. Aberdeen Offshore Wind farm, Request For an Environmental Impact Assessment (EIA) Scoping Opinion. AMEC. 53 pp.

Bech, M., Frederiksen, R., Pedersen, J., Leonhard, S.B., Spanggard, G. and Moeslund, B. 2005. Infauna Monitoring Horns Rev Offshore Wind farm Annual Status Report 2004. Elsam Engineering. 64 pp.

Birklund, J. 2005. Marine Biological Surveys Along the Cable Trench in the Lagoon of Rødsand in October 2003 and October 2004. Energi E2. 49 pp.

Birklund, J. 2006a. The Hard Bottom Communities on Foundations in Nysted Offshore Wind farm and Schonheiders Pulle in 2005 and Development of the Communities in 2003-2005. ENERGI E2 A/S. 64 pp.

Birklund, J. 2006b. Surveys of the Benthic Communities in Nysted Offshore Wind farm in 2005 and Changes in the Communities since 1999 and 2001. ENERGI E2 A/S. 50 pp.

Blake, N.J., Doyle, L.J. and Culter, J.J. 1996. Impacts and Direct Effects of Sand Dredging for Beach Renourishment on the Benthic Organisms and Geology of the West Florida Shelf, Final Report. U.S. Department of the Interior, Minerals Management Service, Office of International Activities and Marine Minerals, Herndon, VA. OCS Report MMS 95-0005. 109 pp.

Bochert, R. and Zettler, M.L. 2004. Long-term exposure of several marine benthic animals to static magnetic field. Bioelectromagnetics 25:498-502.

Buczkowski, B.J., Reid, J.A., Jenkins, C.J., Reid, J.M., Williams, S.J. and Flocks, J.G. 2006. usSEABED: Gulf of Mexico and Caribbean (Puerto Rico and U.S. Virgin Islands) Offshore Surficial Sediment Data Release: U.S. Geological Survey Data Series 146, Version 1.0, CD-ROM.

Carey, A.G., Jr. 1972. Ecological Observations on the Benthic Invertebrates from the Central Oregon Continental Shelf. In Pruter, A.T. and Alverson, D.L. (eds.). The Columbia River Estuary and Adjacent Ocean Waters, University of Washington Press, Seattle, WA. Pp. 422-443.

Carney, R.S. 2005. Characterization of Algal-invertebrate Mats at Offshore Platforms and the Assessment of Methods for Artificial Substrate Studies: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS, New Orleans, LA. OCS Study MMS 2005-038. 93 pp.

CEFAS. 2004. Offshore Wind Farms: Guidance Note for Environmental Impact Assessment In Respect of FEPA and CPA Requirements: Version 2 - June 2004. Crown Publishing. 48 pp.

CMACS (Centre for Marine and Coastal Studies, University of Liverpool). 2003. A Baseline Assessment of Electromagnetic Fields Generated by Offshore Wind Farm Cables Final Report. COWRIE Report EMF - 01-2002 66. 71 pp.

Continental Shelf Associates, Inc. 2005. Survey of Invertebrate and Algal Communities on Offshore Oil and Gas Platforms in Southern California: Final Report. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Camarillo, CA. OCS Study MMS 2005-070. 232 pp. + appendices.

Cochrane, G.R., Conrad, J.E., Reid, J.A., Fangman, S. and Golden, N. 2005. The Nearshore Benthic Habitat GIS for the Channel Islands National Marine Sanctuary and Southern California State Fisheries Reserves, Volume II. Version 1.0: U.S. Geological Survey, Open-file Report 2005-1170. http://pubs.usgs.gov/of/2005/1170/.

Dailey, M.D., Reish, D.J. and Anderson, J.W. (eds). 1990. Ecology of the Southern California Bight: A Synthesis and Interpretation. U.S. Department of the Interior, Minerals Management Service, Pacific Region OCS Contract Study #14-12-0001-30341.

Dokken, Q.R., Withers, K. Childs, S. and Riggs, T. 2000. Characterization and Comparison of Platform Reef Communities off the Texas Coast. Prepared for Texas Parks and Wildlife Department. Texas A&M University, Corpus Christi, TX. TAMU-CC-0007-CCS. 75 pp.

Dong Energy, Vattenfall, The Danish Energy Authority and The Danish Forest and Nature Agency. 2006. Danish Off shore Wind – Key Environmental Issues. 144 pp.

Dong Energy and Vattenfall. 2006. Review Report 2005: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind farms Environmental Impact Assessment and Monitoring. The Environmental Group. 150 pp.

Emu Ltd. 2005. Kentish Flats Monitoring Programme, Fisheries Surveys, Post Construction Oyster Sampling. Report No. 04/J/1/03/0704/0520. Emu Ltd., Southampton, Hampshire. 18 pp. + appendices.

Emu Ltd. 2006. Kentish Flats Wind farm Development, Macrobenthic Ecology Study- 2005. Report No. 05/J/1/03/0772/0510. Emu Ltd., Southampton, Hampshire. 80 pp. + appendices.

E.ON UK Renewables. 2005. Capital Grant Scheme for Offshore Wind Annual Report: January 2005 - December 2005, Executive Summary. Scroby Sands Wind. 15 pp.

Gallaway, B. and Lewbel, G. 1982. The Ecology of Petroleum Platforms in the Northwestern Gulf of Mexico: A Community Profile. U.S. Dept. of the Interior, Fish and Wildlife Service, Biological Services Program FWS/OBS-82/72, BLM Open File Report 82-03. 52 pp.

IAPEME. 2002. Danish Off Shore Windpower Programme: International Advisory Panel of Experts on Marine Ecology (IAPEME): Statement from meeting in March 2002. International Advisory Panel of Experts on Marine Ecology.

IAPEME. 2006. Minutes from the 2003 Meeting of the International Advisory Panel of Experts on Marine Ecology. Secretariat of IAPEME, Danish Forest- and Nature Agency, Haraldsgade 53, DK-2100 København Ø.

Jensen, H., Kristensen, P.S. and Hoffman, E. 2003. Sandeels and Clams (*Spisula sp.*) in the Wind Turbine Park at Horns Reef. Danish Institute for Fisheries Research, Depart of Marine Fisheries, Charlottenlund Castle2920 Charlottenlund. 42 pp.

Jensen, H., Kristensen, P.S. and Hoffman, E. 2004. Sandeels in the Wind Farm Area at Horns Reef. Elsam Engineering. 26 pp.

Leonhard, S.B. and Pedersen, J. 2005. Hard Bottom Substrate Monitoring: Horns Rev Offshore Wind farm: Annual Status Report 2004. Elsam Engineering. 54 pp.

Leonhard, S.B. and Pedersen, J. 2006. Benthic Communities at Horns Rev Before, During and After Construction of Horns Rev Offshore Wind farm: Final Report: Annual Report 2005. Vattenfall. 134 pp.

Leonhard, S.B. 2006. EIA Report Benthic Communities: Horns Rev 2 Offshore Wind farm. Energi E2. 51 pp.

MMS. 2007. Outer Continental Shelf Oil & Gas Leasing Program: 2007-2012, Final Environmental Impact Statement. Minerals Management Service, Herndon, VA, OCS EIS/EA MMS 2007-018.

Lie, W. and Kelley, J.C. 1970. Benthic infauna communities off the coast of Washington and in Puget Sound: Identification and distribution of communities. J. Fisheries Research Board of Canada 27:621-651.

Newell, R.C., Seiderer, L.J. and Hitchcock, D.R. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology 36:127-178.

Npower Renewables. 2005a. North Hoyle Offshore Wind Farm: Annual FEPA Monitoring Report: June 2005. 10 pp.

Npower Renewables. 2005b. North Hoyle Offshore Wind Farm Capital Grant Scheme Annual Report July 2004-June 2005 Part 2: Operational Reporting. 5 pp.

Page, H., Dugan, J. and Bram, J. 2005. Spatial and Temporal Variability in Early Successional Patterns of an Invertebrate Assemblage at an Offshore Oil Platform. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, MMS OCS Study 2005-003. 39 pp.

Petersen, J.K. and T. Malm. 2006. Offshore windmill farms: threats to or possibilities for the marine environment. Ambio 35(2):75-80.

Quest Underwater Services Ltd. 2006. Kentish Flat Offshore Wind farm, Post Construction Debris Survey. Wareham, Dorset. 26 pp.

Rabalais, N.N. and Boesch, D.F. 1987. Dominant Features and Processes of Continental Shelf Environments of the United States. In Boesch, D.F. and Rabalais, N.N. (eds.). Long-term Environmental Effects of Offshore Oil and Gas Development, Elsevier Applied Science, New York. Pp. 71-147.

RAG (Research Advisory Group) COWRIE 2006. Marine Renewable Energy Developments: Compiled List of Environmental Issues and Research Topics. 10 pp.

Reid, J.M., Reid, J.A., Jenkins, C.J., Hastings, M.E., Williams, S.J. and Poppe, L.J. 2005. usSEABED: Atlantic Coast Offshore Surficial Sediment Data Release. U.S. Geological Survey Data Series 118, Version 1.0, CD-ROM.

Reid, J.A., Reid, J.A., Jenkins, C.J., Zimmermann, M., Williams, S.J. and Field, M.E. 2006. usSEABED: Pacific Coast (California, Oregon, Washington) Offshore Surficial-Sediment Data Release: U.S. Geological Survey Data Series 182, version 1.0.

SAIC. 1989. Benthic Reconnaissance of Central and Northern California OCS Areas. Minerals Management Service, Pacific OSC Region, OCS Study MMS 89-0039.

SenterNovem 2005. Concerted Action for Offshore Wind Energy Deployment (COD): WORK PACKAGE 4: ENVIRONMENTAL ISSUES. European Commission. 117 pp.

Tetra Tech, Inc. 2000. Stellwagen Bank National Marine Sanctuary Submarine Cable Final Environmental Assessment. Prepared for National Oceanic and Atmospheric Administration, Silver Spring, MD. 183 pp.

Van Dolah, R.F., Wendt, P.H., Martore, R.M., Levisen, M.V. and Roumillat W.A. 1992. A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project. SC Department of Natural Resources. 86 pp.

Vella, G., Rushforth, I., Mason, E., Hough, A., England, R., Styles, P., Holt, T. and Throne, P. 2001. Assessment of the Effects of Noise and Vibration from Offshore Wind farms on Marine Wildlife. Crown Publishing. 107 pp.

Wigley, R.L. and Theroux, R.B. 1981. Atlantic Continental Shelf and Slope of the United States-Macrobenthic Invertebrates Fauna of the Middle Atlantic Bight Region-Faunal Composition and Quantitative Distribution. U.S. Geological Survey Professional Paper 529-N, 198 pp.

Williams, S.J., Arsenault, M.A., Poppe, L.J., Reid, J.A., Reid, J.M. and Jenkins, C.J. 2006. Surficial Sediment Character of the New York-New Jersey Offshore Continental Shelf Region: A GIS Compilation. U.S. Geological Survey Open-File Report 2006-1046. 51 pp.

References for Section 5.1.4 – Fishery Resources

Adair, R.K., Astumian, R.D. and Weaver, J.C. 1998. Detection of weak electric fields by sharks, rays, and skates. Chaos 8(3):576-587.

Ambrose, R.F. and Swarbrick, S.L. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bull. Marine Science 44:718-733.

AMEC. 2002. AMEC Wind Energy Lynn Offshore Environmental Impact Assessment. 426 pp.

Andrew, R.K., Howe, B.M. and Mercer, J.A. 2002 Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online 3:65-70.

Arkema, K.K, Abramson, S.C and Dewsbury, B.M. 2006. Marine ecosystem-based management: from characterization to implementation. Frontiers in Ecology and the Environment 10(10):525-532.

Astrup, J. 1999. Ultrasound detection in fish–A parallel to the sonar-mediated detection of bats by ultrasound-sensitive insects? Comparative Biochemistry and Physiology A 124:19-27.

Auster, P.J., Joy, K. and Valentine, P. 2001. Fish species and community distributions as proxies for seafloor habitat distribution: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology and Fishes 60:331-346.

Auster, P.J. 1998. A conceptual model of he impacts of fishing gear on the integrity of fish habitats. Conservation Biology 12 (6):1198-1203.

Auster, P.J. and Langton, R.W. 1998. The effects of fishing on fish habitat. Internet website: http://www.nmfs.noaa.gov/habitat/habitatprotection/pdf/efh/Auster&Langton.pdf. Accessed 20 March 2007.

Avent, R. 2004. Minerals Management Service Environmental Studies Program: A History of Biological Investigations in the Gulf of Mexico, 1973-2000. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-015. 44 pp.

Babcock, E.A and Pikitch, E.K. 2004. Can we reach agreement on a standardized approach to ecosystem-based fishery management? Bulletin of Marine Science 74(3):685-692.

Beurskens, L.W.M. and de Noord, M. 2003. Standards for Environmental Impact Assessments: Impacts of Offshore Wind Turbines on the Marine Environment. Hamburg and Rostock.

BioConsult A/S. 2002. Horns Rev: Control and Monitoring Programme: Artificial Reef: Progress Memorandum 2.

Blonder, B.I. and Alevizon, W. S. 1988. Prey discrimination and electroreception in the stingray *Dasyatis sabina*. Copeia 1988(1):33-36.

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G. and Hart, P.J.B. 2004. Implications of a zoned fishery management system for marine benthic communities. J. Applied Ecology 41(5):951-961.

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G. and Hart, P.J.B. 2002. Voluntary management in an inshore fishery has conservation benefits. Environmental Conservation 29:493-508.

Bray, R.N., Miller, A.C. and Geesay, G.G. 1981. The fish connection: a trophic link between planktonic and rocky reef communities: Science 214:204-205

Browman, H.I. and Stergiou, K.I. 2005. Politics and socio-economics of ecosystem-based management of marine resources. Marine Ecology Progress Series 300:241-242.

California Dept. of Transportation. 2001. Fisheries Impact Assessment, Pipe Installation Demonstration Project, PIDP EA 012081. Caltrans Contract 04A0148, PIDP 04-ALA-80-0.0/0.5.

CEFAS (Centre for Environment, Fisheries and Aquaculture Science). 2004. Offshore Wind Farms: Guidance Note for Environmental Impact Assessment: In Respect of FEPA and CPA Requirements: Version 2 - June 2004. Crown Publishing. 48 pp.

Chapman, C. and Hawkins, A. 1973. A field study of hearing in the cod, *Gadus morhua* L. J. Comparative Physiology A: Neuroethology, Sensory, Neural and Behavioral Physiology 85(2):147-167.

Cripps, S.J. and Aabel, J.P. 2002. Environmental and socio-economic impact assessment of Ekoreef, a multiple platform rigs-to-reefs development. ICES Journal of Marine Science 59(S):S300-S308.

Dalen, J., Ona, E., Soldal, A.V. and Saetre, R. 1996. Seismic investigations at sea; an evaluation of consequences for fish and fisheries. (in Norwegian, English summary). Fisken g Havet, IMR, No. 9.

Dauterive, L. 2000. Rigs-to-Reefs policy, progress, and perspective. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS MMS Study 2000-073. 12 pp.

de la Mare, W.K. 2005. Marine ecosystem-based management as a hierarchical control system. Marine Policy 29(1):57-68.

Dokken, Q.R., Withers, K., Childs, S. and Riggs, T. 2000. Characterization and comparison of platform reef communities off the Texas coast. Prepared for Texas Parks and Wildlife Department. Texas A&M University Corpus Christi. TAMU-CC-0007-CCS. 75 pp.

Dong Energy and Vattenfall. 2006. Review Report 2005: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms Environmental Impact Assessment and Monitoring. The Environmental Group. 150 pp.

Elsam Engineering A/S and Energi E2 A/S. 2005. Review Report 2004: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farm Environmental Impact Assessment and Monitoring. The Environmental Group of Danish Offshore Wind Farm Demonstration Projects.

Engell-Sorensen, K. 2002. Possible Effects of the Offshore Wind Farm at Vindeby on the Outcome of Fishing. Seas. Vindeby. No 1920-003-001-rev 2. 23 pp.

Engell-Sørensen, K. and Skyt, P. 2001. Evaluation of the Effect of Noise from Offshore Pile-Driving on Marine Fish. Bio/consult as, Johs. Ewaldsvej 42-44, DK-8230.

Engell-Sorensen, K., Rasmussen, G., Rasmussen, M.B., Hvidt, C.B., Nygaard, K., Klaustrup, M. and Spanggaard, G. 2000. EIA Study of the Proposed Offshore Wind Farm at Rødsand: Technical Background Report Concerning Fishery. SEAS Distribution A.m.b.A.

Formicki, K., Tanski, A., Sadowski, M., Winnicki, A. 2004. Effects of magnetic fields on fyke net performance. J. Applied Ichthyology 20(5):402-406.

FLOWW. 2006. A Study to Identify Those Fishing Activities That Can Be Safely Carried Out in and around Wind Farms. FLOWW. Department of Trade and Industry. London.

FLOWW. 2007. Fisheries Liaison of Offshore Wind and Wet renewables Group. Internet website: http://www.dti.gov.uk/energy/sources/renewables/policy/offshore/stakeholders/fisheries-liaison/page22677.html. Accessed 20 March 2007.

Fletcher, W.J. 2006. Frameworks for managing marine resources in Australia through ecosystem approaches: Do they fit together and are they useful? Bulletin of Marine Science 78(3):691-704.

Fluharty, D. and Cyr, N. 2001. Implementing ecosystem-based management of fisheries in the context of US regional fisheries management: Recommendations of the NMFS ecosystem principles advisory panel. California Cooperative Oceanic Fisheries Investigations Reports 42: 66-73.

Frid, C.L.J., Paramor, O.A.L. and Scott, C.L. 2006. Ecosystem-based management of fisheries: is science limiting? Ices Journal of Marine Science 63(9):1567-1572.

Gallaway, B. and Lewbel, G. 1982. The Ecology of Petroleum Platforms in the Northwestern Gulf of Mexico: A Community Profile. U.S. Dept. of the Interior, Fish and Wildlife Service, Biological Services Program FWS/OBS-82/72, BLM Open File Report 82-03. 52 pp.

Garrison, T. 2002. Oceanography: An Invitation to Marine Science/ Fourth Edition. Wadsworth/Thomson Learning. Pacific Grove, CA.

Gill, A.B. 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. J. Applied Ecology 42:605-615.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A. 2005. The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms – A Review. COWRIE-EM Field 2-06-2004.

Gill, A.B. and Taylor, H. 2001. The Potential Effects of Electromagnetic Fields Generated by Cabling Between Offshore Wind Turbines upon Elasmobranch Fishes. Countryside Council for Wales. Contract Science Report 488. 73 pp.

Gisiner, R.C. 1998. Workshop on the Effects of Anthropogenic Noise in the Marine Environment. Office of Naval Research, Washington, DC.

Guenette, S. and Alder, J. 2007. Lessons from marine protected areas and integrated ocean management initiatives in Canada. Coastal Management 35(1):51-78.

Guerry, A.D. 2005. Icarus and Daedalus: conceptual and tactical lessons for marine ecosystem-based management. Frontiers in Ecology and the Environment 3(4):202-211.

Hassel, A. T. Knutsen, Dalen, J., Lokkeborg, S., Skaar, K., Ostensen, O., Haugland, E.K., Fonn, M., Hoines, A. and Misund, O. 2003. Reaction of Sandeel to Seismic Shooting: A Field Experiment and Fishery Statistics Study. Fisken og Havet. Institute of Marine Research, Bergen, Norway. 62 pp.

Hastings, M.C. and Popper, A.N. 2005. Effects of Sound on Fish. California Department of Transportation Contract No. 43A0139, Task Order 1. January 28, 2005. August 23, 2005 (Revised Appendix B)

Heathershaw, A.D., Ware, P.D. and David, A.M. 2001. The environmental impact of underwater sound. Proc. I.O.A. Vol. 23 Part 4:1-13

Hoffmann, E., Astrup, J., Larsen, F., Munch-Petersen, S. and Stottrup, J. 2000. Effects of Marine Windfarms on the Distribution of Fish, Shellfish and Marine Mammals in the Horns Rev Area. Elsamprojekt A/S.

Hooker, S.K. and Gerber, L.R. 2004. Marine reserves as a tool for ecosystem-based management: The potential importance of megafauna. Bioscience 54(1):27-39.

Hvidt, C.B., Leonhard, S.B., Klaustrup, M. and Pedersen, J. 2006. Hydroacoustic Monitoring of Fish Communities at Offshore Wind Farms, Horns Rev Offshore Wind Farm, Annual Report 2005. Vattenfall A/S.

Hvidt, C.B. and Jensen, B.S. 2005. Hydroacoustic Monitoring of Fish Communities at Offshore Wind Turbine Foundations Nysted Offshore Wind Farm at Rødsand Annual Report - 2004. Energi E2 A/S.

Hvidt, D.B., Brunner, L., Knudsen, F.R., Jensen, B.S. and Spanggard, G. 2005. Hydroacoustic Registration of Fish Abundance at Offshore Wind Farms: Annual Report 2004: Horns Rev Offshore Wind Farm. Elsam Engineering A/S.

Hvidt, C.B., Engell-Sorensen, K. and Klaustrup, M. 2003. Baseline Study: Fish, Fry and Commercial Fishery Nysted Offshore Wind Farm at Rødsand Status Report. SEAS Distribution.

IAPEME. 2002. Danish Off Shore Windpower Programme: International Advisory Panel of Experts on Marine Ecology (IAPEME): Statement from Meeting in March 2002. International Advisory Panel of Experts on Marine Ecology.

IAPEME. 2006. Minutes from the 2003 Meeting of the International Advisory Panel of Experts on Marine Ecology. Secretariat of IAPEME, Danish Forest- and Nature Agency, Haraldsgade 53, DK-2100 København Ø.

Kaiser, M.M. and Jennings, S. 2002. Ecosystem effects of fishing. Handbook of Fish Biology and Fisheries, Vol. 2 (eds P.J.B. Hart and J.D. Reynolds), pp. 342-66. Blackwell Science, Oxford. UK.

Kaiser, M.J., Spence, F.E. and Hart, P.J.B. 2000. Fishing-gear restrictions and conservation of benthic habitat complexity. Conservation Biology 14(5):1512-1525.

Kajiura, S.M. and Holland, K.N. 2002. Electroreception in juvenile scalloped hammerhead and sandbar sharks. J. Experimental Biology 205:3609-3621.

Kalmijn, A.J. 1988. Hydrodynamic and acoustic field detection. In Atema, J., Fay, R.R., Popper, A.N. and Tavolga, W.N. (eds). Sensory Biology of Aquatic Animals New York. Springer-Verlag. Pp. 83-130.

Kalmijn, A.J. 1994. Near field acoustic detection. I. Physical principles and biological relevance. Sensory Systems 8(3-4):202-209.

Kauman, L., Heneman, B., Barnes, J.T. and Fujita, R. 2004. Transition from low to high data richness: An experiment in ecosystem-based fishery management from California. Bulletin of Marine Science 74(3):693-708.

Langton, R.W. and Auster, P.J. 1999. Marine fishery and habitat interactions: to what extent are fisheries and habitat interdependent? Fisheries 24:14-21.

Larsen, J.K. and Kjaer, J.I. 2006. Horns Rev Offshore Wind Farm Annual Status Report for the Environmental Monitoring Programme 2005. Environmental Committee of the Danish Offshore Wind Farm Demonstration Projects.

Leonhard, S.B., Hvidt, C.B., Klaustrup, M. and Pedersen, J. 2006. Hydroacoustic Monitoring of Fish Communities at Offshore Wind Turbine Foundations Nysted Offshore Wind Farm at Rødsand: Annual Report - 2005. Energi E2 A/S. 69 pp.

Mann, D.A., Lu, Z., Hasting, M.C. and Popper, A.N. 1998. Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (Alosa sapidissima). J. Acoustical Society of America 104:62-568.

Magnuson-Stevens Fishery Conservation and Management Act. 2007, H.R.5946. 109th Congress.

Maxon, C.M. 2000. Offshore Wind-Turbine Construction: Offshore Pile-Driving Underwater and Above-water Noise Measurements and Analysis. SEAS and Enron.

McTaggart, K., Taylor, N., Neville, S. and Rogers, S. 2006. A Report on the Perceptions of the Fishing Industry into the Potential Socio-Economic Impacts of Offshore Wind Energy Developments on Their Work Patterns and Income. Sci. Ser. Tech Rep., CEFAS Lowestoft 133:99 pp.

McCauley, Fewtrell, R.D., Duncan, A.J., Jenner, M.N, Penrose, J.D., Prince, R.I.T., Adihyta, A., Murdoch, J. and McCabe, K. 2000. Marine Seismic Surveys: Analysis and Propagation of Air-Gun-Signals and Effects of Exposure on Humpback Whale, Sea Turtle, Fishes and Squid. CMSTR99-15, prepared for the Australian Petroleum Exploration and Production Association from the Centre for Marine Science and Technology, Curtin University, Perth, Western Australia, Australia. R99-15. 185 pp.

McCauley, R., Fewtrell, D. and Popper, A.N. 2003. High intensity anthropogenic sound damages fish ears. J. Acoustical Society of America 113:638-642.

McKay, J., Nides, J. and Vigil, D. (eds.). 2000. Proceeding: Gulf of Mexico Fish and Fisheries: Bringing Together New and Recent Research, October 2000. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-004. 674 pp.

Meyer, C.G., Holland, K.N. and Papastamatiou, Y.P. 2005. Sharks can detect changes in the geomagnetic field. J. Royal Society Interface 2(2):129-130.

NRC (National Research Council). 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystem. National Academies Press, Washington, DC. 288 pp.

NRC. 2002. The Effects of Trawling and Dredging on Seafloor Habitat. National Academies Press, Washington, DC. 136 pp.

NRC. 2003. Ocean Noise and Marine Mammals. National Academies Press. Washington, DC. 192 pp.

Nedwell, J. and Howell, D. 2004. A Review of Offshore Windfarm Related Underwater Noise Sources. Report for Collaborative Offshore Wind Energy Research into the Environment (COWRIE).

Npower Renewables. 2005. North Hoyle Offshore Wind farm: Annual FEPA Monitoring Report: June 2005. 10 pp.

Nestler, J.M., Ploskey, G.R., Pickens, J., Menezes, J. and Schilt, C. 1992. Responses of blueback herring to high-frequency sound and implications for reducing entrainment at hydropower dams. North American J. of Fisheries Management 12(4):667-683.

O'Boyle, R., Sinclair, M., Keizer, P., Lee, K., Ricard, D. and Yeats, P. 2005. Indicators for ecosystem-based management on the Scotian Shelf: bridging the gap between theory and practice. Ices Journal of Marine Science 62 (3):598-605.

O'Boyle, R. and Jamieson, G. 2006. Observations on the implementation of ecosystem-based management: Experiences on Canada's east and west coasts. Fisheries Research 79(1-2):1-12.

Pacific FMC. 2006. Pacific Coast Groundfish Fishery Management Plan. Internet Web site:: www.pcouncil.org/groundfish. Accessed on 12 April 2007.

Patterson, W.F., Cowan, J.H. and Shipp, R.L. 2004. Red snapper site fidelity to, and speed of movement from artificial reef sites off Alabama in the northern Gulf of Mexico. In McKay, J., Nides, J. and Vigil, D. (eds). Proceeding: Gulf of Mexico Fish and Fisheries:, October 2000, U.S. Dept. of the Interior, Minerals Management Service Bringing Together New and Recent Research, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-004. Pp.633-648.

Peabody, M.B. and Wilson, C. A. 2006. Fidelity of Red Snapper (*Lutjanus campechanus*) to Petroleum Platforms and Artificial Reefs in the Northern Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2006-005. 64 pp.

Pearson, W.H., Skalski, J.R. and Malme, C.I. 1992. Effects of sound from a geophysical survey device on behavior of captive rockfish (*Sebastes sp.*). Canadian Journal of Fisheries and Aquatic Sciences 49:1343-1356.

Popper, A.N. and Clarke, N. L. 1976. The auditory system of the goldfish (*Carassius auratus*) effects of intense acoustic stimulation. Comparative Biochemistry and Physiology, A 53:11-18.

Popper, A.N. 1977. A scanning electron microscopic study of the sacculus and lagena in the ears of fifteen species of teleost fishes. J. Morph. 153:397-418.

Popper, A. and Carlson, T. 1998. Application of sound and other stimuli to control fish behavior. Transactions of the American Fisheries Society 127(5):673-707.

Popper, A.N., Fay, R., Platt, C. and Sand, O. 2003. Sound detection mechanisms and capabilities of teleost fishes. In Collin, S.P. and Marshall, N.J. (eds.). Sensory Processing in Aquatic Environments. Springer Verlag, NY. Pp. 3-38.

Popper, A.N., Fewtrell, J., Smith, M.E. and McCauley, R.D. 2003/4. Anthropogenic sound: effects on the behavior and physiology of fishes. Marine Technology Society Journal 37(4):35-40.

Popper, A.N., Carlson, T.J., Hawking, A.D., Southall, B.L. and Gentry, R.L. 2006. Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper. Cal. Dept. of Transportation, Pile Driving Interim Criteria. Internet website: http://www.wsdot.wa.gov/NR/rdonlyres/84A6313A-9297-42C9-BFA6-750A691E1DB3/0/BA_PileDrivingInterimCriteria.pdf. Accessed 20 March 2007.

Reggio, V.C. 1989. Petroleum Structures as Artificial Reefs: A Compendium. OCS/MMS-89/0021:MMS/GM-89-0021. 174 pp.

Rigs-to-Reefs. 2000. Internet website: http://www.gomr.mms.gov/homepg/regulate/environ/rigs-to-reefs/research-rpts.html.

Rilov, G. and Benayahu, Y. 1998. Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. Marine Environmental Research 45:431-451.

Rilov, G. and Benayahu, Y. 2000. Fish assemblage on natural versus vertical artificial reef: the rehabilitation perspective. Marine Biology 136:931-942.

Rilov, G. and Benayahu, Y. 2002. Rehabilitation of coral reef-fish communities: the importance of artificial-reef relief to recruitment rates. Bulletin of Marine Science 70:185-197.

Rijnsdorp, A.D. and von Keeken, O.A. 2004. Changes in the distribution of the North Sea plaice - Pleuronectes platessa -. Report (Int. rep. 04.023). RIVO Biologie en Ecologie. (WUR).

SAFMC (South Atlantic Fisheries Management Council). 2005. Policies for the protection and restoration of essential fish habitats from energy exploration, development transportation and hydropower re-licensing. Internet Web site: http://www.safmc.net/ecosystem/EcosystemManagement/HabitatProtection/HabitatPolicies/tabid/245/Default.aspx. Accessed 17 July 2007.

SAFMC. 2007a. MPA. Internet Web site: http://www.safmc.net/MPAInformationPage/tabid/469/Default.aspx.

SAFMC. 2007b. Habitat. Committee 2007. Internet Web site: http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx. Accessed 17 July 2007.

SAFMC. 2007c. Snapper Grouper. Internet Web site: http://www.safmc.net/Library/SnapperGrouper/tabid/415/Default.aspx. Accessed 17 July 2007.

SAFMC. 2007d. Ecosystem. Internet Web site: http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx. Accessed 17 July 2007.

SAFMC. 2007e. Ecosystem Based Fishery Management, Action Plan. Internet Web site: http://www.safmc.net/Portals/0/FEP%2012_04.pdf. Accessed 17 July 2007.

Sarà, G., Dean, J. M., D'Amato, D., Buscaino, G., Oliveri, A., Genovese, S., Ferro, S., Buffa, G., Lo Martire, M. and Mazzola, S. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. Marine Ecology Progress Series 331:243-253.

Scandol, J.P., Holloway, M.G., Gibbs, P.J. and Astles, K.L. 2005. Ecosystem-based fisheries management: An Australian perspective. Aquatic Living Resources 18(3):261-273.

Schroeder, D.M., Ammann, A.J., Harding, J.A., MacDonald, L.A. and Golden, W.T. 2000. Relative habitat value of oil and gas production platforms and natural reefs to shallow water fish assemblages in the Santa Maria Basin and Santa Barbara Channel, California. In Proceedings of the Fifth California Island Symposium, U.S. Department of the Interior. Mineral Management Service, Feb 2000. Pp. 493-498.

Schroeder, D.M. and Love, M. S. 2002. Recreational fishing and marine fish populations in California. California Cooperative Oceanic Fisheries Investigations Reports 43:182-190.

SenterNovem. 2005. Concerted Action for Offshore Wind Energy Deployment (COD): Work Package 4: Environmental Issues. European Commission. 117 pp.

Skalski, J.R. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes sp.*). Canadian J. Fisheries and Aquatic Sciences 49:1357-1365.

Smith, E., Orvos, D. and Cairns, Jr., J. 1993. Impact assessment using the before-after-control-impact (BACI) model; concerns and comments. Canadian J. Fisheries and Aquatic Sciences 50(3):627-637.

Steele, J.H. 2006. Are there eco-metrics for fisheries? Fisheries Research 77 (1):1-3.

Stokesbury, K.D.E. and Harris, B.P. 2006. Impact of limited short-term sea scallop fishery on epibenthos community of Georges Bank closed areas. Marine Ecology Progress Series 307:85-100.

Sumaila, U.R. 2005. Differences in economic perspectives and implementation of ecosystem-based management of marine resources. Marine Ecology Progress Series 300: 279-282.

Tech-Wise. 2002. Status for the Project Entitled: Investigations on the Artificial Reef Effect on Fish from Marine Wind Turbine Park at Horns Reef. 8 pp.

Thomsen, F., Lüdemann, K., Kafemann, R., Piper, W. 2006. Effects of Offshore Wind Farm Noise on Marine Mammals and Fish. COWRIE Ltd.

Tricas, T. and New, J. 1998. Sensitivity and response dynamics of elasmobranch electrosensory primary afferent neurons to near threshold fields. J. Comp. Physiology A 182:89-101.

University of Liverpool. 2003. A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables: Final Report. COWRIE Ltd.

Villareal, T.A., Hanson, S., Qualia, S., Jester, E.L.E., Granade, H R. and Dickey, R.W. 2007. Petroleum production platforms as sites for the expansion of ciguatera in the northwestern Gulf of Mexico. Harmful Algae 6:253-259.

Wahlberg, M. and Westerberg, H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology Progress Series 288:295-309.

Walker, M.M. 1984. Learned magnetic field discrimination in yellowfin tuna, *Thunnus albacares*. Jour. Comp. Physiology A 155(5):673-679.

Westerberg, H. 1999. Impact Studies of Sea-Based Windpower in Sweden. Technische Eingriffe in marine Lebensraume. Cited in Nedwell and Howell, 2004.

Wilhelmsson, D., Malm, T. and Ohman, M. 2006. The influence of offshore windpower on demersal fish. ICES Journal of Marine Science 63 (5):775-784.

Wilson, C. A., Pierce, A. and Miller, M.W. 2003. Rigs and Reefs: A Comparison of the Fish Communities at Two Artificial Reefs, a Production Platform, and a Natural Reef in the Northern Gulf of Mexico. Prepared by the Coastal Fisheries Institute. Louisiana State University. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-009. 95 pp.

Wilson, C.A. 2006. The effect of depth, location and habitat type on relative abundance and species composition of fishes associated with petroleum platforms and Sonnier Bank in the northern Gulf of Mexico. Prepared by the Coastal Fisheries Institute. Louisiana State University. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. Completion Report Contract number 1435-0001-30660-19947.

Wursig, B., Greene, C. and Jefferson, T. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research 49:79-93.

References for Section 5.1.5 – Marine Mammals

Ackerman, B.B., Wright, S.D., Bonde, R.K., Odell, D.K. and Banowetz, D.J. 1995. Trends and patterns in the mortality of manatees in Florida, 1974-1992. In O'Shea, T.J., Ackerman, B.B. and Percival, H.F. (eds.). Population biology of the Florida manatee. National Biological Service Information and Technology Report 1. Washington, DC. Pp 223-258.

AMEC. 2005. Aberdeen Offshore Wind Farm Request For an Environmental Impact Assessment (EIA) Scoping Opinion: May 2005. AMEC. 53 pp.

AMEC. 2002. AMEC Wind Energy Lynn Offshore Environmental Impact Assessment. AMEC. 426 pp.

Au, W. W. L. and Green, M. 2000. Acoustic interaction of humpback whales and whale-watching boats. Marine Environmental Research 49:469-481.

Barco, S.G., McLellan, W.A., Allen, J.M., Asmutis-Silvia, R.A., Mallon-Day, R., Meagher, E.M., Pabst, D.A., Robbins, J., Seton, R.E., Swingle, W.M., Weinrich M.T. and Clapham, P.J. 2002. Population identity humpback whales (*Megaptera novaeangliae*) in the waters of the US mid-Atlantic states. Journal of Cetacean Research and Management 4(2):135-141.

Barlas, M.E. 1999. The distribution and abundance of harbor seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) in southern New England, winter 1998- summer 1999. MA Thesis, Boston University, Graduate School of Arts and Sciences, Boston, MA. 52 pp.

Barlow, J. 1995. The abundance of cetaceans in California waters. Part I: Ship surveys in summer and fall of 1991. Fisheries Bulletin 93:1-14.

Barlow, J. 1997. Preliminary estimates of cetacean abundance off California, Oregon and Washington based on a 1996 ship survey and comparisons of passing and closing modes. Admin. Rep. LJ-97- 11, Southwest Fisheries Science Center, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA 92038. 25p.

Barlow, J. 2003. Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991_2001. Southwest Fisheries Science Center Administrative Report LJ_03_03. Available from SWFSC, 8604 La Jolla Shores Dr., La Jolla CA 92037. 31pp.

Barlow, J., pers. comm. 2006. Southwest Fisheries Science Center, NOAA Fisheries, La Jolla, CA.

Barlow, J. and Forney, K. A. 1994. An assessment of the 1994 status of harbor porpoise in California. NOAA Tech. Memo. NMFS-SWFSC-205. 17 pp.

Burgess, W.C. and Lawson, J.W. 2000. Marine mammal and acoustic monitoring of Western Geophysical's shallow-hazards survey in the Alaskan Beaufort Sea, summer 2000. In W.J. Richardson (ed.), Marine Mammal and Acoustical Monitoring of Western Geophysical's Open-water Seismic Program in the Alaskan Beaufort Sea, 2000: 90-day Report. Rep. from LGL Ltd., King City, ON and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK and NMFS, Anchorage, AK and Silver Spring, MD. Pp. C-1 to C-28.

Bell, J., pers. comm. 2006. Naval Facilities Engineering Command Atlantic, Norfolk, Virginia.

Buckstaff, K.C. 2004. Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science 20(4):709-725.

Burbo Offshore Wind Farm. 2002a. Chapter 5: Biological Environment. Seascape Energy Ltd. 93 pp.

Burbo Offshore Wind Farm. 2002b. EIA: Technical Report: Marine Ecology. Seascape Energy Ltd. 134 pp.

Calambokidis, J., Cubbage, J.C., Evenson, J.R., Osmek, S.D., Laake, J.L., Gearin, P.J., Turnock, B.J., Jeffries, S.J. and Brown, R.F. 1993. Abundance estimates of harbor porpoise in Washington and Oregon waters. Final Report by Cascadia Research, Olympia, WA, to National Marine Mammal Laboratory, AFSC, NMFS, Seattle, WA. 55 pp.

Carretta, J.V., Forney, K.A., Muto, M.M., Barlow, J. Baker, J., Hanson, B., and Lowry, M.S. 2007. U.S. Pacific Marine Mammal Stock Assessments: 2006. NOAA Technical Memorandum-NMFS-SWFSC-398. Southwest Fisheries Science Center, La Jolla, CA. 321 pp

Caretta, J. V., Taylor, B.L. and Chivers, S.J. 2001. Abundance and depth distribution of harbor porpoise (*Phocoena phocoena*) in northern California determined from a 1995 ship survey. Fishery Bulletin 99:29-39.

Carretta, J.V., Forney, K.A. and Laake, J. L. 1998. The abundance of southern California coastal bottlenose dolphins estimated from tandem aerial surveys. Marine Mammal Science 14:655-675.

Carretta, J.V., Forney, K.A., Muto, M.M., Barlow, J., Baker, J., Hanson, B. and Lowry, M.S. 2006. U.S. Pacific Marine Mammal Stock Assessments: 2005. NOAA Technical Memorandum-NMFS-SWFSC-388. Southwest Fisheries Science Center, La Jolla, CA. 325 pp.

Carswell, L., pers. comm. 2007. Biologist, Southern Sea Otter Recovery Program, U.S. Fish and Wildlife Service. Ventura Fish and Wildlife Office, Ventura, CA.

CEFAS. 2004. Offshore Wind Farms: Guidance Note for Environmental Impact Assessment In respect of FEPA and CPA requirements: Version 2 - June 2004. Crown Publishing. 48 pp.

CETAP. 1982. Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic Areas of the U.S. Outer Continental Shelf. Cetacean and Turtle Assessment Program, University of Rhode Island. Report #AA551-CTB-48 to the U.S. Bureau of Land Management, Washington, DC. 538 pp.

Davis, R.W. and Fargion, G.S. (eds.). 1996. Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico: Final Report. Volume I: Executive Summary. Prepared by the Texas Institute of Oceanography and the National Marine Fisheries Service. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 96-0026. 29 pp.

Davis, R.W., Evans, W.E. and Würsig, B. (eds.). 2000. Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance, and Habitat Associations. Volume I: Executive Summary. Prepared by Texas A&M University at Galveston and the National Marine Fisheries Service. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BRD/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-002. 27 pp.

deHart, P.A.P. 2002. The Distribution and Abundance of Harbor Seals (*Phoca vitulina concolor*) in the Woods Hole region. MA Thesis, Boston University, Graduate School of Arts and Sciences. Boston, MA. 88 pp.

Department of the Navy. 2001. Marine Resources Assessment for the Virginia Capes (VACAPES) Operating Area. Naval Facilities Engineering Command, Norfolk, VA. 473 pp.

Department of the Navy. 2002a. Marine Resources Assessment for the Cherry Point Operating Area. Naval Facilities Engineering Command, Norfolk, VA.

Department of the Navy. 2002b. Marine Resources Assessment for the Charleston/Jacksonville Operating Area. Naval Facilities Engineering Command, Norfolk, VA.

Department of the Navy. 2003. Marine Resource Assessment for the Eastern Gulf of Mexico Testing and Training Areas. Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA. Contract #N62470-95-D-1160, CTO 0053. Prepared By Geo-Marine, Inc., Plano, TX.

Dolman, S.J., Simmonds, M.P. and Keith, S. 2003. Marine wind farms and cetaceans. IWC/SC/55/E4. 18 pp.

Dong Energy, Vattenfall, Danish Energy Authority, and Danish Forest and Nature Agency. 2006. Danish Offshore Wind: Key Environmental Issues. Danish Energy Authority. 144 pp.

Dudzik, K.J. 1999. Population Dynamics of the Pacific Coast Bottlenose Dolphin (*Tursiops truncatus*). M.S. Thesis, San Diego State University, San Diego, CA. 63,pp.

Dudzik, K.J., Baker, K.M. and Weller, D.W. 2006. Mark-recapture abundance estimate of California coastal stock bottlenose dolphins: February 2004 to April 2005. SWFSC Administrative Report LJ-06-02C, available from Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA. 15 pp.

E.ON UK Renewables. 2005. Capital Grant Scheme for Offshore Wind Annual Report: January 2005 - December 2005 Executive Summary. Scroby Sands Wind. 15 pp.

Estes, J.A. 1990. Growth and equilibrium in sea otter populations. Journal of Animal Ecology 59:385-401.

Finneran, J.J., Schlundt, C.E., Dear, R., Carder, D.A. and Ridgway, S.H. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. Journal of the Acoustical Society of America 111(6):2929-2940.

Forney, K. A. 1999. The abundance of California harbor porpoise estimated from 1993-97 aerial line transect surveys. Admin. Rep. LJ-99-02. Southwest Fisheries Center, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA. 16 pp.

Forney, K. A., Barlow, J. and Carretta, J.V. 1995. The abundance of cetaceans in California waters. Part II: Aerial surveys in winter and spring of 1991 and 1992. Fisheries Bulletin 93:15-26.

Foote, A.D., Osborne, R.W. and Hoelzel, A.R. 2004. Whale-call response to masking boat noise. Nature 428: 910.

FWRI (Florida Wildlife and Research Institute). 2007. Manatee Synoptic Surveys. Florida Fish and Wildlife Conservation Commission. Internet Web site: http://research.myfwc.com/features/view_article.asp?id=15246. Accessed May 24, 2007.

Gerstein, E.R., Gerstein, L., Forsythe, S.E., Blue, J.E. 1999. The underwater audiogram of the West Indian manatee (*Trichechus manatus*). J Acoust Soc Am.105:3575-3583.

Gilbert, J.R., Waring, G.T., Wynne , K.M. and Guldager, N. 2005. Changes in abundance and distribution of harbor seals in Maine, 1981-2001. Marine Mammal Science 21:519-535.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A. 2005. COWRIE 1.5 Electromagnetic Fields Review: The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms - a review.

Green, G.A., Brueggeman, J.J., Grotefendt, R.A., Bowlby, C.E., Bonnel, M.L and Balcomb, K.C. 1992. Cetacean distribution and abundance of Oregon and Washington. 1989-1990. Pages 1-100. In Brueggeman J. (ed.). Oregon and Washington Marine Mammal and Seabird Surveys. OCS Study MMS 91-0093. 100 pp.

Hain, J.H.W., pers. comm. 2006. Associated Scientists at Woods Hole, Woods Hole, Massachusetts.

Hain, J.H.W., Ellis, S.L., Kenney, R.D. and Slay, C.K. 1999. Sightability of right whales in coastal waters of the southeastern United States with implications for the aerial monitoring program. In Garner, G.W., McDonald, L.L. and Amstrup, S. (eds.). Marine Mammal Survey and Assessment Methods, A. A. Balkema, Rotterdam, Netherlands. Pp. 191-207

Hansen, L. J. and Defran, R. H. 1990. A comparison of photo-identification studies of California coastal bottlenose dolphins. Rep. Int. Whal. Commn. Special Issue 12:101-104.

Hastie, G.D., Wilson, B., Tufft, L.H. and Thompson, P.M. 2003. Bottlenose dolphins increase synchrony in response to boat traffic. Marine Mammal Science 19:74-84.

Hobbs, R.C., Rugh, D.J., Waite, J.M., Breiwick, J.M. and DeMaster, D.P. In press. Abundance of gray whales in the 1995/96 southbound migration in the eastern North Pacific. J. Cetacean Res. Manage. Special Issue 2. (SC/48/AS9).

Hoggard, W., pers. comm. 2006. National Marine Fisheries Service, Pascagoula, MS.

Janik, V.M. and Thompson, P.M. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Marine Mammal Science 12:597-602.

Jarvis, C.M. 2005. An evaluation of the wildlife impacts of offshore wind development relative to fossil fuel power production. M.S. Thesis, University of Delaware. 125 pp.

Knowlton, A.R. and Brown, M.W. 2007. Running the gauntlet: Right whales and vessel strikes. Pp. 409-435. In, Scott D. Kraus and Rosalind M. Rolland (eds.). 2007. The Urban Whale: North Atlantic Right Whales at the Crossroads. Harvard University Press: Cambridge, MA.

Koschinski, S., Culik, B.M., Henriksen, O.D., Tregenza, N., Ellis, G., Jansen, C. and Kathe, G. 2003. Behavioral reactions of free-ranging porpoises and seals to the noise of a simulated 2 MW windpower generator. Marine Ecology Progress Series 265: 263-273.

Kraus, S. D. and Rolland, R.M. (eds.). 2007. The Urban Whale: North Atlantic Right Whales at the Crossroads. Harvard University Press: Cambridge, MA. 543 pp.

Lake, J., pers. comm. 2007. Outreach officer at Fish and Wildlife Research Institute. FWRI, St. Petersburg, FL.

Laake, J.L., Rugh, D.J., Lerczak, J.A. and Buckland, S.T. 1994. Preliminary estimates of population size of gray whales from the 1992/93 and 1993/94 shore-based surveys. Unpubl. doc. submitted to Int. Whaling Comm. (SC/46/AS7). 13 pp.

Lesage, V., Barrette, C., Kingsley, M.C.S. and Sjare, B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. Marine Mammal Science 15(1): 65-84.

Mann, D. A., Colber, D.E., Gaspard, J.C., Casper, B.M., Cook, M.L.H., Reep, R.L. and Bauer, G.B. 2005. Temporal resolution of the Florida manatee (*Trichechus manatus latirostris*) auditory system. Journal of Comparative Physiology, A. Sensory, Neural, and Behavioral Physiology 191:903–908.

Maritime Aquarium at Norwalk. 2005. Long Island Sound Harbor Seal Census Study. Internet Web site: http://www.sealcensus.org/seals_sound.html. Accessed February 1, 2007.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. and Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecological Progress Series 309:279-295.

McClellan, D.B., Browder, J.A., Tobias J.L., Konoval, G. J., Hearon, M.D., Bass, O. and Osborne, J. 2000. Opportunistic sightings of Bottlenose Dolphin, *Tursiops truncatus*, along the Southeast Florida Coast and Florida Bay, 1992 - 1997. NOAA Technical Memorandum NMFS-SEFSC-435. 18 pp.

McFee, W., pers. comm. 2006. National Ocean Service, National Oceanographic and Atmospheric Administration, Charleston, SC.

MMS. 2007. Possible Effects of OCS Gas and Oil Activities on the California Sea Otter. Pacific OCS Region, Minerals Management Service, Department of Interior. Internet Web site: http://www.mms.gov/omm/pacific/enviro/calseaotter.htm. Accessed May 25, 2007.

Mullin, K.D. and Fulling, G.L. 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico. Marine Mammal Science 20(4): 787-807.

Nachtigall, P.E. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncates*) measured using evoked auditory potentials. Marine Mammal Science 20 (4):673-687.

NCCOS (National Centers for Coastal Ocean Science). 2003. A Biogeographic Assessment off North/Central California: To Support the Joint Management Plan Review for Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries: Phase I - Marine Fishes, Birds and Mammals. National Oceanographic and Atmospheric Administration, Prepared by NCCOS's Biogeography Team in cooperation with the National Marine Sanctuary Program. Silver Spring, MD. 145 pp.

NOS (National Ocean Service). 2004. Stellwagen Bank National Marine Sanctuary: Seals. National Oceanic and Atmospheric Administration, Department of Commerce. Internet Web site: http://stellwagen.nos.noaa.gov/about/sitereport/seal.html. Accessed February 1, 2007.

NMFS (National Marine Fisheries Service). 2002. Small Takes of Marine Mammals Incidental to Specified Activities; Seismic Reflection Data off Southern California. Federal Register: April 1, 2002. Volume 67, Number 62:15360-15365.

NMFS. 2003a. Final Rule: Regulations Governing the Taking and Importing of Marine Mammals; Eastern North Pacific Southern Resident Killer Whales. National Oceanic and Atmospheric Administration, Department of Commerce 50 CFR Part 216. Federal Register Doc. 03-13421 2003, May 29, 2003. 68(103).

NMFS. 2003b. Permit from National Marine Fisheries Service. USGS Open-File Report 03-474, G1-03-GM, Gas Hydrates Cruise Report, R/V Gyre, 1-14 May 2003, Northern Gulf of Mexico. Internet Web site: http://pubs.usgs.gov/of/2003/of03-474/html/append3.html. Accessed May 18, 2007.

NMFS. 2005a. Recovery Plan for the Northern Right Whale, *Eubalaena glacialis*, Revision. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources. 137pp.

NMFS. 2005b. Small Takes of Marine Mammals Incidental to Specified Activities; Low-Energy Seismic Survey on the Louisville Ridge, Southwest Pacific Ocean. Federal Register: October 17, 2005.Volume 70, Number 199: 60287-60301.

NRC (National Research Council). 2003. Ocean Noise and Marine Mammals. National Academies Press, Washington, DC. 192 pp.

Nedwell, J., Langworthy, J. and Howell, D. 2003. Assessment of Sub-Sea Acoustic Noise and Vibration from Offshore Wind Turbines and its Impact on Marine Wildlife; Initial Measurements of Underwater Noise During Construction of Offshore Windfarms, and Comparison with Background Noise, Report No. 544 to COWRIE. 68 pp.

Nedwell, J. and Howell, D. 2004. A Review of Offshore Windfarm Related Underwater Noise Sources. Report No. 544 R 0308 Commissioned by the Collaborative Offshore Wind Energy Research into the Environment (COWRIE). 57 pp.

Neumann, T. 2005. Standards for the assessment of acoustic emissions of offshore wind farms. DEWI Magazine 26:1-4.

NOAA Fisheries. 2005a. Humpback Whale: Gulf of Maine Stock. Marine Mammal Stock Assessment Reports, Office of Protected Resources. Internet Web site: http://www.nmfs.noaa.gov/pr/sars/species.htm#largewhales. Accessed February 11, 2007.

NOAA Fisheries. 2005b. Harbor Porpoise: Gulf of Maine/Bay of Fundy Stock. Marine Mammal Stock Assessment Reports, Office of Protected Resources. Internet Web site: http://www.nmfs.noaa.gov/pr/sars/species.htm#porpoises. Accessed February 11, 2007.

NOAA Fisheries. 2007. Right Whales (Eubalaena glacialis/Eubalaena australis). Office of Protected Resources. Internet Web site: http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale.htm#status. Accessed February 20, 2007.

NOAA. 2004. Final Report of the 2004 NOAA International Symposium on Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology. 18-19 May 2004. Arlington, VA. 38 pp.

NOAA. 2006. SPLASH: Structure of Populations, Levels of Abundance, and Status of Humpbacks. National Marine Mammal Laboratory. Alaska Fisheries Science Center. Internet Web site: http://nmml.afsc.noaa.gov/CetaceanAssessment/Humpback/SPLASH.htm. Accessed February 14, 2007.

Nowacek, S. M., Wells, R. S. and Solow, A. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science 17:673-688.

Nowacek, S.M., Wells, R.S., Owen, E.C.G., Speakman, T.R., Flamm, R.O. and Nowacek, D.P. 2005. Florida manatees, Trichechus manatus latirostris, respond to approaching vessels. Biol. Conserv. 119:517-523.

O'Shea, T.J., 1995. Waterborne recreation and the Florida manatee. In: Knight, R.L. and Gutzwiller, K.J. (Eds.), Wildlife and Recreationists. Island Press, Washington, DC. pp. 297–311.

Palka, D., Garrison, L., Hohn, A.A. and Yeung, C. 2001. Summary of Abundance Estimates and PBR for Coastal Tursiops for Waters between New York and Florida during 1995 to 2000. NMFS/NEFSC Report prepared for the Bottlenose Dolphin Take Reduction Team. Available from: NMFS-Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA.

Payne, P.M. and Selzer, L.A. 1989. The distribution, abundance and selected prey of the harbor seal, Phoca vitulina concolor, in southern New England. Marine Mammal Science 5(2):173-192.

Read, A.J., Foster, B., Urian, K., Wilson, B. and Waples, D. 2003. Abundance of bottlenose dolphins in the bays, sounds, and estuaries of North Carolina. Marine Mammal Science 19:59-73.

Read, A.J., Halpin, P.N., Crowder, L.B., Hyrenbach, K.D., Best, B.D., Fujioka, E. and Coyne, M.S. (Eds.). 2007. OBIS-SEAMAP: Mapping Marine Mammals, Birds and Turtles. World Wide Web electronic publication. http://seamap.env.duke.edu, Accessed on May 23, 2007.

Richardson, W.J., Greene, C.R., Jr., Malme, C.I. and Thomson, D. H. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 pp.

Rugh, D.J., Hobbs, R.C., Lerczak, J.A. and Breiwick, J.M. In press. Estimates of abundance of the eastern North Pacific stock of gray whales 1997-2002. J. Cetacean Res. Manage.

Rugh, D.J., Muto, M.M. Moore, S.E. and DeMaster, D.P. 1999. Status review of the eastern north Pacific stock of gray whales. NOAA Tech. Memo. NMFS-AFSC-103, 93 pp.

San Francisco Public Utilities Commission. 2006. Request for Marine Mammal Protection Act Incidental Harassment Authorization: San Francisco Public Utilities Commission Bay Division Pipeline Geophysical Study. Planning Bureau, San Francisco, CA. 15 pp.

Schlundt, C.E., Finneran, J.J., Carder, D.A. and Ridgway, S.H. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncates*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. Journal of the Acoustical Society of America 107 (6):3496-3508.

Skov, H., Thomsen, F., Spanggaard, G. and Jensen, B.S. 2006. EIA Report Marine Mammals Horns Rev 2 Offshore Wind Farm. Energi E2. 90 pp.

Siniff, D.B. and Ralls, K. 1991. Reproduction, survival, and tag loss in California sea otters. Marine Mammal Science 7(3):211-229.

Smith, T.D., Allen, J., Clapham, P.J., Hammond, P.S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsbøll, P.J., Sigurjónsson, J., Stevick, P.T. and Øien, N. 1999. An ocean-wide mark-recapture study of the North Atlantic humpback whale, *Megaptera novaeangliae*. Marine Mammal Science 15:1-32.

Stevick, P.T., Allen, J., Bérubé, M., Clapham, P.J., Katona, S.K., Larsen, F., Lien, J., Mattila, D.K., Palsbøll, P.J., Robbins, J., Sigurj¢nsson, J., Smith, T.D., Øien N. and Hammond, P.S. 2003. Segregation of migration by feeding ground origin in North Atlantic humpback whales (*Megaptera novaeangliae*). Journal of Zoology 259:231-237.

Sundberg, J. and Soderman, M. 2001. Windpower and Grey Seals: An Impact Assessment of Potential Effects by Sea-based Windpower Plants in a Local Seal Population. Anceps Ekologidata.

Teilmann, J., Carstensen, J., Dietz, R., Edrén, S.M.C. and Andersen, S.M. 2006a. Final Report on Aerial Monitoring of Seals near Nysted Offshore Wind Farm. Technical Report to Energi E2 A/S. Ministry of the Environment. Roskilde, Denmark.

Teilmann, J., Tougaard, J. Cartensen, J., Dietz, R. and Tougaard, S. 2006b. Summary on Seal Monitoring 1999-2005 around Nysted and Horns Rev Offshore Wind Farms: Technical Report to Energi E2 A/S and Vattenfall A/S. Energi E2 A/S.

Teilmann, J., Tougaard, J. and Cartensen, J. 2006c. Summary on Harbour Porpoise Monitoring 1999-2006 around Nysted and Horns Rev Offshore Wind Farms. Report to Energi E2 A/S and Vattenfall A/S. Energi E2 A/S.

Thomsen, F., Ludermann, K., Kafemann, R. and Piper, W. 2006. Effects of offshore wind farm noise on marine mammals and fish. biola, Hamburg, Germany on behalf of COWRIE Ltd. 60 pp.

Torres, L.G., Rosel, P.E., D'Agrosa, C. and Read, A.J. 2003. Improving management of overlapping bottlenose dolphin ecotypes through spatial analysis and genetics. Marine Mammal Science 19:502-514.

Tougaard, J., Carstensen, J., Wisz, M.S., Teilmann, J., Bech, N.I., Skov, H., Henriksen, O.D. 2005a. Harbour Porpoises on Horns Rev: Effects of the Horns Rev Wind Farm: Annual Status Report 2004 to Elsam Engineering A/S. National Environmental Research I.

Tougaard, J., Carstensen, J., Teilmann, J. and Bech, N.I. 2005b. Effects of the Nysted Offshore Wind Farm on Harbor Porpoises: Annual Status Report for the T-POD monitoring Program. National Environmental Research Institute Ministry of the Environment. 51 pp.

Tougaard, J., Carstensen, J., Bech, N.I. and Teilmann, J. 2006a. Final Report on the Effect of Nysted Offshore Wind Farm on Harbor Porpoises. Technical Report to Energi E2 A/S. Ministry of the Environment. Roskilde, Denmark.

Tougaard, J., Carstensen, J., Wisz, M.S., Jespersen, M., Teilmann, J., Bech, N.I. and Skov, H. 2006b. Harbor Porpoises on Horns Rev. Effects of the Horns Rev Wind Farm. Final Report to Vattenfall A/S. NERI Commissioned Report, Roskilde, Denmark.

Tougaard, J., Tougaard, S., Jensen, R.C., Jensen, T., Teilmann, J., Adelung, D., Liebsch, N. and Müller, G. 2006c. Harbor Seals at Horns Rev Before, During and After Construction of Horns Rev Offshore Wind Farm. Final Report to Vattenfall A/S. Biological Papers from the Fisheries and Maritime Museum No. 5, Esbjerg, Denmark, 2006. Internet Web site: www.hornsrev.dk.

University of Liverpool. 2003. A Baseline Assessment of Electromagnetic Fields Generated by Offshore Wind Farm Cables: Final Report. COWRIE. 71 pp.

U.S. Army Corps of Engineers. November 2004. Cape Wind Energy Project Draft Environmental Impact Statement. U.S. Army Corps of Engineers, New England District, Concord, MA. 4 volumes.

Waring, G.T., Josephson, E., Fairfield, C.P., and Maze-Foley, K. (eds). 2007. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments: 2006. NOAA Technical Memorandum-NMFS-NE-201. Northeast Fisheries Science Center, Woods Hole, MA. 388 pp.

s, G. T., Josphson, E., Fairfield, C. P., Foley, C. and Maze-Foley, K. (eds.). 2006. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2005. NOAA Tech. Memo. NMFS-NE-194. National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA. 330 pp.

Waring, G.T., Josephson, E., Fairfield, C.P. and Maze-Foley, K. (eds.). 2007. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assesments – 2006. NOAA Tech. Memo. NMFS-NE-201. National Marine Fisheries Service/Northeast Fisheries Science Center: Woods Hole, MA. 388 pp.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammal Science 2(4):251-262.

Wilson, D.E., Bogan, M.A., Brownell Jr., R.L., Burdin, A.M. and Maminov, M.K. 1991. Geographic variation in sea otters, *Enhydra lutris*. Journal of Mammalogy 72(1):22-36.

Wright, S.D., Ackerman, B.B., Bonde, R.K., Beck, C.A. and Banowetz, D.J. 1995. Analysis of watercraft-related mortality of manatees in Florida, 1979-1991. In O'Shea, T.J., Ackerman, B.B. and Percival, H.F. (eds). Population Biology of the Florida Manatee. National Biological Service Information and Technology Report 1. Washington, DC. Pp. 259-268. Internet Web site: http://fulltext10.fcla.edu/cgi/t/text/text-idx?c=feol&idno=UF00000121&format=jpg. Accessed June 1, 2007.

Würsig, B., Jefferson, T.A. and Schmidly, D.J. 2000. The Marine Mammals of the Gulf of Mexico.: Texas A&M University Press, College Station, TX.

References for Section 5.1.6 – Sea Turtles

Battelle. 2004. Marine Biological Assessment for the Cape Wind Project, Nantucket Sound. App. 5.5-A. U.S. Army Corps of Engineers. 78 pp.

Davis, R.W., Evans, W.E. and Wursig, B. (eds.). 2000. Cetaceans, Sea Turtles, and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance, and Habitat Associations. Volume II: Technical Report. Prepared by Texas A&M University at Galveston and the National Marine Fisheries Service. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BRD CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-003. 346 pp.

Department of the Navy. 2001. Marine Resources Assessment for the Virginia Capes (VACAPES) Operating Area. Naval Facilities Engineering Command, Norfolk, VA. 473 pp.

Department of the Navy. 2002a. Marine Resources Assessment for the Cherry Point Operating Area. Naval Facilities Engineering Command, Norfolk, VA. 279 pp.

Department of the Navy. 2002b. Marine Resources Assessment for the Charleston/Jacksonville Operating Area. Naval Facilities Engineering Command, Norfolk, VA. 344 pp.

Department of the Navy. 2003. Marine Resource Assessment for the Eastern Gulf of Mexico Testing and Training Areas. Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA. Contract #N62470-95-D-1160, CTO 0053. Prepared By Geo-Marine, Inc., Plano, TX. 302 pp.

Gardner, S.C., Fitzgerald, S.L., Vargas, B.A. and Rodríguez, L.M. 2006. Heavy metal accumulation in four species of sea turtles from the Baja California peninsula, Mexico. Biometals 19:91-99.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A. 2005. COWRIE 1.5 Electromagnetic Fields Review: The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms – A Review. Collaborative Offshore Wind Energy Research Into the Environment. 128 pp.

Gitschlag, G.R. and Herczeg, B.A. 1994. Sea turtle observations at explosive removals of energy structures. Marine Fisheries Review 56(92):1-8.

Henwood, T. A. and Ogren, L. H. 1987. Distribution and migrations of immature Kemp's ridley turtles (*Lepidochelys kempii*) and green turtles (*Chelonia mydas*) off Florida, Georgia, and South Carolina. Northeast Gulf Science 9(2):153-160.

Irwin, W.P. and Lohmann, K.J. 2003. Magnet-induced disorientation in hatchling loggerhead sea turtles. Journal of Experimental Biology 206:497-501.

Jarvis, C.M. 2005. An Evaluation of the Wildlife Impacts of Offshore Wind Development Relative to Fossil Fuel Power Production. M.S. Thesis, University of Delaware. 125 pp.

Kemp's Ridley Sea Turtle Recovery Team. 2004. Kemp's Ridley Sea Turtle Recovery Team Stakeholder Meeting Overview. April 13-14, 2004. Houston, TX.

Klima, E.F., Gitschlag, G.R. and Renaud, C.M.F. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Marine Fisheries Review 50(3): 33-42.

Lenhardt, M.L. 1994. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). Bjorndal, K.A. Bolten, A.B., Johnson, D.A., Eliazar, P. J. Compilers, Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-351, 238-241 pp.

Lohmann, K.J. and Lohmann, C.M.F. 1994. Detection of magnetic inclination angle by sea turtles: A possible mechanism for determining latitude. Journal of Experimental Biology 194:23-32.

Lohoefener, R., Hoggard, W., Mullin, K., Roden, C. and Rogers, C. 1990. Association of Sea Turtles with Petroleum Platforms in the North-Central Gulf of Mexico. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. OCS Study/MMS 90-0025. 90 pp.

Lutcavage, M. and Musick, J. A. 1985. Aspects of the biology of sea turtles in Virginia. Copeia 1985(2):449-456.

Lutcavage, M. and Lutz, P. 1997. The diving physiology of sea turtles. In Lutz, P.L. and Musick, J. (eds.). The Biology of Sea Turtles. C.R.C. Press, Boca Raton, FL. Pp 277-296.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhita, A., Murdoch. J. and McCabe. K. 2000. Marine Seismic Surveys: Analysis and Propagation of Air-gun Signals; and Effects of Air-gun Exposure on Humpback Whales, Sea Turtles, Fishes and Squid. A Report Prepared for the Australian Production Exploration Association. Project CMST 163, Report R99-15. 198 pp.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998. Recovery Plan for U.S. Pacific Populations of the East Pacific Green Turtle (*Chelonia mydas*). National Marine Fisheries Service, Silver Spring, MD.

NMFS-SEFSC (National Marine Fisheries Service Southeast Fisheries Science Center). 2001. Stock Assessments of Loggerhead and Leatherback Sea Turtles and an Assessment of the Impact of the Pelagic Longline Fishery on the Loggerhead and Leatherback Sea Turtles of the Western North Atlantic. U.S. Department of Commerce NOAA Technical Memorandum NMFSSEFSC-455, 343 pp.

NMFS (National Marine Fisheries Service). 2002. Southeast Regional Office. Endangered Species Act – Section 7 Consultation Biological Opinion. Gulf of Mexico Outer Continental Shelf Lease Sale 184. Consultation # F/SER/2002/00145.

NRC (National Research Council). 1990. Decline of the Sea Turtles: Causes and Prevention. National Academies Press, Washington, DC. 259 pp.

NOAA Fisheries. 2006. Marine Turtle Research Program: Movements and Habitat Use. Southwest Fisheries Science Center. Internet Web site: http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=212&id=6816. Accessed February 23, 2007.

NOAA Fisheries. 2007. Marine Turtles. Office of Protected Resources. Internet Web site: http://www.nmfs.noaa.gov/pr/species/turtles/. Accessed February 23, 2007.

ONR (Office of Naval Research). 2005. Ocean Life: Green Sea Turtle – Current Research. Internet Web site: http://www.onr.navy.mil/focus/ocean/life/turtle4.htm. Accessed February 20, 2007.

Papi, F., Luschi, P., Akesson, S., Capogrossi, S. and Hays, G.C. 2000. Open-sea migration of magnetically disturbed sea turtles. Journal of Experimental Biology 203:3435-3443.

Richardson, W.J., Greene, Jr., C.R., Malme, C.I. and Thompson, D.H. 1991. Effects of noise on marine mammals. OCS study MMS-90-0093. LGL Rep. TA834-1. Report from LGL Ecol. Res. Assoc., Inc., Bryan, Texas, for U.S. Minerals Management Service, Atlantic Outer Continental Shelf Region, Herndon, VA. NTIS PB91-168914. 462 pp.

Schmid, J.R. 1995. Marine turtle populations on the east-central coast of Florida: results of tagging studies at Cape Canaveral, Florida, 1986-1991. Fish. Bull. 93:139-151.

Schmid, J.R. 1998. Marine turtle populations on the west-central coast of Florida: results of tagging studies at the Cedar Keys, Florida, 1986-1995. Fish. Bull. 96:589-602.

Schmid, J.R. and Witzell, W.N. 1997. Age and growth of wild Kemp's ridley turtles (*Lepidochelys kempi*): cumulative results of tagging studies in Florida. Chelonian Conserv. Biol. 2:532-537.

SEAS. 2000. Rødsand Offshore Wind Farm Environmental Impact Assessment, EIA Summary Report 2000. Internet Web site: http://uk.nystedhavmoellepark.dk/. Accessed February 15, 2007.

Shoop, C.R. and Kenney, R.D. 1992. Seasonal distributions and abundances of loggerhead and leatherback sea turtles in northeastern United States waters. Herpetological Monographs 6:43-67.

Teas, W.G. 1994a. Annual Report of the Sea Turtle Stranding and Salvage Network. Atlantic and Gulf Coasts of the United States. January – December 1993. Contribution No. MIA-94/95-12 from the Miami Laboratory, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Center, Miami, FL. 46 pp.

Teas, W.G. 1994b. Marine turtle stranding trends, 1986 to 1993. In Bjorndal, K.A., Bolten, A.B., Johnson, D.A. and Eliazar, P.J. (eds.). Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration Tech. Memo., National Marine Fisheries Service, Southeast Fisheries Center, NMFS-SEFC-351. Pp. 293-295.

Tougaard, J., Carstensen, J., Wisz, M.S., Jespersen, M., Teilmann, J., Bech, N.I. and Skov, H. 2006. Harbour Porpoises on Horns Reef Effects of the Horns Reef Wind Farm. Vattenfall A/S. 111 pp.

TEWG (Turtle Expert Working Group). 2000. Assessment update for the Kemp's ridley and loggerhead sea turtle populations in the Western North Atlantic. NOAA Tech. Memo. NMFS-SEFSC-444. 115 pp.

University of Liverpool. 2002. Burbo Offshore Wind Farm: EIA: Technical Report: Marine Ecology. Seascape Energy Ltd. 134 pp.

University of Liverpool. 2003. A Baseline Assessment of Electromagnetic Fields Generated by Offshore Wind Farm Cables Final Report. COWRIE. 71 pp.

Witherington, B.A. and Martin, R.E. 1996. Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches. Florida Department of Environmental Protection Technical Report TR-2.

References for Section 5.1.7 – Flying Animals

Ahlen, I. 2003. Wind Turbines and Bats – A Pilot Study. Final Report. Dnr 5210P-2002-00473, Pnr P20272-1.

AMEC. 2002. AMEC Wind Energy Lynn Offshore Environmental Impact Assessment. 426 pp.

Anderson, R., Morrison, M., Sinclair, K. and Strickland, D. 1999. Studying Wind Energy/Bird Interactions: A Guidance Document. National Wind Coordinating Committee. Internet Web site: http://www.nationalwind.org. Accessed February 2007.

Anderson, R.L., Strickland, D., Tom, J., Neumann, N., Erickson, W, Clecker, J., Mayorga, G. Nuhn, G., Leuders, A., Schneider, J., Backus, L., Becker, P. and Flagg, N. 2000. Avian monitoring and risk assessment at Tehachapi and San Gorgonio, WRAS. In Proc. National Avian Wind Power Interaction Workshop III, May, 1998, San Diego, CA, National Wind Coordinating Committee/Resolve, Inc. Pp. 31-46.

Arnett, E., pers. comm. 2006. Bat Conservation International, Austin, Tex.

Atlantic Renewable Energy Corp. and AWS Scientific, Inc. 2004. New Jersey Offshore Wind Energy: Feasibility Study: Final Version. Skillman, NJ. 236 pp.

Avery, M.L., Springer, P.F. and Dailey, N.S. 1980. Avian Mortality at Man-Made Structures: An annotated Bibliography (revised from 1978 ed.). U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team, FWS/OBS-80/54.

Band, W., Madders, M. and Whitfield, D.P. 2005. Developing Field and Analytical Methods to Assess Avian Collision Risk at Wind Farms. In De Lucas, M., Janss, G. and Ferrer, M. (eds.). Birds and Wind Power: Barcelona: Lynx Editions.

Birdlife. 2002. Windfarms and Birds: An Analysis of the Effects of Windfarms on Birds, and Guidance on Environmental Assessment Criteria and Site Selection Issues. Council of Europe. 37 pp.

Bonnell, M.L., LeBoeuf, B.J., Pierson, M.O., Dettman, D.H. and Farrens, G.D. 1981. Marine Mammal and Seabird Surveys of the Southern California Bight Area. Volume II. Synthesis of Findings. Bureau of Land Management, Washington, DC, BLM/YN/SR81/01-VOL-2, 414 pp.

Bonnell, M.L. and Ford, R.G. 2001. Marine Mammal and Seabird Computer Database Analysis System (CDAS). Pacific OCS Region, Minerals Management Service, Contract No. 1435-01-97-PO-14206.

Casella Stanger. 2002. Burbo Offshore Wind Farm: Ornithology Final Report. Seascape Energy, Ltd. 90 pp.

Camphuysen, C.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. Towards Standardised Seabirds at Sea Census Techniques in Connection with Environmental Impact Assessments for Offshore Wind Farms in the U.K. COWRIE. 39 pp.

California Energy Commission. 2004. Bird Strike Indicator/Bird Activity Monitor and Field Assessment of Avian Fatalities; Project Update-March 2004. EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: Technical Report 1005551.

Cape Wind Associates, LLC. 2004. Cape Wind Energy Project Draft Environmental Impact Statement. USACE File No. 24-338-1.

Chamberlain, D.E., Rehfisch, M.R., Fox, A.D., Desholm, M. and Anthony, S.J. 2006. The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models. Ibis 148:198-202.

Clapp, R.B, Banks, R.C., Morgan-Jacobs, D. and Hoffman, W.A. 1982a. Marine Birds of the Southeastern United States and Gulf of Mexico. Part I. Gaviiformes through Pelicaniformes. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-82/01, 637 pp.

Clapp, R.B., Morgan-Jacobs, D. and Banks, R.C. 1982b. Marine Birds of the Southeastern United States and Gulf of Mexico. Part II: Anseriformes. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-82/20. 492 pp.

Clapp, R.B., Morgan-Jacobs, D. and Banks, R.C. 1983. Marine Birds of the Southeastern United States and Gulf of Mexico. Part III: Charadriiformes. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-83/30, xvi and 853 pp.

Cryan, P., pers. comm. 2006. U.S. Geological Survey, Fort Collins, CO.

Cryan, P.W. and Brown, A.C. In press, Migration of bats past a remote island offers clues toward the problem of bat fatalities at wind turbines. Behavioral Conservation.

Davis, R.W., Evans, W.E. and Wursig, B. (eds.). 2000. Cetaceans, Sea Turtles, and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Association. Volume I: Executive Summary. Prepared by Texas A&M University at Galveston and the National Marine Fisheries Service. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BRD/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-002. 27 pp.

Desholm, M., Fox, A.D., Beasley, P.D.L. and Kahlert, J. 2006. Remote techniques for counting and estimating the number of bird/wind turbine collisions at sea: a review. Ibis 148:76-89

Desholm, M. and Kahlert, J. 2005. Avian Collision Risk at an Offshore Wind Farm. Biology Letters 1:296-298.

Dohl, T.P., Bonnell, M.L., Guess, R.C. and Briggs, K.T. 1983. Marine Mammal and Seabirds of Central and Northern California, 1980-1983: Synthesis of Findings. Mineral Management Service, U.S. Department of the Interior, Los Angeles, CA. MMS 84-0042. 248 pp.

Dong Energy and Vattenfall. 2006. Review Report 2005: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms Environmental impact assessment and monitoring. The Environmental Group. 150 pp.

Drewitt, A.L. and Langston, R.H.W. 2006. Assessing the impacts of wind farms on birds. Ibis 148:29-42

DTI. 2006. Aerial Surveys of Waterbirds in Strategic Windfarm Areas: 2004/05 Final Report. 176 pp.

DTI. 2005. Offshore Wind Turbines and Bird Activity at Blyth. AMEC Wind Ltd., Crown Publishing. 18 pp.

Energetics, Inc. 2004. Proc. Bats and Wind Power Generation Technical Workshop, April, 2004, Juno Beach, Fla., Energetics, Inc. 23 pp.

Erickson, W., Johnson, G., Young, D., Strickland, D., Good, R., Bourassa, M., Bay, K. and Sernka, K. 2002. Synthesis and Comparison of Baseline Avian and Bat Use, Raptor Nesting and Mortality Information from Proposed and Existing Wind Developments. WEST, Inc. 129 pp.

Erickson, W.P., Johnson, G.D., Strickland, M.D., Young, Jr., D.P., Sernka, K.J. and Good, R.E. 2001. Avian Collisions with Wind Turbines: A Summary of Existing Studies and Comparisons to Other Sources of Avian Collision Mortality in the United States. WEST, Inc. 67 pp.

Evans W.R., Akashi, Y. Altman, N.S. and Manville A.M. II. 2007. Response of night-migrating birds to colored and flashing light. North American Birds 60(4):476-488.

Evans, W.R. 2000. Applications of acoustic bird monitoring for the wind power industry PNAWPPM-III. 2000. In Proc. of National Avian - Wind Power Planning Meeting III, San Diego, Calif., May 1998. Prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ont. 202 pp. Internet Web site: http://www.nationalwind.org/publications/wildlife/avian98/21-Evans-Acoustics.pdf

Evans, B. pers. comm. 2007. Old Bird, Ithaca, NY.

Everaert, J. and Stienen, E.W.M. 2006. Impact of Wind Turbines on Birds in Zeebrugge (Belgium). Biodiversity and Conservation. DOI 10.1007/s10531-006-9082-1.

Forsell, D., pers. comm. 2006. U.S. Fish and Wildlife Service, Annapolis, MD.

Forsell, D.J. 2005. Atlantic Waterbird Use of Offshore Shoals and Survey Needs to Evaluate Wind Energy Development. In a Special Panel and Workshop Presentations at the 2nd Annual North American Sea Duck Conference, Annapolis, MD. Internet Web site:

http://www.pwrc.usgs.gov/seaduck_conf2005/SeaduckConf2005_Workshops_wind.htm Accessed December 2006.

Forsell, D.J. 2004. Draft Special Report on the Distribution and Abundance of Wintering Seaducks and Waterbirds in mid-Atlantic Coastal Waters Emphasizing the Mouth of the Chesapeake Bay. U.S. Fish and Wildlife Service, Annapolis, MD. 9 pp.

Fox, A.D., Desholm, M., Kahlert, J., Christensen, T.K. and Petersen, I.K. 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis 148:129-144.

Fritts, T.H., Irvine, A.B., Jennings, R.D., Collum, L.A., Hoffman, W. and McGehee, M.A. 1983. Turtles, Birds, and Mammals in the Northern Gulf of Mexico and Nearby Atlantic waters. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC, FWS/OBS-82/65, 455 pp.

Gauthreaux, S. A. Jr. and Belser, C. G. 2006. Effects of artificial night lighting on migrating birds. In Rich, C. and Longcore, T. (Eds.), Ecological consequences of artificial night lighting Covelo, California: Island Press. Pp. 67-93.

Gill, J.P., Sales, D. and Beasley, F. 2006. Kentish Flats Offshore Wind Farm Monitoring Report. Environmentally Sustainable Systems, Ltd. 100 pp.

Global Renewable Energy Partners (GREP). 2002. Kentish Flats Environmental Statement. Kentish Flats, Ltd. 430 pp.

Guillemette, M., Larsen, J.K. and Clausager, I. 1998. Impact Assessment of an Off-shore Wind park on Sea Ducks. NERI Technical Report No. 227. Ministry of Environment and Energy - Denmark, National Environmental Research Institute.

Guillemette, M. Larsen, J.K. and Clausager, I. 1999. Assessing the Impact of the Tuno Knob Wind Farm on Sea Ducks: The Influence of Food Resources. NERI Technical Report No. 263. Ministry of Environment and Energy - Denmark, National Environmental Research Institute. 21 pp.

Holland, R.A., Thorup, K., Vonhof, M.J., Cochran, W.W. and Wikelski, M. 2006. Bat orientation using Earth's magnetic field. Nature 444:702.

Howe, R.W., Evans, W. and Wolf, A.T. 2002. Effects of Wind Turbines on Birds and Bats in Northeastern Wisconsin. Report for Wisconsin Public Service Corp. and Madison Gas and Electric Corp.

Johnson, G. 2004. A review of bat impacts at wind farms in the US. In Proceeding Wind Energy and Birds/Bats Workshop: Understanding and Resolving Bird and Bat Impacts, May 18-19, 2004. Prepared by Resolve Inc., Washington, DC, Schwartz, S.S. (ed.). September 2004. Pp.46-50.

Kahlert, J., Petersen, I.K., Fox, A.D., Desholm, M. and Clausager, I. 2004. Investigations of birds during construction and operation of Nysted offshore wind farm at Rødsand Annual status report 2003. Energi E2 A/S.

Kaiser, M.J., Galanidi, M., Elliott, A.J., Showler, D.A., Caldow, R.W.G. and Sutherland, W.J. 2006. Disturbance Displacement of Common Scoters in Relation to Wind Farms. In Wind, Fire, and Water: Renewable Energy and Birds. Ibis 148 (Suppl. 1):110-128.

Keil, M. 2005. The Effects of Windfarms on Birds: A Review. University of Northern British Columbia Technical Report, Prince George, B.C. 14 pp.

Kerlinger, P. and Curry, R. 2002. Desktop Avian Risk Assessment for the Long Island Power Authority Offshore Wind Energy Project. Curry & Kerlinger, L.L.C., Cape May Point, NJ. 61 pp.

Kerns, J. and Kerlinger, P. 2004. A Study of Bird and Bat Collision Fatalities at the Mountaineer Wind Energy Center, Tucker County, West Virginia. Report on 2003 mortality for Florida Power and Light Energy.

Koford, R., Jain, A., Zenner, G. and Hancock, A. 2004. Avian Mortality Associated with the Top of Iowa Wind Farm: Progress Report, Calendar Year 2003. Iowa Cooperative Fish and Wildlife Research Unit, Iowa State University, Ames, IA. 9 pp.

Kunz, T.H. 2004. Wind power: bats and wind turbines. In Proc. Wind Energy and Birds/Bats Workshop: Understanding and Resolving Bird and Bat Impacts, May 18-19, 2004. Prepared by Resolve Inc., Washington, DC, Schwartz, S.S. (ed.). September 2004. Pp. 50-56.

Kunz, T. H., pers. comm. 2006. Boston University, Department of Biology.

Langston, R.H.W. and Pullan, J.D. 2003. Wind Farms and Birds: An Analysis of the Effects of Wind Farms on Birds, and Guidance on Environmental Assessment Criteria and Site Selection Issues. Report to the Standing Committee on the Convention on the Conservation of Wildlife and Natural Habitats. Strasbourg: Council of Europe. 37 pp.

MANEM Waterbird Working Group. 2006. Waterbird Conservation Plan for the Mid-Atlantic/New England/Maritimes Region. 2006-2010. Waterbird Conservation for the Americas (www.waterbirdconservation.org).

Morrison, M.L. 2006. Bird Movements and Behaviors in the Gulf Coast Region: Relation to Potential Wind Energy Developments: November 22, 2000-October 31, 2005. National Renewable Energy Laboratory, Golden, Colo., NREL/SR-500-39572. 38 pp.

National Wind Power 2003. North Hoyle Offshore Wind Farm Baseline Monitoring Report: June 2003. National Wind Power Ltd.

Nicholson, C.P. 2003. Buffalo Mountain Windfarm Bird and Bat Mortality Monitoring Report: October 2001 – September 2002. Tennessee Valley Authority, Knoxville, TN.

NOAA National Centers for Coastal Ocean Science (NCCOS). 2003. A Biogeographic Assessment off North/Central California: To Support the Joint Management Plan Review for Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries: Phase I – marine fishes, birds, and mammals. Prepared by NCCOS's Biogeography Team in cooperation with the National Marine Sanctuary Program, Silver Spring, MD. 145 pp.

Orloff, S. and Flannery, A. 1996. A Continued Examination of avian mortality in the Altamont Pass Wind Resource Area. P700-96-004CN. Rep. from Ibis Environ. Serv. And BioSystems Analysis Inc., Santa Cruz, CA for Calif. Energy Comiss., Sacramento, CA. 55 pp.

Orloff, S. and Flannery, A. 1992. Wind Turbine Effects on Avian Activity, Habitat Use, and Mortality in Altamont Pass and Solano County Wind Resource Areas (1989-91). Final Report. Planning Departments of Alameda, Contra Costa, and Solano Counties and the California Energy Commission. Tiburon, CA: BioSystems Analysis, Inc.

Pandey, A., Hermence, J. and Harness, R. 2006. Development of a Cost-Effective System to Monitor Wind Turbines for Bird and Bat Collisions—Phase I: Sensor System Feasibility Study. California Energy Commission, PIER Energy-Related Environmental Research.

Percival, S.M. 2001. Assessment of the Effects of Offshore Wind Farms on Birds. Crown Publishing. ETSU W/13/00565/REO, DTU/Pub URN 01/1434. 96 pp.

Perrow, M.R., Skeate, E.R., Lines, P., Brown, D. and Tomlinson, M.L. 2006. Radio Telemetry as a Tool for Impact Assessment of Wind Farms: The Case of Little *Terns Sterna albifrons* at Scroby Sands, Norfolk, UK. Ibis 148:57-75.

Pettersson, J. 2005. The Impact of Offshore Wind Farms on Bird Life in Southern Kalmar Sound, Sweden: A Final Report Based on Studies 1999-2003. ISBN 91-631-6878-2. 128 pp.

Powers, K.D. 1983. Pelagic Distribution of Marine Birds Off the Northeastern United States. Woods Hole, Massachusetts: NOAA Technical Memorandum NMFS-F/NEC-27. U.S. Department of Commerce, Washington, D.C. 201 pp.

Research Planning, Inc. (RPI). 2005. Sensitivity of Coastal Environments to Spilled Oil: Central California Atlas. Prepared by RPI, Columbia, S.C., for Monterey Bay National Marine Sanctuary, Department of Fish and Game Office of Spill Prevention and Response, and Monterey Bay Sanctuary Foundation, 41 maps.

Richardson, W.J. 1998. Bird Migration and Wind Turbines: Migration Timing, Flight Behavior, and Collision Risk. LGL Ltd.

Russell, R.W. 2005. Interactions Between Migrating Birds and Offshore Oil and Gas Platforms in the Northern Gulf of Mexico: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2005-009. 348 pp.

Sea Duck Joint Venture Continental Technical Team. 2003. Sea Duck Joint Venture Species Status Reports, March 2003. Internet Web site: http://www.seaduckjv.org/meetseaduck/species_status_summary.pdf. Accessed February 2007.

Scottish Natural Heritage. 2000. Windfarms and Birds: Calculating a Theoretical Collision Risk Assuming No Avoiding Action. Guidance Note Series. 9 pp.

Still, D., Little, B. and Lawrence, S. 1996. The Effects of Wind Turbines on the Bird Population at Blyth Harbour. DTI contract ETSU W/13/00394/REPORT.

The Offshore Wind-Farm Working Group. 1997. Action Plan for the Offshore Wind Farms in Danish Waters. The Offshore Wind-Farm Working Group of the Danish Utilities and the Danish Energy Agency. SEAS, Haslev. 44 pp.

Tulp, I., Schekkerman, H., Larsen, J.K., van der Winden, J., van de Haterd, R.J.W., van Horssen, P., Dirksen, S. and Spaans, A.L. 1999. Nocturnal Flight Activity of Sea Ducks Near the Windfarm Tunø Knob in the Kattegat. Novem, Utrecht, The Netherlands. 70 pp.

Verhoef, J.P., Eecen, P.J., Nijdam, R.J., Korterink, H. and Scholtens, H.H. 2004. WT-Bird: A Low Cost Solution for Detecting Bird Collisions. Petten, The Netherlands: ECN Wind Energy.

Warwick Energy, Ltd. 2002. Barrow Offshore Wind Farm Environmental Impact Statement. Warwick, UK. 463 pp.

Watson, M., pers. comm. 2007. New York State Energy Research and Development Association (NYSERDA), Senior Project Manager for Environmental Research.

Wiggelinkhuizen, E.J., Rademakers, L.W.M.M., Barhorst, S.A.M. and den Boon, H.J. 2006. Bird Collision Monitoring System for Multi-Megawatt Wind Turbines WT-Bird®: Summary of Prototype Development and Testing. ECN. 17 pp.

Williams, T.C., Williams, J.M., Ireland, L.C. and Teal, J.M. 1977. Autumnal bird migration over the western North Atlantic Ocean. American Birds 31:251-267.

References for Section 5.2 – Impacts of Wave Energy

ABPmer. 2005. Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters. Countryside Council for Wales Policy Research Report No. 04/8. 79 pp.

Addis, P., Cau A., Massuti, E., Merella, P., Sinopoli, M. and Andaloro, F. 2006. Spatial and temporal changes in the assemblage structure of fishes associated to fish aggregation devices in the Western Mediterranean. Aquat. Living Resources 19:149-160.

Anderson, J. and Gates. P. 1996. South Pacific Commission Fish Aggregating Device (FAD) Manual. Volume I: Planning FAD Programmes. South Pacific Commission, Noumea, New Caledonia. 46 pp.

AquaEnergy, Ltd. 2006. Makah Bay Offshore Wave Energy Pilot Project: FERC Docket No. DI02-3-002: Preliminary Draft Environmental Assessment. FERC. 179 pp.

Bailey, D. and Bulleit, K. 2002. Defining "Adverse Environmental Impact" and making 316(b) decisions: A fisheries management approach. The Scientific World Journal 2:147-168.

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G. and Hart, P.J.B. 2004. Implications of a zoned fishery management system for marine benthic communities. Jour. Applied Ecology 41(5):951-961.

Bryan, G. and Gibbs, P. 1991. Impact of low concentrations of tributyltin (TBT) on marine organisms: a review. In Metal Ecotoxicology: Concepts and Applications. Advances in Trace Substances Research Series. Lewis Publisher, Inc., Chelsea, MI. Pp. 323-361.

Camphuysen, C.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. Towards standardized seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the UK. A comparison of ship and aerial survey methods for marine birds and their applicability to offshore wind farm assessments. Report by Royal Netherlands Institute to COWRIE BAM 02-2002. London: Crown Estate Commissioners. Internet Web site: http://ww.thecrownestate.co.uk/1352_bird_survey_phase1_final_04_05_06.pdf.

Castro, J., Santiago, J. and Santana-Ortega, A. 2001. A general theory on fish aggregation to floating objects: An alternative to the meeting point hypothesis. Reviews in Fish Biology and Fisheries 11(3):1573-5184.

CEFAS. 2006. Scroby Sands Offshore Wind Farm Coastal Processes Monitoring. Final Report. Report prepared for The Department of Trade and Industry, UK. Contract Ref. No. AE0262.

Champ, M.A. and Pugh, W.L. 1987. Tributyltin antifouling paints: introduction and overview. In Oceans 87 Proceedings. International Organotin Symposium, Institute of Electrical and Electronic Engineers, New York. 14, 1296-1308.

Champ, M.A. 2000. A review of organotin regulatory strategies, pending actions, related costs and benefits. The Science of the Total Environment 258:21-71.

Chapman, L., Pasisi, B., Bertram, I., Beverly, S. and Sokimi, W. 2005. Manual on Fish Aggregating Devices (FADs): Lower-cost Moorings and Programme Management. South Pacific Commission, Noumea, New Caledonia.

Christensen, L., Friis-Madsen, E., Kofoed, J.P. and Tedd, J. 2006. World's Largest Wave Energy Project 2007 In Wales. PowerGen 2006 Europe Conference – Wave Dragon.

Crowder, L., Osherenko, G., Young, O., Airame, S., Norse, E., Baron, N., Day, J., Douvere, F., Ehler, C., Halpern, B., Landgon, S., McLeod, K., Ogden, J., Peach, R., Rosenberg, A. and Wilson, J. A. 2006. Resolving mismatches in U.S. Ocean Governance. Science 313:617-618.

Department of the Navy. 2003. Environmental Assessment Proposed Wave Energy Technology Project, Marine Corps Base Hawaii, Kaneohe Bay, Hawaii. Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. 300 pp.

Department of Trade and Industry, UK. 2005. Guidance on the Assessment of the Impact of Offshore Wind Farms: Seascape and Visual Impact Report. DTI/Pub 8066/0.3k/11/05/NP. 127 pp.

Dempster, T. 2005. Temporal variability of pelagic fish assemblages around fish aggregation devices: biological and physical influences. Jour. Fish Biology 66 (5):1237-1260.

Deudero, S., Merella, P., Morales-Nin, B., Massuti, E. and Alemany, F. 1999. Fish communities associated with FADs. Sci. Mar. 63(3-4):199-207.

Elsam Engineering and Energi E2. 2005. Review Report 2004: The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms: EIA and Monitoring. Environmental Group of Danish Offshore Wind Farm Demonstration Projects. 135 pp.

EMEC. 2005. Environmental Impact Assessment (EIA): Guidance for Developers at the European Marine Energy Center. European Marine Energy Center. 18 pp.

Emu Ltd. 2005. Kentish Flats Offshore Windfarm Post-Construction Swath Survey 2 For Kentish Flats Ltd. Report No. 05/J/1/02/0869/0564: December 2005 Job No. J/1/02/0869. Kentish Flats Ltd.

Emu Ltd. 2006. Kentish Flats Offshore Windfarm Post-Construction Swath Survey 3 For Kentish Flats Ltd. Report No. 06/J/1/02/0942/0590: April 2006 Job No. J/1/02/0942. Kentish Flats Ltd.

Entec UK Ltd. 2003. Ocean Power Delivery Ltd.: Offshore Wave Energy: Environmental Impact Assessment: Generic Scoping Study. Ocean Power Delivery Ltd. 2 pp.

Fent, K. and Hunn, J. 1993. Uptake and elimination of tributyltin in fish-yolk-sac larvae. Marine Environmental Research 35(1-2):65-71.

Ferraro, N., Fenocchio, A., Mantvani, M., De Oliveira Ribeiro, C. and Cestari, M. 2004. Mutagenic effects of tributyltin and inorganic lead (Pb II) on the fish *H. malabaricus* as evaluated using the comet assay and the piscine micronucleus and chromosome aberration tests. Genet. Mol. Biology 27(1):103-107.

Gates, P., Cusack, P. and Watt, P. 1996. South Pacific Commission Fish Aggregating Device (FAD) manual. Volume II: Rigging deep-water FAD moorings, South Pacific Commission, Noumea, New Caledonia. 43 pp.

Gates, P., Preston, G. and Chapman, L. 1998. Secretariat of the Pacific Community Fish Aggregating Device (FAD) manual. Vol. III: Deploying and maintaining FAD systems, Secretariat of the Pacific Community, Noumea, New Caledonia. 43 pp.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A. 2005. The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms – A Review. COWRIE-EM Field 2-06-2004.

Hagerman, G. and Bedard, R. 2004. Offshore Wave Power in the US: Environmental Issues. Global Energy Partners, LLC. E2I Global EPRI-007-US. 29 pp.

Halcrow Group Ltd. 2006a. South West of England Regional Development Agency Wave Hub Environmental Statement. Sowton, Exeter. 268 pp.

Halcrow Group Ltd. 2006b. South West of England Regional Development Agency Wave Hub Development and Design Phase, Coastal Processes Study Report. Sowton, Exeter. 72 pp.

Halcrow Group Ltd. 2006c. South West of England Regional Development Agency Wave Hub EIA Baseline Fisheries Surveys. 2005. Report No. 05/J/1/06/0782/0521. Sowton, Exeter.

Halcrow Group Ltd. 2006d. South West of England Regional Development Agency Wave Hub Development EIA Commercial Fisheries Study. Sowton, Exeter. XI-XV.

Holm, G., Norrgren, L. and Linden, O. 1991. Reproductive and histopathological effects of long-term experimental exposure to bis(tributyltin)oxide (TBTO) on the three-spined stickleback, *Gasterosteus aculeatus Linnaeus*. Jour. Fisheries Biology 38(3):373-386.

ICCAT. 2006. Report of the Meeting of the Standing Committee on Research and Statistics. Report. International Commission for the Conservation of Atlantic Tuna. 2-6 October 2006, Madrid. Spain. PLE-14/2006. 192 pp.

Lough, R. and Manning, J. 2001. Tidal-front entrainment and retention of fish larvae on the southern flank of Georges Bank. Deep Sea Research II., v48:631-644.

Magnuson-Stevens Fishery Conservation and Management Act. 2007. H.R. 5946. 109th Congress. Washington, DC.

Marsac, F. and Cayre, P. 1998. Telemetry applied to behaviour analysis of yellowfin tuna (*Thunnus albacares*, Bonnaterre, 1788) movements in a network of fish aggregating devices. Hydrobiologia Bol. 371-372:155-171.

Massuti, E., Morales-Nin, B. and Deudero, S. 1999. Fish fauna associated with floating objects sampled by experimental and commercial purse nets. Sci. Mar. 63(3-4): 219-227.

Naeem, A. and Latheefa, A. 1994. Biosocioeconomic assessment of the effects of fish aggregating devices in the tuna fishery in the Maldives. Working Papers. BOBP/WP/95 Food and Agriculture Organization of the United Nations. Rome, Italy.

Npower renewables, Ltd. 2005. Annual FEPA monitoring report: North Hoyle offshore wind farm, Chapter 9: Underwater noise & vibration. NWP Offshore Ltd. NH/FEPA/2003-04- Final. Pp. 83-86.

NRC (National Research Council). 2002. The Effects of Trawling and Dredging on Seafloor Habitat. National Academies Press. Washington. DC. 136 pp.

Osawa, H. and Miyazaki, T. 2004. Wave-PV hybrid generation system carried in the offshore floating type wave power device “Mighty Whale”. Oceans’04 MTS/IEEE Techno-Ocean ’04. Kobe, Japan. Conference Proceedings. 4:1860-1867.

Resolve, Inc. 2006. Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. Washington, DC. October 26-28, 2005. 111 pp.

Roullot, J., Venkatasami, A. and Soondron, S. 1988. The first three years experience in the use of fish aggregating devices in Mauritius. SWIOP/WP/55. Food and Agriculture Organization of the United Nations. Rome, Italy.

Shimsaki, Y., Kitano, T., Oshima, Y., Inoue, S., Imada, N. and Honjom, T. 2003. Tributyltin causes masculinization in fish. Environmental Toxicology and Chemistry 22(1):141-144.

Taylor, P. 1986. Experimental evidence for geomagnetic orientation in juvenile salmon, *Ohcorhynchus tschawytscha* Walbaum. Jour. Fish Biology 28(5):607-623.

UK House of Commons Select Committee on Science and Technology. 2000. Seventh Report on Wind and Tidal Energy. Internet Web site: http://www.parliament.the-stationery-office.co.uk/pa/cm200001/cmselect/cmsctech/291/29105.htm. Accessed on 25 January 2007.

Venkatasami, A. and Sheik Mamode, A. 1996. Fish-aggregating devices (FADS) as a tool to enhance production of artisanal fishermen: problems and perspectives. Internet Web site: http://hdl.handle.net/1834/511. Accessed on 25 March 2007.

Wave Dragon. 2006. Internet Web site: http://www.wavedragon.net/index.php?option=com_content&task=view&id=5&Itemid=6. Accessed on 25 March 2007.

WaveNet, 2003. WaveNet March 2003: Results from the Work of the European Thematic Network on Wave Energy. ERK5-CT-1999-2001 2000-2003. 502 pp.

References for Section 5.3 – Impacts of Ocean Current Energy

ABPmer. 2005. Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters. Countryside Council for Wales Policy Research Report No. 04/8. 79 pp.

Arnell N., Tompkins, E., Adger, N. and Delaney, K. 2005. Vulnerability to abrupt climate change in Europe. Tyndall Centre Technical Report 34. Report submitted to ESRC Environment and Human Behavior Programmer. Project RES-221-25-0011.

Bahaj, A.S., Molland, A.F., Chaplin, J.R. and Batten, W.M.J. 2007. Power and thrust measurements of marine current turbines under various hydrodynamic flow conditions in a cavitation tunnel and a towing tank. Renewable Energy 32(3):407-426.

Benedet L., Stive, M., Hartog, W., Walstra, D. and Van Koningsveld, M. 2006. Effects of wave diffraction and initial bathymetric conditions on beach fill volume change predictions. Proceedings of the International Conference on Coastal Engineering 2006, San Francisco CA, 2-8 September 2006.

Bihlmayer, A. 2006. Turbine Matrix / Hydromatrix. In Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. October 26-28, 2005. Washington, DC. Resolve, Inc. Pg. 16-17.

Broecker, W.S. 1997. Thermohaline circulation, the Achilles' Heel of our climate system: Will man-made CO2 upset the current balance? Science 278(5343):1582-1588.

Camphuysen, C.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. Towards standardized seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the UK. A comparison of ship and aerial survey methods for marine birds and their applicability to offshore wind farm assessments. Report by Royal Netherlands Institute to COWRIE BAM 02-2002. London: Crown Estate Commissioners. Internet Web site: http://ww.thecrownestate.co.uk/1352_bird_survey_phase1_final_04_05_06.pdf

Champ, M.A. and Pugh, W.L. 1987. Tributyltin antifouling paints: introduction and overview. In Oceans 87 Proceedings. International Organotin Symposium, Institute of Electrical and Electronic Engineers, New York. 14:1296-1308.

Champ, M.A. 2000. A review of organotin regulatory strategies, pending actions, related costs and benefits. The Science of the Total Environment 258:21-71.

Croll, D.A., Gaston, A.J., Burger, A.E. and Konnoff, D. 1992. Foraging behavior and physiological adaption for diving in thick-billed murres. Ecology 73(1):344-356.

Devine Tarbell & Associates, Inc. 2006. Instream Tidal Power in North America: Environmental and Permitting Issues. Prepared for the Electric Power Research Institute, Inc. Palo Alto, CA. EPRI-TP-007-NA. 152 pp.

Elcock, D. 2006. Potential Alternative Energy Technologies on the Outer Continental Shelf. ANL/EVS/TM/06-5, Argonne National Laboratory, Argonne, IL. 54 pp.

EMEC. 2005. Environmental Impact Assessment (EIA): Guidance for Developers at the European Marine Energy Center. European Marine Energy Center. 18 pp.

Fraenkel, P.L. 2006. Tidal current energy technologies. Ibis 148:145-151.

Fisher, P.R. and Tregenza, N.J.C. 2003. An Assessment of the Effect of a Tidal Power Generator on Porpoise Habitat Use and an Evaluation of the Acoustic Methods Employed, August–October 2003, report prepared for Highlands and Islands Enterprise, Shetland Islands Council, The Crown Estate, and Engineering Business Ltd.

Gibson, J. 2006. Resource questions associated with free-flow axial turbines. In Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. October 26-28, 2005. Washington, DC. Resolve, Inc. Pg. 58-59.

Hoover, M. 2005. The Gulf Stream Energy Project. Gulf Stream Energy, Inc. 29 pp.

Irwin, W.P. and Lohmann, K.J. 2003. Magnet-induced disorientation in hatchling loggerhead sea turtles. J. Experimental Biology 206:497-501.

Lohmann, K.J. and Lohmann, C.M.F. 1994. Detection of magnetic inclination angle by sea turtles: A possible mechanism for determining latitude. Journal of Experimental Biology 194:23-32.

Luschi, P., Hayes, G.C. and Papi, F. 2003. A review of long-distance movements by marine turtles, and the possible role of ocean currents. Oikos 103:293–302.

NRC (National Research Council). 2002. Abrupt Climate Change: Inevitable Surprises. National Academies Press. Washington, DC. 244 pp.

O'Donnell, P. 2005. Update '05: Ocean Wave and Tidal Power Generation Projects in San Francisco. Power Engineering Society General Meeting, 2005. IEEE Vol. 2:1990-2003.

Prince, P.A. Huin, N. and Weimerskirch, H. 1994. Diving depths of albatrosses. Antarctic Science 6(3):353-354.

Resolve, Inc. 2006. Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. October 26-28, 2005. Washington, DC. 111 pp.

Scott Wilson Ltd. and Downie, A.J. 2003. A Review of Possible Marine Renewable Energy Development Projects and Their Natural Heritage Impacts from a Scottish Perspective. Scottish Natural Heritage Commissioned Report F02AA414. 90 pp.

The Engineering Business Ltd. 2005. Stingray Tidal Stream Energy Device – Phase 3. DTI Technology Programme URN 05/864. 130 pp.

Triton Consultants, Ltd. 2002. Green Energy Study for British Columbia: Phase II: Mainland, Tidal Current Energy.

UK House of Commons Select Committee on Science and Technology. 2000. Seventh Report on Wind and Tidal Energy. Internet Web site: http://www.parliament.the-stationery-office.co.uk/pa/cm200001/cmselect/cmsctech/291/29105.htm. Accessed on 30 November 2006 and on 25 January 2007.

Usachev, I., Shpolyanskii, Y. and Istorik, B. 2004. Performance control of a marine power plant in the Russian Arctic coast and prospects for the wide-scale use of tidal energy. Power Technology and Engineering 38(4).

Witherington, B.A. and Martin, R.E. 1996. Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches. Florida Department of Environmental Protection Technical Report TR-2.