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Improving Efficiencies of National Environmental Policy Act Documentation for Offshore Wind Facilities Case Studies Report

US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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CONTENTS

APPENDICES

TABLES IN THE MAIN TEXT

FIGURES IN THE MAIN TEXT

CASE STUDIES IN MAIN TEXT

ABBREVIATIONS

AC	Alternating Current
ADCP	Acoustic Doppler Current Profiler
ADD	Acoustic Deterrent Device
AR	Artificial reef
BACI	Before, After, Control, Impact
BHP	Back Hoe Plough
BHS	German Federal Maritime and Hydrographic Agency
BOEM	Bureau of Ocean Energy Management
BTO	British Trust for Ornithology
CEMP	Construction Environmental Management Plan
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
COP	Construction and Operations Plan
COWRIE	Collaborative Offshore Wind Research into the Environment
CPUE	Catch Per Unit Effort
CRM	Collision Risk Modelling
DC	Direct Current
DECC	Department of Energy and Climate Change (now Department of Business Environment and Industrial Strategy
DEPONS	Disturbance Effects on the Harbor Porpoise Population in the North Sea
DOI	Department of the Interior
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMF	Electromagnetic Field
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EPS	European Protected Species
ES	Environmental Statement
ESA	Endangered Species Act
ESP	Environmental Studies Program
EU	European Union
FLOW	Far and Large Offshore Wind
FONSI	Finding of No Significant Impact
GIS	Geographic Information System
GPS	Global Positioning System
HDD	Horizontal directional drilling
IMC	integrated coastal management
JCP	Joint Cetacean Protocol
JJNC	Joint Nature Conservation Committee
MALSFM	Marine Aggregate Levy Sustainability Fund
MESH	Mapping European Seabed Habitats
MoC	Management of Change

MMPA	Marine Mammal Protection Act
MMO	Marine Management Organisation
MMOs	Marine Mammal Observers
MMS	Minerals Management Service
MS	Marine Scotland
MDS	Multi-dimensional Scaling
MSFD	Marine Strategy Framework Directive
MUMM	The Management Unit of the North Sea Mathematical Models
NE	Natural England
NEPA	National Environmental Policy Act
NGOs	Non-governmental Organizations
NSW-MEP	Monitoring and Evaluation Programme (Netherlands)
OBS	Optical Backscatter
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OWF	Offshore Wind Farm
ORJIP	Offshore Renewables Joint Industry Programme
PAM	Passive Acoustic Monitoring
PEIS	Programmatic Environmental Impact Statement
PEMP	Project Environmental Management Plan
POM	Particulate Organic Matter
PVA	Population Viability Analysis
RAVE	Research at Alpha Ventus
RBINS	Royal Belgium Institute for Natural Sciences
REC	Regional Environmental Characterizations
RODEO	Real-time opportunity for development of environmental observations
RSPB	The Royal Society for the Protection of Birds
SAP	Site Assessment Plan
SCANS	Small Cetacean Abundance in the North Sea
SMRU	Sea Mammal Research Unit
SNCBs	Statutory Nature Conservation Bodies
SOSS	Strategic Ornithological Support Services
SpORRAn	Scottish Offshore Renewables Research Framework
SSC	Suspended Sediment Concentrations
T	Tesla
TCE	The Crown Estate
TTS	Temporary Threshold Shift
UK	United Kingdom
US	United States
UXO	Unexploded Ordnance

1. INTRODUCTION

1.1 Background to the Study

The United States (US) is currently embracing offshore wind farm (OWF) development as part of its expanding renewable energy generation objectives in response to renewables targets, financial incentives, and technological advancements. Expansion of the US offshore renewables industry was initially facilitated by amendments to the Outer Continental Shelf Lands Act (OCSLA), made under Section 388 of the Energy Policy Act (EPAct) (2005), which granted authority for the leasing of offshore renewables developments to the Department of the Interior (DOI) and subsequently to the Bureau of Ocean Energy Management (BOEM). In 2009, BOEM released its Renewable Energy Program Regulations (30 CFR 585) setting out the statutory framework within which the offshore renewables industry would be regulated and has subsequently disseminated rules and guidelines to further enable offshore renewables developments.

As well as the regulatory regime laid out by the EPAct Section 388, BOEM also considers the requirements of the National Environmental Policy Act of 1969 (42 U.S.C. §4321-4347) (NEPA). This discusses the potential environmental consequences of federal actions, including detailed site specific environmental analyses that are typically needed to evaluate the likelihood and significance of impacts of proposed federal actions on physical, biological, and historic resources, societal values and socio-economic factors. The findings of the impact analyses are typically reported in an Environmental Assessment (EA) and/or Environmental Impact Statement (EIS) and made available for public consumption and scrutiny[1]. Identification of the scope of issues to be reviewed and addressed in EA and EIS are commonly identified through extensive project scoping and consultation exercises with relevant agencies, stakeholders, and interested parties. These exercises also draw out the scale of the perceived concerns, the methods of the analyses to be used in EIS and the scope of supporting investigative studies.

With respect to offshore wind leasing, most of BOEM EAs to date have addressed only the installation of meteorological buoys or towers to gather wind resource data and conducting surveys to gather geotechnical and geophysical data. When BOEM receives construction and operations plans (COP) for the installation of wind facilities, BOEM will likely prepare EISs to analyze potential impacts. Additionally, there will be other NEPA analyses throughout the project. Determinations of NEPA adequacy (DNA), or Categorical Exclusions may also be used. Design changes and new information may require additional analyses throughout the life of the project.

For large infrastructure proposals within nascent industries with limited experience, consultations may be extensive and the level of perceived statutory and stakeholder concern may be substantial. This can result in the identification of a wide range of issues that are required to be addressed in sufficient depth and detail to provide the necessary knowledge, comfort, and precaution to underpin confident decision making. Applications for larger projects, such as OWFs, can therefore place a considerable burden on permitting authorities to undertake and complete environmental analyses and reviews and permit them to proceed in a timely and responsible fashion. This is particularly relevant in light of the Council on Environmental Quality (CEQ) Regulations (40 CFR 1502.5) which calls for respective

[1] The findings of intermediate levels of environmental review are reported in an Environmental Assessment (EA) and a finding of no significant impact (FONSI) is issued as appropriate.

agencies to prepare EIS in a sufficiently timely fashion to enable findings to be used practically within the decision-making processes and to be available prior to that portion of public hearings relevant to impact statement.

In light of increased numbers of applications for offshore wind development and associated increases in case load, as well as the ambitions of the CEQ Regulations, BOEM has recognized the need to streamline the preparation, review and, analysis of associated environmental information required under NEPA.

To facilitate potential streamlining of the NEPA review processes, Fugro noted that substantial environmental analyses of large offshore wind projects have already been completed in Europe where commercial scale developments have been operating for approximately 20 years. These analyses have been undertaken as required by the European Union (EU) Environmental Impact Assessment (EIA) Directive and which may be considered analogous to NEPA in terms of the broad environmental aims, sustainability aspirations and dissemination of conclusions among stakeholders and the wider public. In addition, many OWFs in Europe have been subject to environmental monitoring and research under the terms of their specific development licenses and in response to stakeholder concerns. This means that there is considerable empirical evidence available as to the actual environmental impacts of OWF construction and operation. Fugro considered that a systematic review and synthesis of these monitoring studies, where publicly available, may be appropriate to develop a robust evidence base to demonstrate consistent impacts for given receptors, conditions, geographic locations, and vulnerabilities and thereby help identify some elements that, in time, could be subject to reduced NEPA analysis or removed from repeated study entirely. This may be possible, for instance, where perceived concerns have not been realized following post-construction monitoring campaigns, or where impacts are consistently shown to be of minor or negligible significance. In particular, it may be possible to reduce certain aspects of planned activities, or environmental components, from the consideration of NEPA analysis where the following conditions exist:

- Precedent for impacts to be of minor or negligible significance;
- High confidence in the baseline environmental data;
- Receptor similarity of conditions;
- A robust design envelope; and
- Effective and agreed mitigation which can be conditioned within the final Construction and Operations Plan (COP) approval.

Similarly, where adverse impacts have been successfully mitigated, evidence of that outcome can also be used to inform mitigation implementation. Conversely, where unanticipated adverse impacts have occurred, this data too could be used to ensure the future EIA include the necessary evaluation of these impacts.

This document presents the findings of a systematic review and synthesis of European OWF monitoring campaigns and consolidates available impact and mitigation data with the intention of improving stakeholder understanding of comparable work done in Europe, reducing uncertainties associated with current state-of-the-practice knowledge in the US and identifying critical data gaps requiring further and more detailed study specific to US conditions.

1.2 Aims and Objectives

The aim of this document is to present a concise summary and synthesis of the empirical evidence of environmental changes attributable to OWF construction and operation, identify opportunities for the rationalization of NEPA review efficiency efforts, and highlight any important data gaps and limitations in the evidence base. This has been achieved by completing the following objectives:

- Review of information drawn from environmental monitoring studies of European OWFs, principally field monitoring reports but also environmental impact statements, license conditions, collaborative studies and academic research;
- Consolidation of the available evidence and European experience pertaining to observed environmental impacts attributable to OWFs for selected key topics;
- Synthesis of the evidence base to identify consistent impacts and mitigation measures for given OWF activities and receptors in Europe and which may support proposed rationalization of NEPA review efficiency efforts and with reference to the US situation; and
- Identification of knowledge gaps to caveat conclusions.

1.3 Limitations

There are currently 3,230 wind turbines installed across 84 OWFs in 11 European countries. A further 6 OWFs are scheduled to be constructed in 2017 (EWEA, 2016). Many of these are in construction for which pre- and during environmental monitoring studies are being undertaken and for which post-construction campaigns have yet to commence. In addition, there are very few deep-water floating wind turbine structures installed. Furthermore, there can be a significant time lag between completion of post-construction monitoring surveys and release of the respective report to the public domain, usually over a year or more. The review presented here is therefore unlikely to be exhaustive as new monitoring is continuously being undertaken, updated and released to the public. Periodic reviews, such as this, will become increasingly important in the future so that the evidence base is continually refreshed and strengthened and that new observations covering contemporary OWF designs, new construction and mitigation methodologies and environmental conditions are captured.

The stages of development covered in this study include construction and initial operation (in general up to 3 or 5 years post-construction, but occasionally up to 10 years). Large scale decommissioning of offshore wind has not taken place yet in Europe and thus observation of environmental effects of this activity have not been recorded. To date, only five very shallow water turbines at the Yttre Stengrund wind farm in Sweden and two turbines in Liverpool Bay, United Kingdom (UK) have been decommissioned. The Vindeby offshore wind farm in Denmark is being prepared for decommissioning in the near future. Environmental impacts of larger scale decommissioning are therefore currently not known, but are presently accepted to be generally comparable to those associated with the construction phase, in terms of spatial scale and magnitude.

Similarly, there are no operational, large scale, commercial floating wind farm arrays in operation at present and so impacts associated with these facilities that are dissimilar to pile foundation turbines have not been observed or measured, yet. Statoil's Hywind project (five floating turbines off the east coast of Scotland) has recently been awarded planning consent with commissioning due in 2017 and the proposed Kincardine and Dounreay floating OWFs (both Scotland) are currently in application stage. While these projects present a good opportunity to monitor impacts associated with floating turbines in the near future, these data will not be available within the timeframe of this study.

Finally, it should be noted that the current monitoring information is presented within a European context and relates to European species, habitats and value systems. While it can be assumed that species groups will broadly react to OWF impacts in similar ways, any species that is particular to the US might respond differently, for example, either be more tolerant or sensitive to a received stressor, or may be influenced by different environmental factors which may nuance behavior contrary to that observed in these European case studies.

1.4 Study Context

1.4.1 Comparison Between National Environmental Policy Act and European Union Environmental Impact Assessment Directive

NEPA requires Federal officials to make decisions concerning development proposals based on an understanding of environmental consequences and to take actions that protect, restore, and enhance the environment while also considering alternatives that would otherwise minimize environmental harm. CEQ Regulations (40 CFR Parts §1500-1508) implementing NEPA state that this should be done at the earliest moment to avoid delays and to identify and resolve potential constraints. The regulations include procedures to be used by Federal Agencies for the environmental review process.

Similarly, in Europe, the EIA Directive exists to ensure that development proposals deemed likely to have significant effects on the environment are made subject to an EA, prior to their approval or authorization. The original Directive of 1985 (85/337/EEC) and its three amendments have been codified by Directive 2011/92/EU, which was amended in 2014 by Directive 2014/52/EU. Consultation with the public is a key feature of the EIA procedure. The Directive aims to provide a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation of projects with a view to reducing their environmental impact. It ensures public participation in decision-making and thereby strengthens the quality of decisions.

The NEPA and European EIA processes have a number of broad similarities both in their ultimate objectives and also the steps in the processes. The environmental assessments under NEPA and the EIA Directive are included in EISs or Environmental Statements (ESs), respectively. Both processes require an initial scoping phase whereby public and stakeholder input is sought in order to help determine the appropriate contents of the environmental statement, typically in relation to environmental and socio-economic issues. Scenarios are developed based on the known and anticipated project parameters, which allows for potential impacts to be highlighted and assessed. EISs under NEPA and ESs under the EIA Directive share similar formats, in that the document typically sets out the purpose and need for the development, consideration of alternatives, the existing ‘affected’ or ‘baseline’ environment, expected impacts and consultation. The impact analyses/assessment under both NEPA and the EIA Directive look to estimate the nature, magnitude, severity, and duration of impacts that have the potential to occur and to compare the impacts of the development proposal and alternatives. This allows for impacts to be mitigated, where required. Again, further similarities exist in that cumulative and transboundary impacts should be considered. Both the NEPA and EIA process also require consideration to be given to climate change and potential implications of the project on this.

Some significant differences between NEPA and EIA exist in terms of the institutions that are responsible during the various phases of the processes. BOEM prepares the NEPA analyses for Outer Continental Shelf (OCS) renewable energy proposals with support from other agencies. To summarize the EIA procedure, the developer may request the competent authority to advise what should be covered by the EIA information to be provided by the developer (scoping stage). Rather than the relevant agency, it is the developer that provides the necessary information on the environmental impact (EIA report); the environmental authorities and the public (and affected Member States) must be informed and consulted. Finally, the competent authority decides whether the development should receive consent, after taking into consideration the consultation outcomes. The decision is presented to the public and they can challenge the decision in court.

1.4.2 Status of Offshore Wind Farm Development and Environmental Monitoring in Europe

At the time of writing, Europe currently has 11,027 megawatts (MW) of installed offshore wind capacity. Countries with the most significant OWF installed capacities include UK (5,060.5 MW), Germany (3,294.6 MW), Denmark (1,271.3 MW), Belgium (712.2 MW), the Netherlands (426.5 MW) and Sweden (201.7 MW). Figure 1.1 illustrates the cumulative and annual offshore wind installation in Europe to date.

In the UK, monitoring typically takes place for 3 to 5 years post-construction depending on the presence of any specific site or project conditions which might demand further extensions to the monitoring campaign being determined on a case by case basis, as determined by the relevant authority. While other pieces of supporting legislation provide further regulatory drivers for post-consent monitoring, it is the EIA Directive and the associated Marine Works and Electricity Works EIA Regulations which are the principal drivers in the UK.

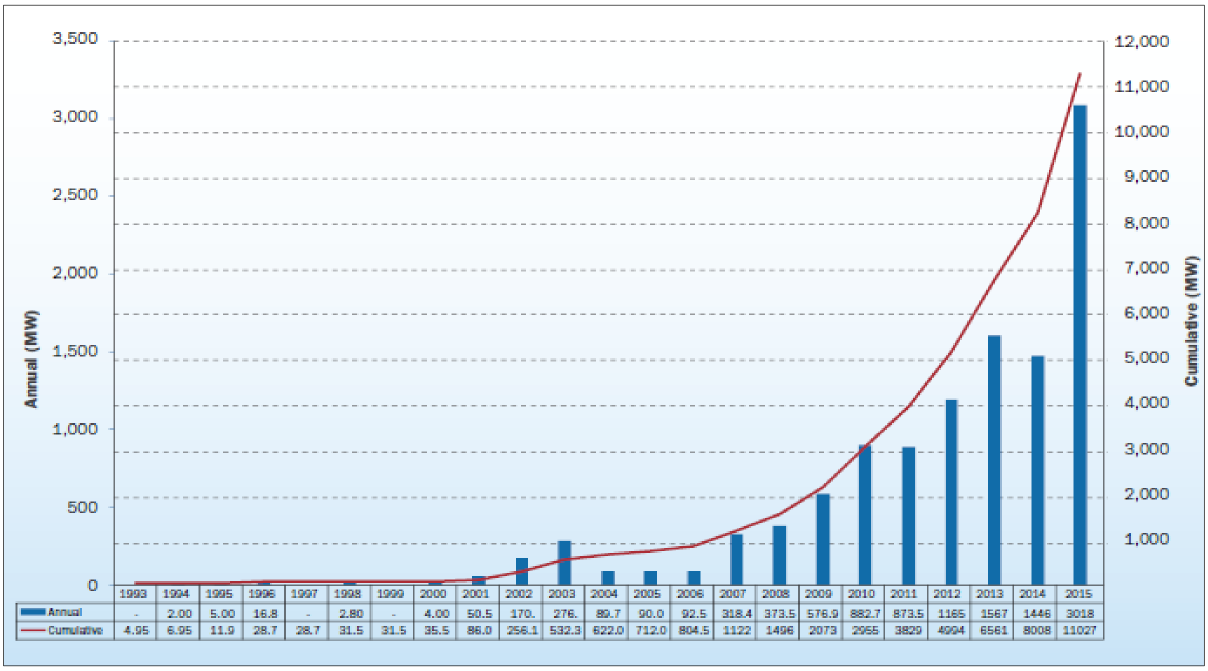


Figure 1.1: Cumulative and annual offshore wind installations in Europe

(Source: EWEA, 2016)

The drivers for monitoring differ slightly between countries, although the ultimate objective remains the same, i.e. to gain an understanding of the environmental interactions and impacts of OWFs based upon empirical evidence. Once a development has received authorization, certain environmental monitoring conditions can be translated into the permit authorization. These are required to be undertaken at appropriate intervals and for a pre-determined duration during all or parts the project life-cycle, and reported subsequently to regulators. These monitoring efforts are predominantly driven to ensure compliance with mitigation measures assigned to address potentially significant impacts, to identify any unforeseen impacts and to validate predictions made in the environmental assessments. Therefore, monitoring will often consider 'uncertainty' (the level of error or assumptions that were involved in the determination of an impact); and 'significance' (the level to which the impact is considered be significant). In respect of uncertainty, the less certainty there is surrounding an impact, the greater the requirement to monitor. In respect of significance, monitoring against developed hypotheses is used to validate the individual conclusions from the EIA. The resulting monitoring data should help inform future EIAs for similar developments, and the knowledge gained should be pooled together in a collective manner with knowledge gained elsewhere, in order to allow future EIAs to build on the real-world outcomes of previous projects. The following outline some of the various national approaches to monitoring implementation.

1.4.2.1 United Kingdom

A significant amount of post-consent monitoring work has been undertaken by OWF developers in the UK in order to discharge licence conditions. To date, it has been the developer's responsibility to acquire, analyze and report the necessary environmental data to satisfy EIA and licensing requirements and ensure compliance with license monitoring obligations before, during and after construction. A more strategic and collaborative approach is currently being attempted in the UK to address cumulative effects of multiple OWFs and to provide better insight on the ecology of highly mobile receptors to help contextualize and further improve impact assessment. The Collaborative Offshore Wind Research into the Environment (COWRIE) initiative has resulted in a comprehensive body of peer reviewed studies on the impacts of OWF as well as guidance documents and best practice (see https://www.thecrownestate.co.uk/energy-minerals-and-infrastructure/downloads/cowrie/).

1.4.2.2 Belgium

Belgium requires by law that an environmental permit for an OWF will impose a monitoring program. The Management Unit of the North Sea Mathematical Models (MUMM) (an agency of the Royal Belgian Institute of Natural Sciences (RBINS)) coordinates and manages the research and monitoring of OWF impacts. This institution has two main monitoring objectives; the first objective is concerned with observing impacts rather than understanding why an impact has occurred; this may lead to activities being stopped if the impact is deemed unacceptable. The second objective focuses on targeted monitoring which is intended to facilitate an understanding of the processes associated with the impacts that have cause-effect hypotheses. This helps develop mitigation, increase potential for better impact prediction in the future, and allows for empirical site specific data to translate into wider generic knowledge for the industry.

1.4.2.3 Denmark

Denmark has a wealth of environmental monitoring experience, having conducted two phases of a major environmental monitoring in relation to the environmental impacts of offshore wind. The first phase was conducted between 2000 and 2006 and focused on the Nysted and Horns Rev 1 OWFs as the selected environmental demonstration projects, with the second, follow-up phase running from 2007 until 2012. The demonstration projects aimed to investigate and clarify the relevant environmental issues to inform future planning. The project was funded with public money, financed by electricity consumers as part of their electricity bill, with some funds set aside for research and development projects. The initial program was commissioned by the Danish government, while the program was run by the Danish Nature Agency, Danish Energy Agency, and the operators Elsam and Energi E2. The latter program was undertaken on behalf of the Danish Energy Agency by a group which comprised of the Danish Nature Agency, the Danish Energy Agency and the operators of the Nysted and Horns Rev 1 OWFs (i.e. DONG Energy and Vattenfall, respectively).

1.4.2.4 Germany

The first German OWF, Alpha Ventus, has been the subject of an extensive research program known as RAVE (Research at Alpha Ventus). The program comprised numerous research projects, including ecological studies. The ecological research was designed to aid development of novel methods, facilitate testing of noise mitigation and to appraise the framework for regulation in respect of EIAs. A framework known at StUK (Investigation of the impacts of offshore wind turbines on the marine environment) was undertaken by the permitting authority Bundesamt für Seeschifffahrt und Hydrographie (BSH) (German Federal Maritime and Hydrographic Agency), and determines the minimum thematic and technical requirements for environmental surveys and monitoring, during various phases of a project including construction and operation for the purposes of verifying the assumptions made in the EIA. StUK also provides the standard for EIA. Alongside the RAVE initiatives, three research platforms have been established in the North and Baltic Seas (FINO). The aim of these platforms is to collect information on the potential interactions between wind turbines and seabirds, marine mammals and benthos. Results are intended to address uncertainties regarding the design of installations and filling information gaps regarding the biotopes and the changes to them during the construction of OWFs. Currently, BSH operates a highly precautious approach to offshore wind permitting and generally only approves pilot scale OWFs, of 80 turbines or less. This reflects current uncertainties surrounding impacts on navigation and the marine environment. The purpose of these smaller wind farms is to gather detailed information on environmental impacts.

1.4.2.5 Netherlands

In the Netherlands, the most significant monitoring efforts have been concentrated on the Egmond aan Zee OWF. An extensive program of monitoring has investigated the ecological, social, technical and economic impacts of the wind farm. Monitoring between 2002 and 2010 has encompassed the baseline monitoring (referred to as T-0) and post-construction (referred to as T-1).

1.4.2.6 Sweden

Sweden has an environmental monitoring program known as ‘Vindval’. Vindval is a knowledge program which is being developed through collaboration between the Swedish Energy Agency and the Swedish Environmental Protection Agency (EPA). The Energy Agency finance the project, while the EPA run the program. The program intends to gain and disseminate scientific knowledge regarding the environmental impacts of OWFs. The monitoring research helps provide a basis for EIA, planning and permitting. The program comprises 30 individual research projects (around half of which relate to OWFs) and four synthesis projects which collate and synthesize the findings of the research.

Appendix A presents the results of data collation and review which was undertake during an earlier phase of this work study and discusses principle sources of offshore wind impact research in Europe.

1.5 Environmental Impacts of Offshore Wind Farms

The environmental consequences of the construction and operation of OWFs are becoming increasingly well understood through monitoring and specific academic research. Appendix A presents a selection of specific studies on the environmental impacts of offshore wind facilities. Figure 1.2 presents a conceptual diagram of some of the key environmental impacts of OWFs.

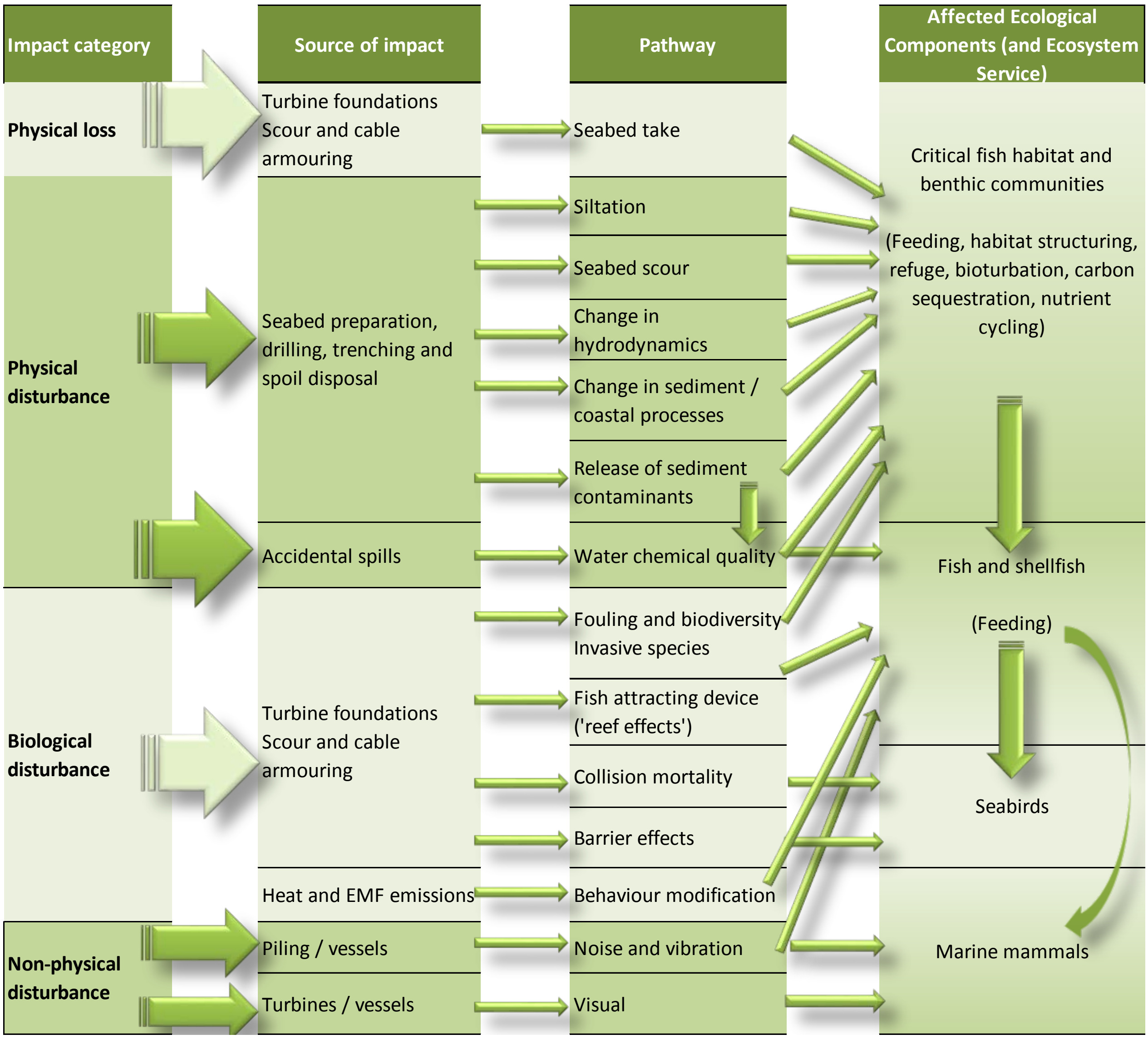


Figure 1.2: Conceptual diagram of offshore wind farm environmental impacts

The presence of turbines and foundations in the water column and on/into the seabed can alter hydrodynamic and sediment processes, modify benthic and fish habitat conditions and encourage the development and growth of epibenthic communities, including marine invasive species, which are different to those inhabiting surrounding soft sediments. Larger mobile species may also be attracted to the placed seabed structures for feeding or refuge which may alter the distributions of mobile epibenthic assemblages compared to the pre-construction situations. Underwater piling during the construction can introduce significant adverse noise into the marine environment which may harm, or disturb, marine mammals and fish, alter their behavior and disrupt life cycle stages such as spawning and migration. Other potential construction impacts relate to the raising and settlement of sediment plumes as a result of dredging, drilling and cable trenching activities and which could increase scour and smothering effects on seabed habitats and communities. Benthos is entirely lost under the footprint of offshore turbines, scour area and any installed protection material. Seabirds may also be affected during construction through noise and visual disturbances resulting in displacement from feeding or breeding areas while operational wind farms could present considerable barriers to bird movements leading to increased collision risk.

1.6 Conservation Benefits

Notwithstanding the substantial carbon offsets and reduced emissions that offshore wind facilities provide, many EIAs and commentators point to the potential additional nature conservation benefits that can be offered by OWF. This section briefly reviews the typical discussion points raised in relation to the presence of offshore wind turbines and the potential conservation benefits that can be achieved.

For navigational safety and to prevent damage to cable infrastructure, trawling is generally not permitted or undertaken within OWF (Hammar et al., 2016). In some ways, this exclusion creates a *de facto* marine reserve (Bailey et al., 2014).

Wilhelmsson (2013) notes that trawling is one of the most severe threats to the marine environment, particularly for fish and benthic invertebrate assemblages, and acknowledges that, if well planned and coordinated, OWF can be beneficial to marine planning and conservation. He states "*areas of several square kilometers may therefore, in some important respects, resemble Marine Protected Areas… Primary data from [OWF] are still scarce, but results to date … in Denmark, the Netherlands, and Sweden basically indicate either increased abundance of some fish species (e.g., sand eels, cod, whiting, sole) or no effect compared to conditions before construction of the wind farm. Effects are likely to be most prominent for species that had been heavily exploited in the area prior to the wind or wave farm establishment. It is believed that a relatively large area of exclusion is required to enhance biodiversity and generate spill-over effects*."

However, Wilhelmsson also notes that artificial reef (AR) effects associated with OWF are not necessarily positive for conservation. Recent studies in Sweden, the Netherlands, Belgium, and Denmark indicate that densities of a number of fish and decapod species do increase with proximity to OWF structures. Where ARs only aggregate fish from surrounding areas and do not contribute to added production, it is possible that an 'ecological trap' might be created; i.e. an area where predators (e.g. birds or mammals) can hunt more efficiently, with negative consequences for prey populations. Wilhelmsson also notes that densities of some benthic prey items have been shown to decrease with proximity to ARs due to predation by fish residing on the structures (Wilhelmsson, 2013).

The prohibition of bottom trawling is particularly relevant in places where it occurs prior to the development of the OWF, as this activity is known as a major threat to marine biodiversity and benthic habitats (Turner et al., 1999). When trawling for benthic fish and crustaceans occurs on soft bottom seabed substrates, the trawl boards cut through sediments like a plough and the net scrapes off macrobenthos and any biogenic structure as it swipes over the seabed. When trawling for scallops and other shells, the beam of the trawl or dredge digs deep into the seabed. Hammar et al. (2016) notes that "*the loss of benthic animals, particularly filter-feeders, is massive in all areas exposed to bottom trawling. For example, in the North Sea alone thousands of square kilometers of oyster beds have been lost to bottom trawls and scallop dredging. In the Kattegat Sea, previously abundant reefs built by the filter-feeding crustaceans Haploops spp. have become virtually extinct due to bottom trawling. In areas of intense bottom trawling the seabed can be disturbed several times per year … In areas where bottom trawling ceases the benthic fauna recover with time, ranging from months to decades. The installation of a wind farm in waters previously exposed to bottom trawling would imply at least 20 - 30 years of protection and could be an important means of conservation*".

It is also worth considering that trawlers prohibited from OWF might then move into other areas to cause impacts elsewhere. The impacts need to be carefully analyzed.

Hammar et al. (2016) concludes that wind farms and marine conservation interests are compatible, or even synergistic, depending on their location. Indirect impacts of reduced fishing inside the wind farm can be highly valuable from a conservation point of view. Benthic habitats and benthos, hard substrate benthos, some mammals and many species of fish are positively affected, he notes. Wind farms located in favor of marine connectivity or in areas of importance for ecological functions such as reproduction, can thus be a powerful means of conservation (Hammar et al., 2016).

Wilhelmsson (2013) describes a range of design and location factors that may influence the fish community structure on artificial reefs, such as height, size, inclination, protuberance, surface structure, void space and number of interior hollows, shade effects, distance between modules, isolation, and composition of the surrounding seabed. Design of OWF may be optimized through low-cost manipulations of the structural complexity of foundations to enhance the production of associated fish and crustaceans where desired.

While it is generally accepted that cessation of bottom trawling is positive for the marine ecosystem, Rumohr and Kujawski (2000) pointed out that large amounts of discards and moribund benthos generated by trawling stimulate production of scavenging and predatory species of crustaceans, gastropods, and sea stars. Similarly, Groenewold and Fonds (2000) estimated that a single beam trawl makes 6% to 13% of the annual secondary production of macrozoobenthos per unit area suddenly available to scavengers and to the detritus food chain. However, this is not necessarily a good outcome.

Wilhelmsson (2010) points out that there is an opportunity for habitat enhancement that could compensate for loss of biologically important areas elsewhere, in line with indications in the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC). While this may be technically correct, it implies a notion of biodiversity credits that should perhaps be treated with caution. Wilhelmsson (2010) notes that the significance of such habitat enhancement will depend on the location and scale; for most species, he suggests, it will probably be negligible at regional scales. Exceptions may occur when heavily fished, habitat limited and/or vulnerable species are protected from exploitation.

2. METHODOLOGY AND RATIONALE

2.1 Data Collection

OWF environmental monitoring information has been collated from the sites listed in the Table 2.1 and illustrated in Figure 2.1. Appendix A describes the information sources used.

Table 2.1: European Offshore Wind Farm Environmental Monitoring Studies Considered in this Study

Wind Farm	Country	Start Date	Capacity [MW]	No. of Turbines	Foundation Type	Depth [m]	Dist. Shore [km]
Thorntonbank 1	Belgium	2008	30	6	Gravity base	18 - 27.5	28
Belwind	Belgium	2009	165	55	Monopile	15 - 24	45
Alpha Ventus	Germany	2009	60	12	Tripod and jacket	27	56
BARD Offshore 1	Germany	2010	400	80	Tripile	40	101
Dan Tysk	Germany	2014	288	80	Monopile	21 - 31	70
Global Tech 1	Germany	2015	400	80	Tripod	38 - 41	115
Meerwind Süd/Ost	Germany	2014	288	80	Monopile	24 - 27	53
Nordsee Ost	Germany	2014	295	48	Jacket	22 - 25	57
Riffgat	Germany	2014	108	30	Monopile	18 - 23	42
Horns Rev 1	Denmark	2002	160	80	Monopile	6 - 14	18
Horns Rev 2	Denmark	2009	209	91	Monopile	9 - 17	32
Rødsand/Nysted II	Denmark	2010	207	90	Gravity base	6 - 12	9
Nysted	Denmark	2002	165.6	72	Gravity base	6 - 10	11
Vindeby	Denmark	1991	5	11	Gravity base	2 - 4	2
Middelgrunden	Denmark	2000	2	20	Gravity base	3 - 6	5
Prinses Amalia	Netherlands	2006	120	60	Monopile	19-24	45
Egmond aan Zee	Netherlands	2006	108	36	Monopile	16 - 21	14
Bockstigen Valar	Sweden	1998	3	5	Monopile (drilled)	5 – 6	6
Nogersund-Svante 1	Sweden	1990	0.22	1	Tripod	3-6	1
Utgrunden I	Sweden	2000	10.5	7	Monopile	6 - 15	7
Lillgrund	Sweden	2006	110.4	48	Gravity base	4 - 8	9
Barrow	United Kingdom	2005	90	30	Monopile	15 - 20	13
Burbo Bank	United Kingdom	2006	90	25	Monopile	0.5 - 8	8
Dudgeon	United Kingdom	2017	402	67	Monopile	12 - 24	35
Greater Gabbard	United Kingdom	2009	504	140	Monopile	20 - 32	33
Gunfleet Sands 1 & 2	United Kingdom	2008	172.8	48	Monopile	2 – 15	7
Gunfleet Sands 3 (Demo)	United Kingdom	2013	12	2	Monopile	5 – 12	8
Gwynt y Môr	United Kingdom	2012	576	160	Monopile	12 - 28	17
Humber Gateway	United Kingdom	2015	219	73	Monopiles	10 - 18	10
Inner Dowsing	United Kingdom	2007	97.2	27	Monopile	6 – 14	6
Kentish Flats	United Kingdom	2004	90	30	Monopile	5	10
Lincs	United Kingdom	2011	270	75	Monopile	10 - 15	9.4
London Array	United Kingdom	2011	630	175	Monopile	0 - 25	28
Lynn	United Kingdom	2007	97.2	27	Monopile	6 - 18	7
North Hoyle	United Kingdom	2003	60	30	Monopile	7 - 11	9
Ormonde	United Kingdom	2010	150	30	Jacket (Piled)	17 - 22	12
Rhyl Flats	United Kingdom	2008	90	25	Monopile	6.5 - 12	11

Wind Farm	Country	Start Date	Capacity [MW]	No. of Turbines	Foundation Type	Depth [m]	Dist. Shore [km]
Robin Rigg	United Kingdom	2007	174	58	Monopile	4.5 - 13	11
Scroby Sands	United Kingdom	2003	60	30	Monopile	0 - 15	3
Sheringham Shoal	United Kingdom	2009	316.8	88	Monopile	15 - 22	21
Teesside	United Kingdom	2012	62.1	27	Monopile	7 - 15	2
Thanet	United Kingdom	2009	300	100	Monopile	20 - 25	18
Walney	United Kingdom	2010	183.6	51	Monopile	19 - 28	19
West of Duddon Sands	United Kingdom	2013	389	108	Monopile	18-23	20
Westermost Rough	United Kingdom	2014	210	35	Monopile	10 - 25	12
Block Island*	United States	2016	30	5	Jacket	23 - 28	5
Note: * - not shown on Figure 2.1							

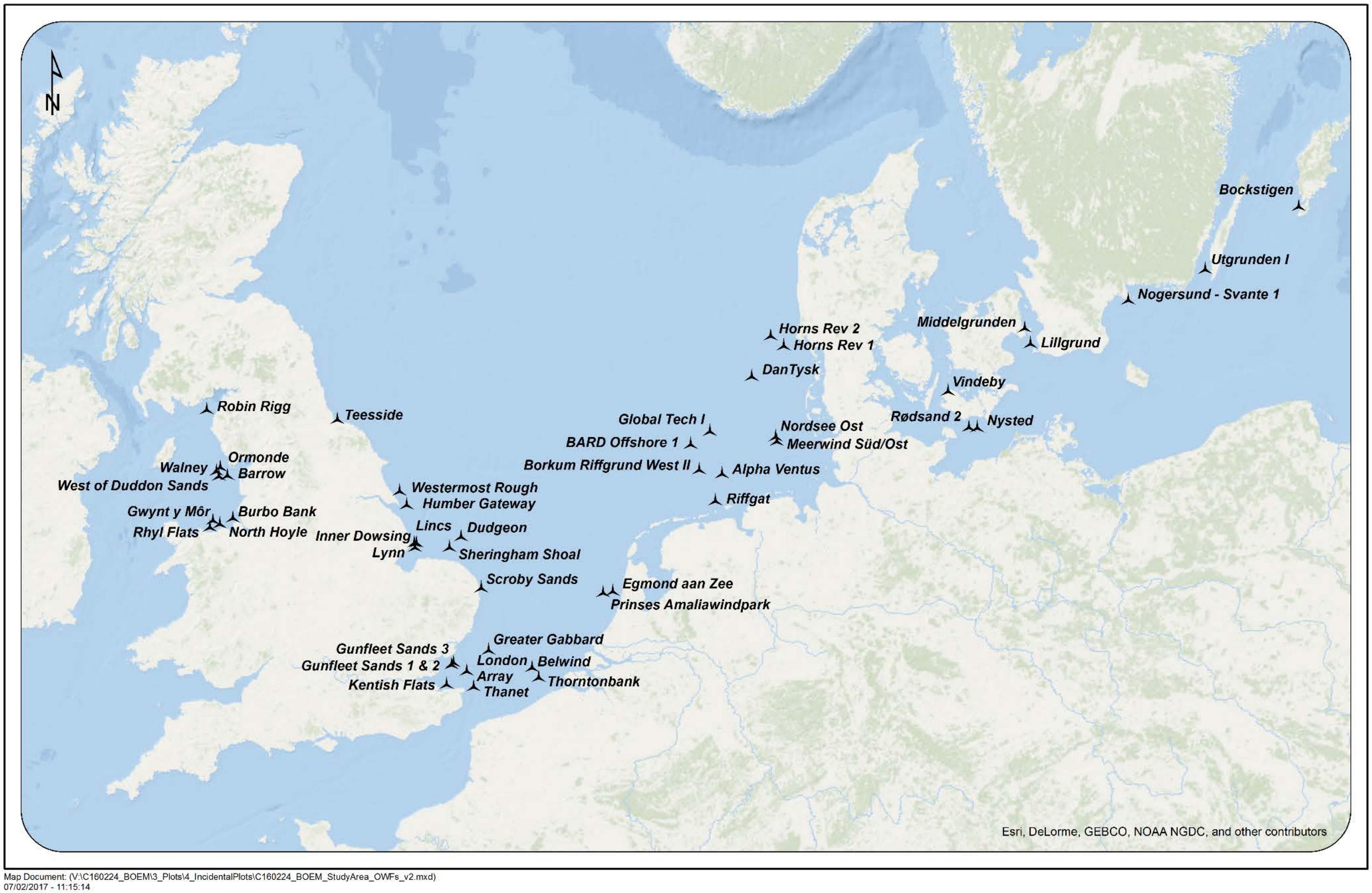


Figure 2.1: Location map of European offshore wind farms considered in the study

2.2 Report Structure

Information drawn from the review of OWF monitoring reports has been organized into the following technical chapters corresponding with key marine environmental topics normally addressed during impact assessments for OWF developments:

- Physical processes (Chapter 3);
- Underwater noise (Chapter 4);
- Benthic ecology (Chapter 5);
- Fish and shellfish ecology (Chapter 6);
- Birds (Chapter 7); and
- Marine mammals (Chapter 8).

Other NEPA topics such as view-sheds, commercial fisheries, marine archaeology, other users and terrestrial ecology are outside of the scope of this current study. Only marine ecological aspects of the topics above are covered here.

For each technical topic chapter, the relevant stakeholder concerns and perceived impacts are briefly described. These concerns and perceptions are normally identified and documented during EIA consultations and are used to frame the detail and scope of the necessary environmental analyses, supporting field investigations and, where necessary, the mitigation measures and monitoring campaigns. As such, it is relevant to consider stakeholder concerns here as drivers for environmental monitoring.

The focus of the review is on identifying and describing consistent impacts for which there is growing consensus and confidence in terms of predicted environmental outcomes. It may be possible that individual OWF have additional site specific environmental issues over and above those described here and thus could require further separate consideration and study.

The technical chapters also present a description of the impacts relevant to the topic in question highlighting the source – receptor – pathways and typical mitigation options adopted to ameliorate adverse impacts. These sections of the report are intended standalone, so that all of the pertinent information is contained with each discrete chapter without the need for the reader to cross refer to other chapters where shared impacts may occur. The possible exception to this is the chapter on underwater noise which refers to relevant ecological chapters for descriptions of impacts on specific receptors. This has resulted in a degree of repetition within the text in some instances, as some impacts will be relevant to multiple topics. In such cases, the text may be repeated but an attempt has nonetheless been made to nuance the description to the topic under consideration.

An account of the observations of each monitoring campaign at each wind farm is provided describing the temporal and spatial scales of any change attributable to OWF construction and operation. This is organized on a wind farm by wind farm basis describing what (if any) changes have been observed and whether or not the change constitutes an impact. In this way, a body of evidence of OWF impacts has been compiled for regulator and stakeholder consumption and reference during NEPA review and analysis. More detailed accounts of specific monitoring results are provided as case studies, to illustrate the general themes being discussed.

Finally, a synthesis of the monitoring data is presented to clarify the potential implications for streamlining NEPA reviews, identifying strengths and weaknesses in the available evidence base and highlighting possible options for, and applicability of transferring European experiences and learning to the US situation. Consistent impacts and proven mitigation options are highlighted and discussed in terms of the levels of confidence and certainty that currently exists regarding impact prediction and the potential levels of comfort in statutory decisions for confident decision making. In instances of high stakeholder confidence and comfort, underpinned by the available scientific evidence base, it may be possible to suggest reducing or removing some aspects from NEPA review.

2.3 Impact Significance

Throughout this document, reference is made to the significance of impacts. Four categories of impact significance are used including ‘negligible’, ‘minor’, ‘moderate’, and ‘major’. Table 2.2 presents the definitions for each of these significance categories.

The categories have been taken from BOEM (then the Minerals Management Service (MMS)) Programmatic Environmental Impact Statement (PEIS) for Alternative Energy Development and Production and Alternative Use of Facilities on the Outer Continental Shelf, Final Environmental Impact Statement (MMS, 2007) and were originally developed to provide consistency in its discussion of impacts. BOEM continues to refine theses definitions as part of its NEPA decision making process to indicate relative impact levels on biological and physical resources. For biota, these levels are based on population-level impacts rather than impacts on individuals.

Table 2.2. Impact Levels for Biological and Physical Resources (source: MMS, 2007)

Impact Significance Level	Criteria
Negligible	No measurable impacts.
Minor	Most impacts on the affected resource could be avoided with proper mitigation. If impacts occur, the affected resource would recover completely without any mitigation once the impacting agent is eliminated.
Moderate	Impacts on the affected resource are unavoidable. The viability of the affected resource is not threatened although some impacts may be irreversible, or the affected resource would recover completely if proper mitigation is applied during the life of the project or proper remedial action is taken once the impacting agent is eliminated.
Major	Impacts on the affected resource are unavoidable. The viability of the affected resource may be threatened, and the affected resource would not fully recover even if proper mitigation is applied during the life of the project or remedial action is taken once the impacting agent is eliminated.

3. PHYSICAL PROCESSES

3.1 Introduction

Marine habitats upon which species rely for food and refuge are, for the main part, a function of the geological and sedimentological properties of the seabed and the hydrodynamic characteristics of the overlying water. Wave climate, tidal strengths, shear bed stresses, sediment particle composition, and illumination, amongst other factors, all interact to create distinct physical habitat conditions to which marine plant and animal communities can respond in specific and predictable ways. Depending on the severity, change in any one of these physical factors could elicit change in habitat conditions with associated consequences for marine populations and communities. An understanding of the potential influences that the construction and operation of an OWF can exert on the physical processes of a site is therefore fundamental in the assessment of potential impacts on marine ecological receptors and is the subject of this chapter.

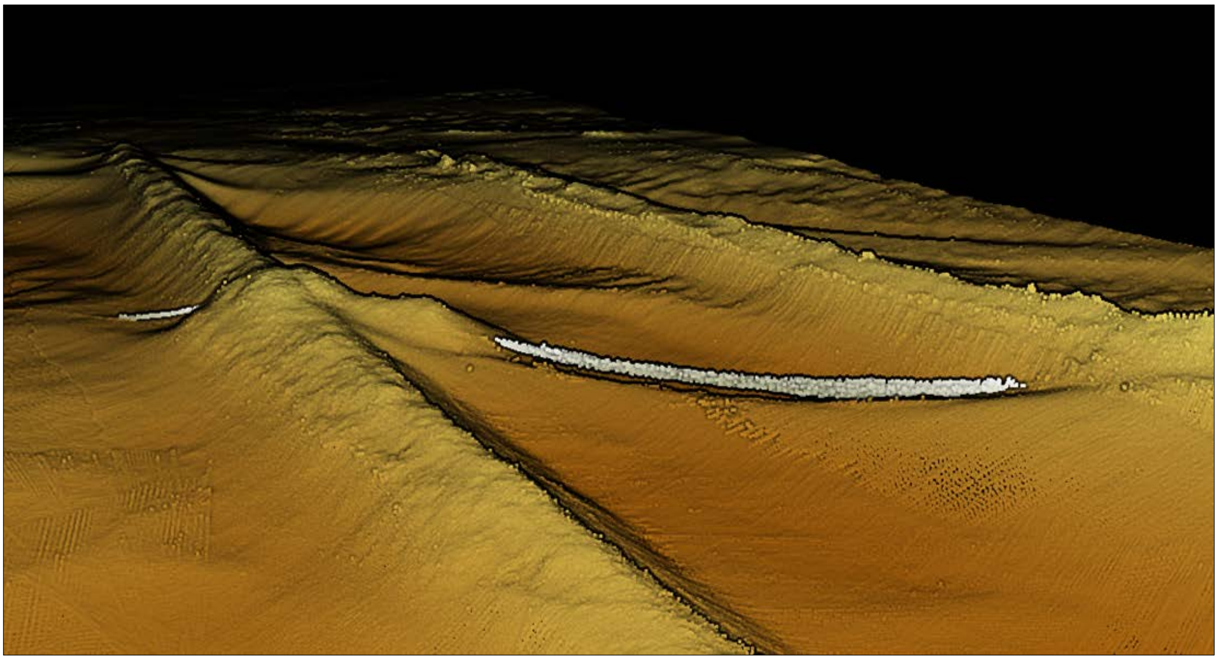


Figure 3.1: Acoustic image of an exposed electrical cable potentially in free-span at the location of a cable crossing
(source: Fugro EMU)

As well as the ecological interest, understanding the site's physical processes, is vital in assessing and optimizing the OWF engineering design. Consideration of the changes in hydrodynamic conditions due to the placement of a turbine foundation and/or cable in the water and associated changes in seabed sediment transport and erosion rates, is fundamental for the assessment of scour and the overall risk to asset integrity. Likewise, knowledge of the natural movement of bed forms within a site is vital in understanding the minimum requirements for cable burial depth and exposure risk. It is for these [engineering] reasons, rather than environmental drivers, that much of the monitoring of the impacts on physical processes has been undertaken.

This chapter describes the results of the monitoring of physical processes (principally suspended sediment concentrations (SSC) and scour) undertaken during engineering led seabed investigations of OWF.

3.2 Stakeholder Concerns

In terms of the physical environment, geological, and hydrodynamic processes are not considered sensitive receptors, *per se*. Instead they can be classified as marine processes which may potentially be altered due to OWF infrastructure (such as turbine foundations, cables, and substations) and associated construction activities such as piling and export and inter-array cable installation.

However, an understanding of potential changes in oceanographic and sedimentary processes is fundamental in predicting and assessing potential change in ecological, cultural, and socio-economic receptors; therefore, assessing the magnitude of change to baseline physical processes attributed to OWFs is standard practice. A summary of issues typically identified by stakeholders for inclusion in impact assessment is provided in Table 3.1 below.

Table 3.1: Identified Hydrodynamic and Sedimentary Effects Based on Stakeholder Consultation and Regulatory Requirements

Perceived Impact	Source	Pathway	Permanent/ Temporary Effect?	Typical Mitigation
Construction and Decommissioning Phase				
Increase in suspended sediment concentrations (SSC)	Piling, dredging trenching, drilling	Re-distribution of fines sediment via tidal current movements	Temporary, localized	Construction program
Seabed sediment deposition				
Operational Phase				
Changes to tidal and wave regimes, coastal impacts, sedimentary characteristics and SSCs	Placement of infrastructure on the seabed	Obstruction	Permanent	
Development of scour holes around foundations		Acceleration of water movements around structures	Permanent	Scour protection
Potential for cable exposure and free span (including coastal landfall)	Cable burial	Mobile sediments and scour	Temporary - permanent	Re-burial and rock placement

3.3 General Monitoring Rationale

Monitoring has generally been undertaken to understand SSC and sediment plume settlement from construction activities and the development of seabed scour and wake effects and coastal morphological change during the operation of wind farms.

Monitoring of scour has been undertaken primarily as an engineering issue to ensure the integrity of installed turbines and cables remain intact and to assess the need for scour protection.

With regards to ecological receptors, scour is typically assessed as a highly localized impact causing local sediment instability with possible scour pits forming, during strong tidal conditions with periods of partial infilling during reduced tidal movements. Settlement of larvae and colonization by benthos may be comparatively reduced in areas subject to scour, depending upon the severity of the disturbance.

SSC monitoring has been undertaken to validate mathematical models but also in some cases to determine levels in the vicinity of sensitive receptors, in particular fish and shellfish including oysters, crabs and lobsters and herring spawning grounds. In general, SSC monitoring is not a requirement of current marine licenses and is frequently assessed as a temporary and localized impact of minor or negligible significance.

Similarly, there are no present license requirements for the monitoring of wake effects. Monitoring coastal locations is generally limited to instances where there may be concern relating to a protected habitat, to determine the presence of increased erosion or to address a specific engineering concern (i.e. cable burial).

3.4 Typical Mitigation Measures

Measures to mitigate OWF impacts on physical processes primarily relate to engineering and asset integrity concerns. Interventions may include the introduction of scour protection material at the base of turbine foundations and the placement of cable protection measures to prevent excessive under-mining, exposure and damage to critical infrastructure. Other measures may include appropriate tool selection for the installation of export and inter-array cables to alleviate potential suspended sediment impacts while still achieving adequate burial. Such measures may themselves have consequences on local ecological receptors and which have been reviewed in the following chapters.

The nature of the mitigation is typically informed by predictive numerical modelling of the physical environmental parameters in question and is assessed in the ES as part of the overall project design. The efficiency of the mitigating measures, post deployment, is regularly assessed through scour and cable monitoring surveys, usually via acoustic techniques.

3.5 Description of Impacts

The main impacts on physical processes include baseline changes to the local hydrodynamics (waves, tides, and currents) and changes to sedimentary processes (suspended sediments, scour, erosion, and deposition). Local coastal morphology and processes may also be affected.

Changes to hydrodynamic and sedimentary processes may potentially impact sensitive receptors, including fisheries, benthic organisms, and coastal processes. The majority of changes to physical processes attributed to construction or operational phases of offshore wind are most often either localized or temporary.

The temporal scale of changes to hydrodynamic and sedimentary processes is very much dependent on the phase of OWF development. Temporary changes are mostly associated with construction and decommissioning activities (e.g. increased SSC compared to ambient levels during cable burial) in contrast to permanent changes throughout the operational phases (e.g. wake effects behind turbine foundations).

Spatial changes to physical processes are always localized, either directly in the vicinity of the seabed infrastructure (e.g. scour around foundations) or taking place within the boundaries of the OWF (e.g. suspended plumes which may extend a few hundred meters from each turbine).

Cumulative effects from multiple turbines (or even adjacent wind farms) are not an issue since the wide spacing of individual turbines (at least 500 m in most cases) and the localized and/or temporary changes to hydrodynamic and sedimentary processes do not result in any overlapping effects.

UK based license specific ESs and associated impact predictions are mostly in agreement with regard to the spatial and temporal predictions and negligible to minor significance levels of impacts. A range of monitoring methods (including numerical model outputs) during construction and post-construction phases shows that changes to sedimentary and hydrodynamic processes were either temporary or localized, with no far field effects (extending beyond the boundary of the OWF or the immediate vicinity of the cable route and cable landfall location).

General observation from the monitoring include:

- Predictions of construction related suspended sediment concentrations, based on numerical models, were often significantly higher than actual monitoring results;
- Subsea power cables, including export and inter-array cables, in some instances became exposed post-burial (including free span), suggesting that depth of burial estimates were not conservative enough based on knowledge of hydrodynamic and sedimentary characteristics and processes; and
- Scour predictions around foundations presented in ESs were sometimes inconsistent with actual observations. The mathematical models used to predict scour were often different for each wind farm, resulting in a variety of scour depth and lateral extent predictions, including over- and under-estimates. For instance, some models did not consider unconsolidated sediment thickness when assessing scour rates; instead a straightforward depth and lateral spatial extent was directly based on turbine foundation width, without considering, for example, limited scour potential in areas of consolidated glacial tills with minimal capacity for scour.

3.6 Observed Environmental Effects from Monitoring and Research

3.6.1 Increased Suspended Sediment Concentrations

Surveys were completed at the Ormonde OWF to monitor suspended sediment concentrations (SSCs) arising from the piling of quadropod jacket foundations over a single tide (RPS, 2012a). An optical backscatter sensor and OSIL Minibat towed system were deployed along a series of transects aligned perpendicular to the anticipated direction of the plume dispersion to record conditions at ¾ water depth (equating to 4 m to 5 m above seabed). Transects were completed both up and down tide of the piling operation and to a distance downstream of the piling where SSCs became comparable with background levels. Sediment conditions within the wind farm array were described during benthic ecology surveys as predominately muddy sand (CMACS, 2015).

The first survey at Ormonde OWF was conducted over a neap tide and did not detect any evidence of a sediment plume. On this occasion the survey vessel was positioned 500 m from the piling due to the imposition of an exclusion zone around the piling vessel. Also, it was noted that the survey commenced towards the end of the piling activity on this occasion and that only one pile was installed during the period of the field measurements. The apparent absence of any evidence of a sediment plume was attributed to the comparatively weaker tide which was insufficient to transport the plume to the location of the sensor during the time of the survey.

A second survey was therefore undertaken at a closer distance of 300 m from the piling and during a period of stronger tidal conditions. Three piling events were completed during the period of the field measurements. Again, this did not detect any evidence of a sediment plume arising from the piling activity although a small and short lived (approximately 13 minutes) plume of turbid water was noted from subsequent pile cleaning. In conclusion, piling at Ormonde OWF did not result in detectable sediment plumes beyond 300 m of the activity.

SSC levels were recorded during the drilling and piling of monopile foundations at the North Hoyle OWF (nPower Renewables, 2005). Turbidity was measured at three separate locations using Hydrolab DataSonde 4a optical turbidity sensors deployed in bottom frames to enable detection of both near (i.e. 3 km to 4 km) and far-field (i.e. > 5 km) SSCs. Reading of SSCs were taken from water sampled at 1 m above the surface of the seabed once every 5 minutes over a total deployment period of 38 days. SSCs arising from the installation of 4 monopiles via drill/piling was monitored during this time. Sediment conditions within the boundaries of the wind farm were described during baseline benthic ecology surveys and included mixed coarse sand and gravel substrates (National Wind Power Offshore Limited, 2003).

No detectable increase in SSC attributable to monopile installation was recorded during the North Hoyle SSC studies. It was considered that natural tidal influences and weather conditions had a greater effect on SSC than the construction activities. The actual SSC measured during construction at the different monitoring stations was equal to, or slightly less, than that predicted from numerical simulation in the ES. It is noted that only 50% of the material predicted to be available for dispersal in the ES was actually potentially available as a result of the construction and that this may be a contributory factor in the apparent disparity between predicted and observed SSCs at North Hoyle OWF.

Following statutory advice, it was decided that bottom mounted optical sensors would not be required to undertake licence compliance SSC monitoring during the installation of foundations and cables at the Barrow OWF (BOWind, 2005). Instead, it was agreed to tow the sensors through the predicted sediment plumes. The following case study describes the SSC monitoring undertaken at Barrow OWF.

Case Study 1: Monitoring suspended sediment concentrations from foundation drilling and cable installation
Barrow Offshore Wind Farm

Background

Barrow OWF comprises 30 monopile turbines located in the east Irish Sea, UK. Construction of the wind farm commenced in March 2005 and was completed in July 2006.

In compliance with conditions of the license for the construction and operation of the wind farm, a program of suspended sediment monitoring during the construction was required. Monitoring was conducted during both the drilling of the monopile foundations and during the jetting of a section of the export cable. This Case Study reviews the field reports and the summary Environmental Monitoring report that were prepared in compliance with licence requirements to measure suspended sediment levels during drilling operations as part of the installation of turbine foundations and during the jetting of cable installation (Osiris Projects, 2005; 2006 & BOWind, 2006).

Methods

Optical backscatter and water sampling surveys were conducted during drilling operations as part of the installation of a monopile foundation at the Barrow OWF. The objective of the monitoring was to record any sediment plume arising from the drilling and installation of monopile locations. The main purpose of the study was to validate and confirm predictions made in the ES of '*slight*' increases in SSC only and to ensure that expected maximum SSC thresholds were not exceeded. Seabed composition was described as mainly medium grained sand and shells with some gravel. Tides of up to one knot were observed on site during the monitoring of both the drilling and jetting operations.

A series of vessel survey transects were conducted, over a single tide, during the drilling operations to record turbidity via optical backscatter sensor and via water sampling for suspended solids, across the area of the anticipated sediment plume. The vessel traversed the treatment area down-tide of the drilling operation following transects set perpendicular to the direction of the assumed direction of plume dispersion gradually moving further away from the monopile location with each transect completed. Figure 3.2 illustrates the transect survey sample design.

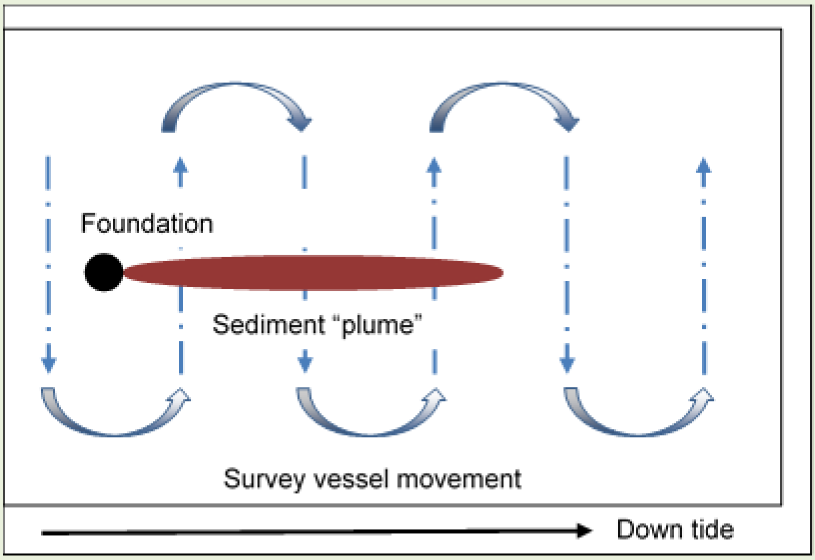


Figure 3.2: Planimetric representation of the turbidity monitoring transect survey at Barrow Offshore Wind Farm
(source: BOWind, 2006)

Background observations were also taken up-tide of the operation in order to monitor the naturally occurring suspended sediment levels. The majority of the water samples and readings were taken at a point approximately 25% of the water depth above the seabed (4 m to 5 m) (BOWind, 2006). Observations were made from with 100 m of the operations to 700 m down tide.

As well as the drilling operation, raised SSC from jetting of the cable trenches was also conducted at Barrow OWF. Readings were taken over one day at a section of the export cable route located approximately 17 km offshore. Three transects were conducted through the area of the anticipated plume. The sensor was suspended 2 m to 3 m above the seabed.

Note that on both monitoring occasions, the survey vessel was unable to get any closer than 100 m to the respective operations due to the presence of the construction vessel.

Results

Results for the towed turbidity sensor surveys indicated no correlation between distance down tide of the drilling and jetting operations and turbidity levels although it was noted that the vessel was unable to get close (< 100 m) to the drilling operation. The sampling and analysis of water samples showed a reduction in suspended solids with both distance down-tide of the drilling and decreasing depth through the water column although the reductions in concentrations in all instances were not significant ($p>0.05$). The apparent lack of turbidity readings down tide of the operation was attributed to the dominant medium grained sand and shell sediment present at the site which was considered to settle relatively quickly following disturbance by drilling.

Conclusion

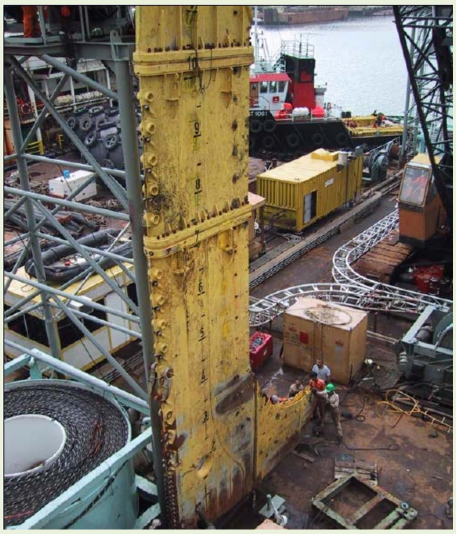
It was concluded that any raised SSC from both the drilling of the monopile foundation and the jetting of the cable trenches at Barrow OWF must be localized to the activity and remain within 1 m to 2 m of the seabed. Differences between up tide and down tide suspended solids concentrations were not significant. The authors noted that 's*eabed composition at the site is known to be mainly medium grained sand and shells with some gravel and this would support the observations that much of the agitated sediment drops out of the water column relatively quickly and very little increase is seen much above 2.0 m above bed level'* (Osiris Projects, 2006). It was concluded that construction work in the area monitored had not created unacceptable levels of suspended sediments and that all measurements were within the range of natural variation.

A vessel based monitoring strategy was also adopted at the Burbo Bank OWF to measure SSCs arising from cable installation activities and to ensure that these did not exceed agreed threshold values. The following case study reviews the methodology employed and presents the monitoring results.

Case Study 2: Monitoring Suspended Sediments from Cable Installation Operations
Burbo Bank Offshore Wind Farm

Background

Burbo Bank OWF comprises 25 x 3.6 MW turbines located approximately 6 km offshore within Liverpool Bay, UK. Construction of the OWF commenced in May 2006 with first power generation in July 2007. A licence under the Food and Environment Protection Act (FEPA) to construct and operate the site was granted to SeaScape Energy in April 2005.



Vertical injector tool
(source: CMACS, 2006)

Monitoring of SSCs during the installation of one of the three export cables and selected inter-array cables at the Burbo Bank OWF (CMACS, 2006) was undertaken to validate numerical model predictions provided in the ES and to confirm that suspended sediments remained within parameters that were agreed with regulators before construction (i.e. not more than 5 times background (control area), or 3,000 mg/l throughout the water column (measured as close as safely possible to construction activity), whichever is greater). This case study reviews the 'during-construction' field monitoring and results as reported to the licensing authority in compliance with the licence conditions (CMACS, 2006).

A total of three export cables were installed to a target depth of approximately 3 m below the seabed by vertical injector ploughing while array cables were installed to a similar depth by jetting assisted ploughing following initial pre-lay grapnel runs. The relatively deep cable target burial depth (3 m) was a requirement of the FEPA licence in recognition of the dynamic nature of the local seabed and the desire to minimize the risk of cable emergence and reduce any electromagnetic field (EMF) effects.

Vertical injector ploughing of the export cable was anticipated to cause limited sediment mobilization whereas array cable installation via jetting was thought to have a higher potential to mobilize fine sediments. In both instances the rate of the installation of the export and inter-array cables was approximately 250 m per hour with pauses at roughly half hourly intervals to re-position vessel anchors. The trenching of the 8 km export cable route under investigation took approximately one week to complete. The seabed comprised predominately mobile fine sediments.

Methods

Suspended sediment monitoring was undertaken using a hand held suspended sediment probe deployed from a small vessel. Measurements were collected along transects aligned both perpendicular to and parallel with the direction of tidal flow (see Figure 3.3) and throughout the water column. Regular control readings were also collected at points of 100 m up tide of the activity to ensure adequate characterization the natural variability during the field survey. Calibration of the probe was achieved using local sediments.

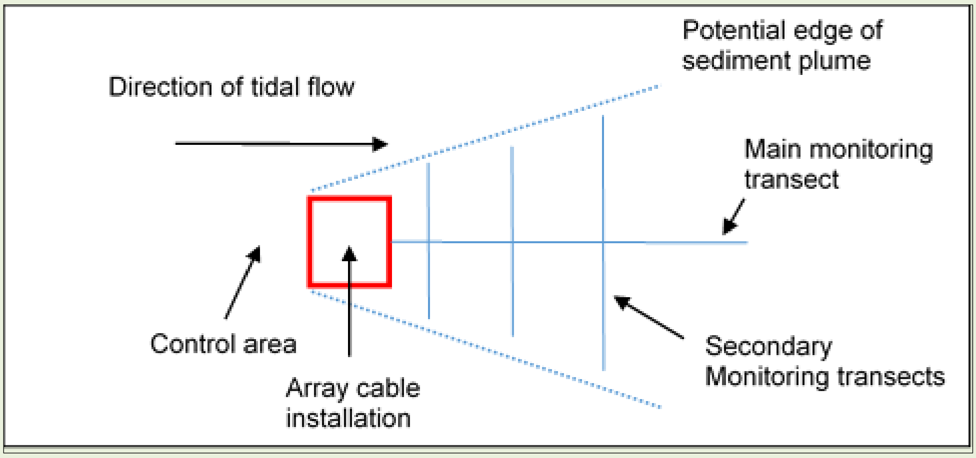


Figure 3.3: Schematic of the suspended sediment sampling survey at Burbo Bank Offshore Wind Farm

(source: CMACS, 2006)

Results

Initial monitoring at the commencement of the export cable installation (T+9 minutes) in nearshore waters (approximately 6 m depth) showed high levels of SSCs (207 mg/l) near the seabed, compared to controls (up to 48.5 mg/l), within 30 m of the export cable installation but that SSC in surface water were only marginally increased relative to background values. Within 300 m of the activity, SSCs within surface waters were comparable to background levels but were still around twice as high as control data near the seabed. Seabed SSCs remained 2 times greater than background values at a distance of 500 m from the export cable installation.

One hour after the commencement of the installation of the export cable SSCs had largely reduced to background levels at all depths (to 6 m) within 200 m distance from the activity although it was noted that the tidal flow speed was reducing down toward a slack water period at the time of these measurements.

At, or close to, slack tide SSCs within surface waters were largely within background levels at a distance of 20 m from the installation activity but remained high (up to 2.5 times higher) near the seabed. This was attributed to the influence of the thrusters of the construction vessel.

During the installation of the inter-array cables, it was noted that the water within the array site was much more colored than at the export cable but that this seemed typical of the wider area including the control locations. Background SSCs up to 338.7 mg/l at the seabed and up to 124.2 mg/l at the surface were recorded within the array. At a distance of 50 m from the installation activity, SSCs were approximately twice the background levels at both surface and seabed depths but that at greater distances (75 and 150 m distances) levels fell within the range of the control data. It was further noted that at 50 m distance, seabed SSCs remained above background for 22 minutes following the cessation of works.

Conclusions

Summarizing the field results CMACS (2006) reported that that the maximum increase in SSC over background levels at any time during either installation was up to 4.8 times and that this magnitude of increase was spatially restricted to within 50 m of the activity only. Over the wider area, the impact of cable laying on SSCs was detectable above background within around 500 m. Strong tidal flows dispersed the sediment plume mobilized by the works; at slack water, the absolute increase over background was similar to that at other states of the tide but impacts were restricted to within 100 m of works. In conclusion, the effects on SSC due to cable installation works were found to be short term and relatively localized to the activity, supporting the initial ES assessments of no significant effect.

Monitoring against agreed threshold values was also undertaken during the construction of the Kentish Flats OWF and in light of local commercial oyster beds (*Ostrea edulis*). Suspended sediments arising from the installation of three export cables were measured in compliance with licence obligations as mitigation for potentially adverse impacts on the local oysters (EMU Ltd, 2005). The substrate at the site comprises fine sand with a shallow sub-layer of clay. Data were collected using optical backscatter (OBS) profiling through the water column from a moving vessel. Monitoring was conducted over three separate occasions, corresponding to the installation of the three different cables, and over a period of 13 hours on each occasion. Profile data were collected from areas predicted to be within the sediment plume movements and within distances of 500 m from the installation vessel. Measures of turbidity were collected and calibrated via simultaneous water sampling. Reference data were also collected during each of the monitoring surveys for subsequent comparison. No information on the method of cable installation was given.

Reference suspended sediment levels did not, in general, exceed 120 mg/l and varied between approximately 20 mg/l and 100 mg/l for the majority of the period of observation. Within the areas of investigation, suspended sediment levels were comparable with baseline values during the installation of two of the export cables. However, levels during the installation of the third cable were higher, occasionally reaching values in excess of 140 mg/l. Baseline values rarely exceeded 120 mg/l but were reached nearly 20% of the time in the treatment area during the installation of the third cable. Average values during installation of this cable were calculated to be approximately 9% higher than baseline conditions. No cause-effect relationship was attributed to this observation. In conclusion, raised levels of suspended sediments were detected down-tide of cable laying at Kentish Flats OWF but these remained well below threshold values levels indicative of potentials adverse impact on local oysters.

Real-time water quality monitoring during the installation of the Block Island OWF export cable was undertaken to characterize the spatial extent and SSCs of associated sediment plumes. A range of vessel based sensors (acoustic backscatter, acoustic Doppler current profiler and optical backscatter) were deployed in tandem with water sampling for total suspended sediment content, to detect and measure the extent, dispersal and concentrations of sediment plumes arising from export cable installation (jet plough) (Fugro, 2016).

The results showed that no sediment plume was observed as a result of the jet plough operations on the cable route. Background sampling and sampling within the anticipated plume down tide of the activity were comparable across all datasets. This finding was considered to be particularly important as the levels of suspended sediment that were predicted to occur due to the jet plough activity were 100 times higher than those actually recorded during the field survey.

A plough share cable installation tool was commissioned at Thanet OWF and for use in local areas of outcropping chalk on the seabed. At that time, it was successfully argued by the proponents that pre-construction tests of the plough share would provide opportunity to monitor the dispersion of sediment plumes, including chalk plumes, via aerial surveillance and that this would discharge associated licence conditions (Royal Haskoning, 2009). The following case study provides a review of the monitoring of sediment plume, including chalk plumes, using over flights and aerial photography at Thanet OWF (Royal Haskoning, 2009).

Case Study 3: Monitoring of Chalk Sediment Plumes Arising from Cable Ploughing
Thanet Offshore Wind Farm

Background

Thanet OWF comprises 100 monopile turbines located approximately 13 km offshore of the south east coast UK in the southern North Sea, UK. Construction of the wind farm started in March 2009. It became operational in 2010.

Aerial view of the Thanet OWF
(source: https://corporate.vattenfall.co.uk/projects/operational-wind-farms/thanet/)

Opportunity to monitor sediment plumes, including fine chalk plumes, arose during field trials of a specialist plough share cable installation tool commissioned specially for use in local areas of outcropping chalk geology. Numerical modelling predicted a shore parallel plume excursion of up to 10 km with a decay half-life of a few tides to a week depending on tidal current conditions. (Royal Haskoning, 2009).

Methods

Prior to construction, the developer undertook field testing of the plough share designed specifically for use in chalk bedrock and which provided the opportunity for monitoring of the chalk plumes. Field testing and associated monitoring of the plough share performance was completed along sections of the proposed cable route. Rather than in-water measures and sampling it was decided to undertake aerial surveys of the plume with subsequent analysis of photographic records to determine temporal and spatial plume extents. The basis of this decision was threefold including (i) the agreement that the effects of increasing suspended sediments, in particular chalk fines, during cable installation, would have an aesthetic rather than biological impact (ii) the development and dispersion of sediment plumes would represent those encountered during the construction phase of the project and monitoring at this time would avoid potential interaction with construction vessels on site and (iii) agreement that fixed sediment meters would not provide useful data against natural background turbidity levels within the Thanet site and the surrounding environment (Royal Haskoning, 2009).

Results

Chalk sediment plumes at the water surface ranged between highly distinguishable to barely perceptible. Figures 3.4 and 3.5 show examples of distinctive chalk sediment plume estimated to be up to 40 m wide Figure 3.4) and 750 m wide (Figure 3.5) at their greatest extents.

Continued monitoring showed that the plume dissipated quickly through the water column and became indistinguishable within 15 hours. In contrast, other monitoring surveys of the plough share operation at other trench locations revealed that very little chalk sediment plume was apparent.

Figure 3.4: Example image of chalk sediment plumes arising from plough share dredging at the Thanet Offshore Wind Farm export cable route
(source: Royal Haskoning, 2009)

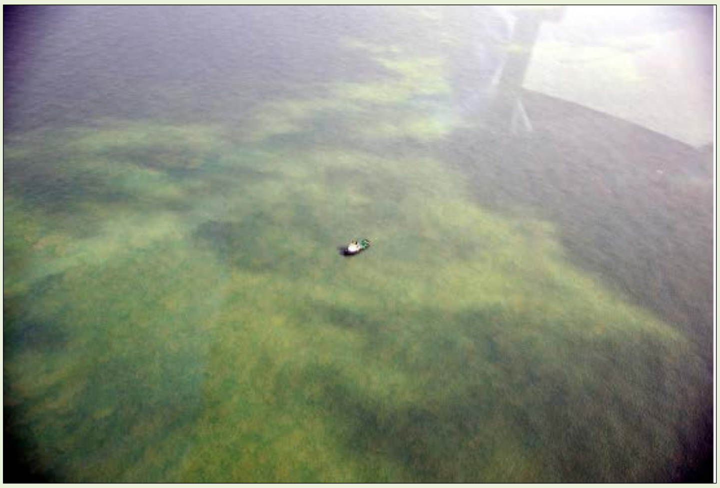


Figure 3.5: Example image of chalk sediment plumes arising from plough share dredging at the Thanet Offshore Wind Farm export cable route
(source: Royal Haskoning, 2009)

Conclusion

It was concluded that overall, only minor levels of suspended sediments were raised during the cable plough share operations at Thanet OWF in comparison to the annual variation and routine operations at the local harbor at Ramsgate.

3.6.2 Seabed Sediment Deposition

Monitoring of seabed sediment deposition was undertaken in relation to the installation of the export cable route for the North Hoyle OWF with the objective of determining any changes to seabed sediment distribution and potential consequences to benthic habitat distribution. Pre-installation surveys were conducted in September 2002 and were repeated a little over 1 year later in October 2003. Comparison between the two survey occasions and with reference conditions did not detect any significant effects attributable to the activity and any change that was noted was found to be within the natural variation. No adverse impacts of cable installation on sediment habitats and associated benthic communities were found.

A licence was granted for the deposition of drill cuttings from the drilling of six monopile foundations on the seabed during the construction of the Lynn and Inner Dowsing OWFs (RPS, 2012b). In compliance with licence conditions, a program of sediment plume monitoring was undertaken alongside a series of investigations of the drill cuttings spoil mounds. The spoil mounds were initially investigated by divers following deposition on the seafloor. Subsequently, selected mounds were monitored for up to 3 years following the completion of construction using a combination of geophysical survey, grab sampling, and seabed video surveillance. Contrary to predictions, the spoil mounds persisted as raised features on the seabed throughout the monitoring period. The following case study presents a review of the sediment plume and spoil mound monitoring report created from the construction survey in 2007 and the post-construction surveys in 2009, 2010 and 2011 and as summarized in RPS (2012b).

Case Study 4: Changes to Seabed Sediment Deposition Due to Foundation Installation.
Lynn and Inner Dowsing Offshore Wind Farms

Background

The Lynn and Inner Dowsing OWFs are two adjacent wind farms located between 5 and 9 km offshore the east coast of England in water depth ranging from 6 m to 18 m. Collectively the OWFs comprise 54 monopile turbines 4.75 m in diameter. Seabed substrates include a mix of silty sands and coarse gravels, including cobbles, with under-lying chalk.

Lynn and Inner Dowsing OWFs

(source: RPS, 2012b)

Installation of the foundations was achieved by a combination of both drilling and piling. In total, six of the monopiles required drilling because of the presence of an underlying layer of hard chalk at the foundation locations. Cuttings from the drilling activity were deposited on the seabed at a location 150 m from each of the installed (drilled) monopiles via a discharge pipe positioned 1 m above the seafloor. This allowed the finer chalk particles to be dispersed via tidal currents while the heavier chalk fractions were deposited on the seafloor. A series of investigations, initially using divers, but later employing geophysical, grab sampling and seabed video techniques were conducted to monitor the predicted erosion of the spoil mounds over time.

Additionally, a program of monitoring was conducted to assess the spatial extent of the fine sediment plume and surface residency periods of chalk fines resulting from the deposition of drill cuttings during the installation period. The findings were used to validate and confirm predictions made in the ES regarding the dispersal and settlement of chalk material and to ensure that expected maximum SSC thresholds were not exceeded.

Methods

The sediment plume monitoring campaign was based upon a series of sediment traps deployed at 100 m, 1 km and 5 km distances down tide from the proposed drilled monopole locations. The purpose of the traps was to capture and analyze the particle types in transit from the construction site and to identify chalk particles associated with the installation rather than monitoring for SSC alone.

The survey was carried out in two phases. The first phase collected data on suspended materials 8 days after the drilling of one monopile foundation (LN02). Phase 2 collected data following a 30-day deployment of the sediment traps and following the combined effects of partial drilling of 5 monopile foundations. The survey operations also included some preliminary seabed sampling and photography at and around some of the monopile locations prior to and immediately after drilling (CREL, 2007). In addition, the survey also included a diver inspection of the spoil pile created by the deposition of drill cuttings. Subsequent surveys of selected spoil mounds then followed to monitor their erosion over time.

Results

Results from the suspended sediment traps from both phase 1 and phase 2 surveys indicated an extremely large natural suspended sediment flux at all sites surveyed. Chalk residues from the discharge of the drill cuttings were only recorded at one sediment trap, deployed within close proximity (100 m) of the LN02 location. However, even here, the settlement of chalks within the sample was minor compared to the natural sediment flux recorded during the 8-day period. The survey revealed that chalk deposits remained unrecorded in all near and far-field stations. This contradicted numerical predictions of the spoil disposal assessment which forecast that drilling operations would increase SSCs above the background conditions although they would not be detectable beyond a few kilometers from the monopile drilling locations, or after seven days of dispersion. Increases in SSC were predicted to be high immediately after disposal (120 to 205 mg/l), but will remain localized and temporary.

Diver inspection surveys revealed that the spoil from the drill cuttings covered an area of 450 m^2 and reached a thickness of 3 m at the center. The coarsest material was located at the center of the spoil with increasingly finer grades present towards the edges. The size of the pile observed by the diver inspections was larger than that predicted in the spoil disposal study, as the size of the sediment particles deposited within the main pile were of a larger diameter (50 mm to 100 mm) than those used within the model (3.2 mm to 15 mm). Indeed, much of the spoil material was deposited as pebble and cobble sized particles which was noted would not be easily dispersed. This would account for the lack of finer chalk particles found within the sediment traps.

A repeat diver section survey of the spoil pile was conducted 4 months later and revealed a diminished spoil pile with maximum thickness of 1.2 m and covered an area 382 m^2.

A bathymetry survey of the Lynn and Inner Dowsing OWF to check on placements of cable protection material some 1½ years later provided opportunity to check on the erosion of two previously surveyed spoil piles. This showed that rather than eroding, the piles had persisted and exhibited similar dimensions to those previously recorded. It was suggested that the piles had in fact stabilized and had not decreased or increased in size over the intervening 1½ years. This was unexpected and prompted regulator queries as to why erosion of the piles had not continued. Two further annual surveys of the piles were then undertaken as part of the routine license compliance monitoring program. This showed that the piles had only reduced in height by a few tens of centimeters but had not decreased in height at all during the last year.

Figure 3.6 compares photographs of the sediment composition of the spoil piles taken after deposition on the seabed in 2007 (A) and in 2011 (B) and appear to show that finer sediment material is being incorporated over time (RPS, 2012b).

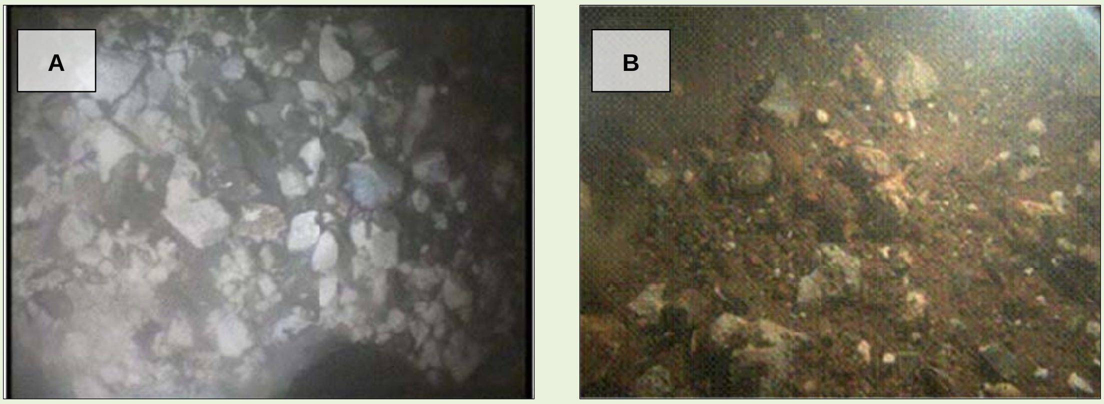


Figure 3.6: Seabed photographs showing the composition of disposed drill spoils n 2007 (A) and 2011 (B) at the Lynn and Inner Dowsing Offshore Wind Farms

Biological analysis of sediment grab samples collected from the spoil piles revealed a poorer community with substantially reduced abundance and biomass compared to the surrounding seabed area. The species composition was, however, suggestive of a recovering fauna (RPS, 2012b).

Conclusion

SSCs arising from the drilling and piling of turbines or the disposal of drill cuttings on the seabed were not detected above background conditions in contradiction to numerical model predictions. Numerical simulations predicted enhanced SSCs within the locale but this was not detected by the monitoring.

The drill cuttings from the monopile installations comprised larger pebble and cobble sized particles than previously forecasted, resulting in reduced quantities of fine chalk available for dispersal. The larger drill cuttings particles would also result in the persistence of spoil mounds on the seabed which remained discernible (approximately 1.0 m above seabed) on the seabed for more than 4 years after disposal.

3.6.3 Changes to Tidal and Wave Regimes, Coastal Impacts, and Sedimentary Characteristics

3.6.3.1 Wake Effects

Post-construction acoustic doppler current profiler (ADCP) monitoring was undertaken through the wake region to monitor the predictions made in the ES of a wake effect downstream of each monopile at the Barrow OWF. Surveys were conducted using a vessel mounted ADCP during periods of peak ebb and peak flood tides to map the wakes generated behind three monopiles within the wind farm. From interpretation of the data acquired, it was apparent that in all cases wakes could be traced out to a distance of at least 6 to 10 times the diameter of the monopile downstream of each monopile (30 m to 50 m) and often a good deal further, in the order of 100 m to 200 m.

In compliance with licence conditions, a vessel mounted ADCP study was also undertaken at the Inner Dowsing OWF to assess the extent of hydrodynamic interference imposed by the placement of a representative 4.7 m diameter monopile installed in the wind farm. The study was conducted during a spring tide occasion. As above, turbulent wakes were traced out to a distance of at least 6 to 10 diameters distance from the pile (25 m to 50 m) and up to distances of 100 m to 400 m during peak tidal movements. In addition, turbulent structures of 10 m to 20 m in length were observed some

400 m downstream of the monopile, increasing the likelihood of interaction with other turbine wakes, particularly in areas where turbines would be positioned within 500 m from each other.

3.6.3.2 Scour

Licence compliance scour monitoring was conducted at Gunfleet Sand OWF via swath bathymetry approximately 3 months following installation of the monopile foundations. Data were collected for 45 turbine locations plus the substation. The seabed environment at this site is dynamic with mobile bedforms; the sediment is predominantly fine mobile sand.

Scour pits had developed at the base of all foundations surveyed. Depths of the pits varied from 1.2 m to 8. 2 m and their diameters ranged from 14 m to 44 m. In addition, scour wakes were observed at a limited number of foundations.

A bathymetric survey at selected foundations three years after construction showed that these initial scour pits had increased in size and depth. Depths of the scour pits under surveillance at this time (at six foundations and at one substation) ranged between 5.6 m and 8.0 m with maximum diameters ranging from 29 m to 62 m. Furthermore, the bathymetry data revealed further evidence of extended scour for a distance of a few hundred meters down tide at one of the foundation locations, as illustrated in Figure 3.7. However, having reached this depth, a state of equilibrium appears to have been achieved. During the most recent monitoring occasion available (2012 - 2013), the change in scour had only varied between 0.0 and - 0.3 m at the monopile foundations and by +0.8 m at the substation, suggesting the rate of change had slowed over time (GoBe Consultants, 2014).

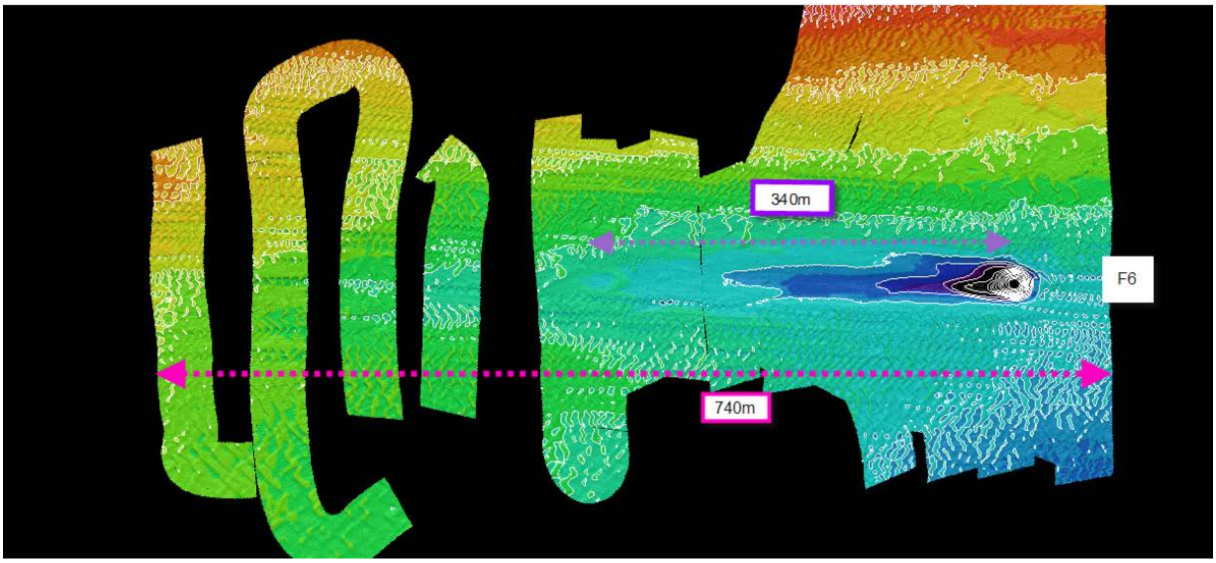


Figure 3.7: Extended scour observed in bathymetric data at a turbine foundation at Gunfleet Sands Offshore Wind Farm
(source: Port of London Authority (PLA), 2012)

Scour pits were monitored during and after construction of the Scroby Sands OWF using sidescan and swath bathymetry survey. The OWF consists of 30 monopile of 4.1 m diameter driven into the seabed up to 30 m below the seabed surface. The local environment is a dynamic shallow sandbank, exposed to waves and tides with mobile bedforms.

Scour pits up to 4 m to 5 m deep with diameters of up to 60 m were observed to have developed during the construction period. Factors influencing the size of the pits included water depth, wave – current exposure, as well as the time elapsed since installation (Whitehouse et al., 2011). The scour pits were subsequently infilled with protection material. However, following the installation of the scour protection material, secondary scour pits were created around the edge which, in some cases, were deeper than the original scour at the turbine. Figure 3.8 compares the depths of the scour pits at three adjacent turbines located less than 400 m apart, before and after the installation of protection material in March 2004 and September 2015, respectively.

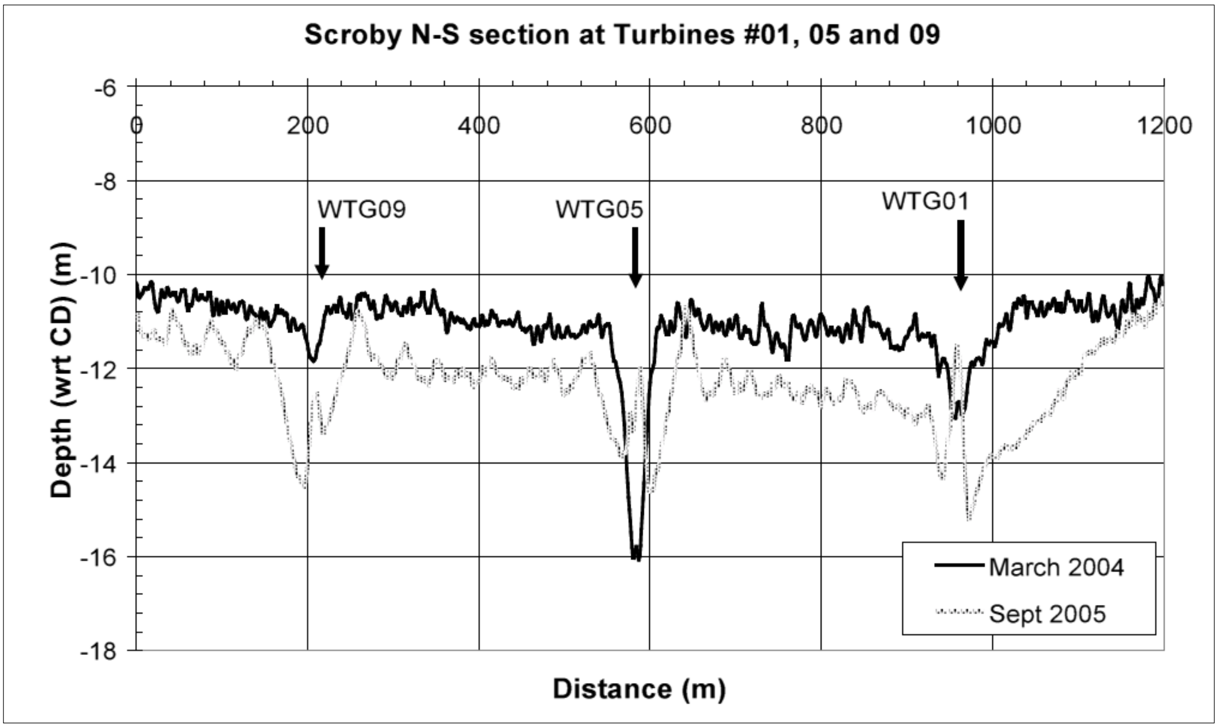


Figure 3.8: Comparison of seabed levels along a section of seabed intersecting with three turbines at Scroby Sands Offshore Wind Farm

(source: Whitehouse et al, 2011)

Further monitoring over subsequent visits noted overall bed level changes to the wider sand bank area, but attributed this to the natural dynamic nature of the environment.

Scour surveys using multibeam echo sounder techniques were conducted around four turbines at the Kentish Flats OWF and demonstrated that although there was some initial variability in scour depths these had stabilized over the subsequent two years. The small variations noted between survey occasions were attributed to storm events or variations in tidal velocities and the prevailing bedload transport properties. Table 3.2 shows the recorded scour depths at the monopile locations during each survey occasion. The diameters of the scour pits ranged between 5 m to 10 m. No scour associated with the inter-array cabling was recorded.

Table 3.2: Scour Depths Recorded at Selected Monopiles at Kentish Flats Offshore Wind Farm During Scour Surveys Each Monopile Foundation (source: Vattenfall, 2009)

Survey Date	Turbine ID			
	E2	F2	F3	F4
January 2005	-0.8 m	-1.1 m	-1.4 m	-1.1 m
November 2005	-1.2 m	-2.3 m	-2.1 m	-1.8 m
April 2006	-1.4 m	-1.6 m	-1.7 m	-1.7 m
October 2006	-1.4 m	-1.7 m	-1.7 m	-1.5 m
March 2007	-1.5 m	-1.9 m	-1.7 m	-1.7 m
November 2007	-1.5 m	-1.9 m	-1.7 m	-1.9 m

As well as a record of the development of localized scour, the monitoring program also recorded the persistence of seabed depressions which had been caused by the placement of the feet of the jack-up construction vessel on the seabed during the original OWF installation. Immediately following construction, these seabed depressions were 0.5 m to 2.0 m deep. However, by November 2007, the depths of these depressions had reduced to an average of 0.6 m. The reduction in depth over time was attributed to infilling of the depressions by the natural mobile sediments present across the area. Despite the evidence of infilling of these seabed depressions, it is clear from the monitoring program at Kentish Flats OWF that the physical impacts of the jack up feet of the construction vessels on the seabed can take a long time to disappear and, in this instance, are still visible on the seabed nearly 3 years after the initial event.

A useful summary of scour development across a range of physical environmental conditions and OWF characteristics is provided in Whitehouse et al. (2011) and is presented in Table 3.3 below.

Table 3.3 Scour and seabed characteristics at selected offshore wind farm sites (source: Whitehouse et al., 2011)

	OWF	Seabed Description	Monopile diameter (m)	Scour protection	Depth range (m)	Peak current speed (m/s)	Scour depths (D= monopile diameter)
Sand influenced sites	Scroby Sands	Dynamic sandbank, presence of mobile bedforms, exposed to waves and strong tidal currents. Medium sand, some ravel/shell, clay at depth.	4.2m	Yes	3 – 12	1.65	0.95D to 1.38D after 1 – 5 months.
	Arklow Bank	Sand bank, dynamic environment exposed to waves and strong tidal currents. Loose to medium dense sand and sandy gravel	5	Yes	2 - 6	2	0.8D after 9 weeks
	N7 (Monopile)	Open seabed, southern North Sea (Dutch sector), dynamic seabed, Fine medium dense sand.	6	No	5.2	0.75	Maximum of 0.55D after 9 months and 1.05D after 5 years.
	Scarweather Sands (Met mast)	Dynamic sand bank environment, exposed to wave and strong tidal currents. Medium to fine shelly sand.	2.2	No	6	1.1	Variable between 0.27D and 0.59D after one month.
	Egmond aan Zee (met mast)	Medium sand	2.9				0.7D after 3 years.
enc	Barrow	Open stable seabed environment, exposed to	4.75	No	12 - 18	0.8	Up to 1.21D in the sandy deposits in

		waves, moderate currents. Fine to muddy sand, some gravel overlying clay with exposed clay.					the west of the site but only up to 0.1D in areas of clay.
	Kentish Flats	Open, stable seabed environment, exposed to waves, moderate currents. Fine sand; infilled palaeochannel with clay and sand. Clay near surface or exposed.	5	No	3 - 5	0.9	Variable between 0.28D and 0.46D, possibly as a result of sediment transport processes causing fluctuations in scour depths.
	North Hoyle	Open, stable seabed environment, exposed to waves, moderate currents. Gravelly medium sand or sandy gravel overlying clay.	4	No	6 - 12	1.17	Less than 0.125D after one year. No scour recorded 2 years post installation.

In addition to scour development at the base of turbines, shallow water and dynamic seabed environments may present challenges during cable burial and emergence of cables over time due to the natural mobility of the seabed. The following case study presents a review of field reports created during a comprehensive monitoring campaign undertaken at Gunfleet Sands I and II OWF to document morphological changes to local bedforms along the export cable route and as summarized in GoBe (2014).

Case Study 5: Exposure and Possible Free Span of Export and Inter-Array Cables
Gunfleet Sands Offshore Wind Farms

Background

The Gunfleet Sands OWF is located 7 km off the southeast coast of England, in water depths ranging from 2 m to 15 m. The OWF, together with its extension (Gunfleet Sands 2) comprises 48 monopile turbines, each with a 3.6 MW capacity and a total project capacity of 172.8MW. Construction of the OWF commenced in October 2008 and was completed in June 2010.

The surficial geology and substrate of the OWF consists of 10 m to 14 m thick, cross-bedded mobile Holocene sands with minor components of gravel and silt. In compliance with licence conditions, a series of post-construction acoustic surveys of the export cable route corridor were undertaken to monitor effects on bedform morphology to ensure that cables remain buried, amongst other factors. This case study reviews the findings of two geophysical surveys conducted along the export and inter-array cables during the first and third years of operation of the wind farm together with summary information provided by GoBe (2014).

Figure 3.9: Gunfleet Sands Offshore Wind Farm
(source: Dong Energy)

The 9 km offshore export cable installation was installed in December 2008. The planned burial depth was 1 m to 3 m and post burial surveys indicated that the cable was installed to a depth of 1.5 m for the majority of the cable route, with only short sections buried at less than 1 m depth. The majority of the export cable was installed using the 'Sea Stallion' plough, which achieved simultaneous laying and cable burial. The remaining 300 m closest to the offshore substation was installed by means of jetting with a ROV.

The landfall section of the cable was installed using horizontal directional drilling (HDD); the offshore export cable was fed through the ducts and jointed with the onshore cable at the cable jointing bay.

Methods

A post-construction scour and debris monitoring program was required along the export cable between the windfarm substation and landfall site. For the year 1 post-construction survey, a hull-mounted multibeam echo sounder (MBES) and a sidescan sonar (SSS) survey was undertaken, covering a 100 m wide corridor along the length of the export cable route, from the substation to shore. The year 3 post-construction survey was identical to Year 1, except backscatter from the MBES was used instead of a towed SSS system. No export cable survey was undertaken during Year 2.

Monitoring Results

Surveys were conducted at 6 monthly intervals. Data available for the current review derive from monitoring surveys undertaken in September 2010, March 2011 and March 2012. Summary information relating to surveys conducted in August 2011 and April 2013 have also been considered here.

Monitoring was conducted in September 2010 some 1 year and 10 months after installation (PLA, 2010). The survey revealed numerous seabed features along the cable corridor subsequently interpreted as anchor drag marks made during the positioning of the installation vessel. In some cases, the drag marks were several hundred meters long and appeared to cross the charted cable route. The seabed transition pit at the point of cable landfall was also clearly visible in the data. The export cable route itself was also clearly visible in the dataset, although no exposures or free span of the export cable were seen in the data.

Monitoring was undertaken 6 months later in March 2011. Features previously attributed to anchor drag marks remained visible on the seabed but were less well defined suggesting that they were being eroded. Again, no cable exposures were recorded.

The survey undertaken in March 2012 and over 4 years from the initial installation showed that anchor drag marks were still visible on the seabed. In addition, two exposures along the export cable were identified. The first exposure, which had been identified previously in August 2011 (not reviewed here), was near the landfall section. The cable was positioned in its trench and did not appear to be spanning (see Figure 3.10). The second location consisted of an 11 m cable exposure with associated free spanning approximately 1.1 m above the seabed.

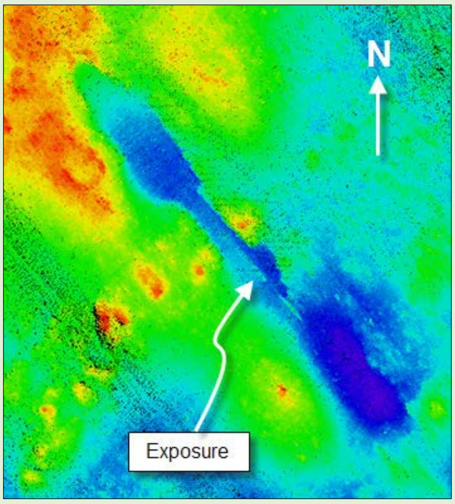


Figure 3.10: Multibeam echo sounder image of a cable exposure along the Gunfleet Sands export cable
(source: PLA, 2012)

Subsequent survey along the cable route in April 2013 (not reviewed here) (GoBe Consultants, 2014) noted that the export cable route remained clearly visible with exposure of the cable route noted at two locations. One of these locations included a section of cable in free-span at the base of a sand bank and up to 0.8 m above the seabed and 10.7 m in length. Comparison of seabed profiles in the vicinity of the cable span revealed that the northern edge of the sand bank has had eroded between September 2010 and 2013.

The aforementioned anchor drag marks were still visible in April 2013. GoBe Consultants (2014) suggested that these features remain stable and do not appear to have changed.

Conclusion

According to the Environmental Statement, there were no predictions of cable exposure or free span, since it was assumed that sufficient cable burial would prevent any exposure. Contrary to expectations, there were two locations of cable exposure along the export cable, which were not identified until a few years after construction. As more monitoring reports from other OWFs become available, it is likely that cable exposures and potential free span are not isolated incidents, especially in areas of mobile surface sands.

Erosion of seabed physical impacts from anchor drag were not eroded after 4 years highlighting the potential persistence of these features even in areas of naturally occurring mobile substrates.

3.7 Section Conclusion

Changes to naturally occurring physical processes can have consequences on the physical habitat conditions that they maintain, resulting in indirect effects on associated communities of marine species. The available monitoring has largely upheld conclusions made in the ESs and has shown that sediment plumes arising from the installation of turbine foundations and seabed cables are generally not detectable above natural variation at distances of more than a few 100 m down tide. Fine sediments, such as chalk, are more easily dispersed over wider distances but concentrations return to background levels quickly with observation of chalk plumes apparently dissipating to background levels within 15 hours. Mathematical models appear to have been very conservative in some instances with regards to the levels of SSCs arising from construction activity; direct measurement in the field has been useful in qualifying the actual impact incurred. Data from monitoring of SSCs from dredging activities during foundation installation, i.e. from bed levelling prior for gravity base foundations, is lacking in this review. However, monitoring of eelgrass beds (*Zostera marina*) and mussel beds (*Mytilus edulis*) during pre-installation dredging activities prior to the installation of wind turbine foundations at Lillgrund OWF, revealed no significant adverse ecological effects (see Chapter 5).

Contrary to developer and regulator expectations, spoil mounds on the seafloor from the deposition of predominantly chalk drill cuttings can comprise large particles (pebbles and cobbles) and can persist for years altering local topography, sediment composition, and benthic communities. It appears however, that the effects remain highly localized and limited to the footprint of the spoil on the seabed. Likewise, seabed depressions on the seafloor created by the placement of the jack-up legs of construction vessels can also persist for many years

Scour develops in mobile sediments in dynamic shallow water environments exposed to waves and strong tidal currents. The depth of scour is usually a function of the thickness of the mobile sediment and is limited by the presence of underlying hard, more resistant substrates such as glacial till or chalk. While scour pits are expected features of OWFs, the development of deep secondary scour holes, which occasionally were deeper than the original scour, at the edge protection material was not anticipated. Despite this, scour effects remain local around the individual turbines. The dynamics of scour development over tidal, weekly and monthly timescales, and in response to high energy wave events, are generally not well understood and are missing from this review. Data from the scour monitoring which is ongoing at Block Island OWF under the BOEM RODEO initiative will provide useful data in this regard.

Wake effects have been underestimated in impact assessments and have been shown to occur up to 100 m to 200 m down tide of the monopile. Length of the turbulence wake relates to the width of the turbine foundation and current speed. Cumulative effects are not considered an issue where turbines are spaced sufficiently far apart (i.e. at least 500 m spacing between turbines). Evidence of wake effects associated with jacket and floating structures are lacking.

4. UNDERWATER NOISE

4.1 Introduction

This chapter describes the impacts of underwater noise during OWF construction and operation drawn from a review of licence condition monitoring reports and industry experience. Information used to inform this chapter is presented in Appendix A. Accounts of receptor responses to underwater noise impacts are provided in Chapter 6 (Fish and Shellfish Ecology) and Chapter 8 (Marine Mammals).

Figure 4.1: Hammer piling of a monopile

(Photographer: Subacoustech Ltd)

4.2 Stakeholder Concerns

Underwater noise is frequently identified as a key environmental concern of stakeholders and one of the greatest potential impacts of OWF on marine life, particularly during the construction phase due to percussive piling of foundations. For this reason, sound-intensive construction activities are invariably associated with detailed mitigation measures and specific management plans are often required to be agreed across a number of agencies and stakeholders to ameliorate and control potential adverse effects.

The installation of foundations for offshore windfarms in Europe have typically been undertaken by impact or percussive pile driving, where a long steel tube or group of tubes, known as piles, are forced into the seabed by a series of hammer strikes. Noise arising from impact piling can be considerable and at very close distances (usually within a few meters) can potentially cause mortality and physiological damage to marine species. The underwater noise from these sources can still be discernible above background at many kilometers distance from the activity.

So far across Europe, 80% of the turbine foundations that have been installed are monopiles with a further 11% involving pin piles or piled jacket structures. While some of these foundations will have been installed using drilling techniques, it is clear that wind farm construction can frequently involve high levels of underwater noise from percussive piling for which considerable concern is raised. The US looks to continue the trend of installing piled wind turbine foundations. The Block Island OWF, for example, has recently installed piled jacket foundations while the Cape Wind OWF, if constructed, would involve the installation of monopiles. However, all OFW projects under BOEM jurisdiction in the Pacific Ocean are assumed to be floating structures.

With regards to piled foundations, stakeholders are primarily concerned with the hammer strikes, which produce high underwater sound levels in the water and are transmitted over distances of tens of kilometers. The exposure of marine mammals and fish to these high underwater sound levels can cause harm with a range of effects from disturbance to injury and potentially mortality.

The overall size of the wind farm and the design of its turbine foundations can add additional dimensions to the consideration of potential ecological effects arising from underwater noise impacts. Larger wind farms take a longer time to install than smaller developments extending the temporal scale of the impact and increasing the risk of adverse interactions with sensitive ecological periods, such as spawning or migration periods. In addition, the larger numbers of piles required for jacket installations could further increase the temporal scale of underwater impacts over monopile foundations, although this may not be universally the case. The underlying geological conditions can also influence the levels of construction noise emitted to the underwater environment as comparatively more resistant soil types may require greater hammer energies or a greater number of hammer strikes to achieve successful installation.

The significance of the potential environmental impacts of underwater noise from OWF construction can be considered to be up to major depending on the presence and value of receptors and construction methodology requiring mitigation to be applied. Table 4.1 summarizes the principal concerns identified by stakeholders, and associated mitigating measures, with regards to underwater noise.

Table 4.1: Underwater Noise Impacts of Offshore Wind Farm Identified by Stakeholders as Requiring Assessment

Perceived Impact	Source	Pathway	Permanent/ Temporary Effect?	Typical Mitigation
Physical or auditory injury to individuals	Percussive piling	Underwater noise propagation	Temporary/ permanent	Marine mammal observers, soft starts, noise reduction, seasonal restrictions, noise barriers
Behavioral or displacement effects	Percussive piling	Underwater noise propagation	Temporary	
Increase in background noise level	Percussive piling and operational turbine noise	Underwater noise propagation	Temporary/ permanent	
Reduction in	Operational	Underwater noise	Permanent	Selection of low

populations in vicinity of turbines	turbines	propagation		noise machinery

4.3 General Monitoring Rationale

The significance of the impacts of underwater noise is assessed as a function of the effect on the receptor and can range from minor to major depending upon the nature and value of the receptor predicted to be affected and the temporal scale of the impact. In Europe it is illegal to deliberately harm or harass European Protected Species (EPS) which include all marine mammals. Any assessment that identifies potentially significant impacts on these species would therefore require mitigation. Many OWF in Europe identify potential major adverse effects from underwater noise generation which subsequently require mitigation and monitoring plans to be agreed with the regulators to protect marine mammals and fish. The nature of the mitigation varies considerably between the different European member states and, drawing upon the European experiences, there are a number of possible options that can be applied in the US. A review of current receptor specific mitigation typically applied across Europe is provided in Chapter 6 (Fish and Shellfish Ecology) and Chapter 8 (Marine Mammals) and is reviewed in Section 4.4 below.

Likewise, in the US, it is an offence to harm or harass species that are listed on the Endangered Species Act (ESA) (1973) and all marine mammals are protected under the Maine Mammal Protection Act (MMPA) (1972). Any potential adverse impact on these list species, or on the ecosystems upon which they depend, is therefore likely to be judged to be of major significance. Again, some form of counter-measure will be required to ameliorate predicted effects and activities may be subject to additional management including further assessment, application, and issuance of some form of ‘take’ authorization.

The above impacts are related primarily to the level of noise produced at source and how readily it propagates through the water. Many jurisdictions require the level of noise to be measured while it is present, both over short or long term timescales and over the range of geological conditions present. This is typically undertaken using underwater sound measurement devices (hydrophones) that are either used to take short term samples at defined distances from the noise source or at fixed measurement stations which could operate for hours, weeks or longer periods to identify variations in the noise level with time or other varying environmental parameters.

These monitoring data are used to verify the results of numerical simulations upon which the initial impact assessments are based and also for the purposes of research to investigate a dose response function for an individual, species or group of species.

4.4 Typical Mitigation Measures

Mitigation options can either directly affect the level of noise produced, reduce the noise exposure of individuals or restrict the construction piling to avoid interaction with sensitive ecological periods. The following paragraphs briefly describe a number of generic mitigation options.

4.4.1 Noise Control

This can involve reducing the amount of noise produced at source, for example by using low noise piling technologies, striking the pile with a lower force or for a shorter period, or by limiting the noise propagation by inserting a barrier in the noise path. Low noise technologies are being developed for installation of the foundations, including vibro-piling, suction buckets, drilling, floating structures, and gravity base foundations which do not require significant piling, and other techniques where a great force can be applied without generating high levels of noise.

For a barrier, bubble curtains or other sources of air have been utilized, particularly in German waters. These may include (i) big bubble curtains, which involve perforated pipes laid on the seafloor at distances from 70 to 150 m from the turbine and which encircle the construction site (e.g. Verfuß, 2014), or (ii) little bubble curtains, which wrap around the pile throughout the water column. Figure 4.2 illustrates the concepts of large and little bubble curtains.

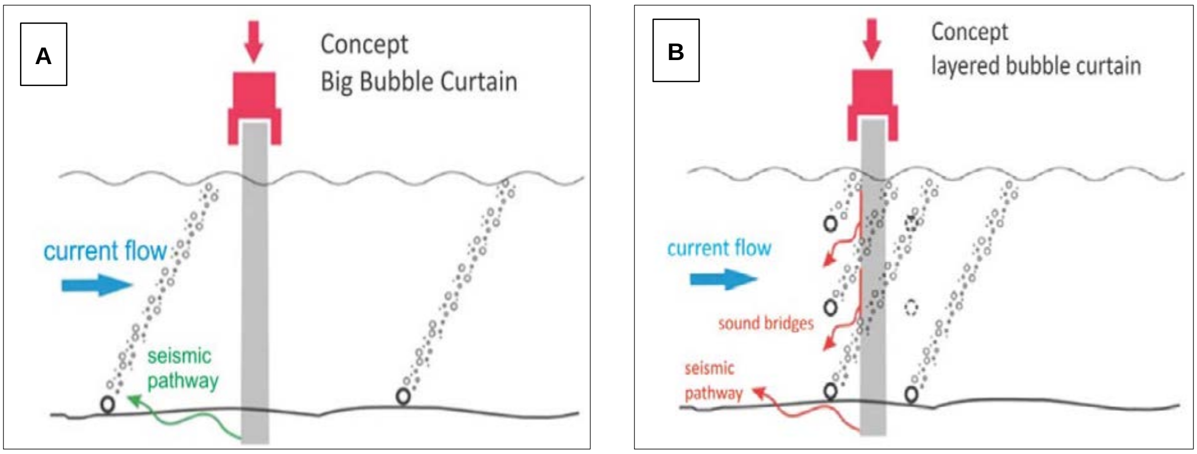


Figure 4.2. Illustration of the concepts of big (A) and little (B) bubble curtains

(source: Koschinski & Lüdemann, 2013)

4.4.1.1 Big bubble curtains

Big bubble curtains have been used at the FINO 3 research platform during the piling of 4.7 m diameter piles in 23 m depth of water. On this occasion, sound exposure levels (SEL) were reduced by 12 dB re: 1µPa^2-s whereas sound pressure levels (SPL) were reduced by approximately 14 dB re: 1µPa (0-peak). For ease of reading, the units for SEL (dB re: 1µPa^2-s) will be referred to as "dB (SEL)" for the remainder of this report. Similarly, when referring to zero to peak SPL values (dB re: 1µPa (0-peak)), these will be shortened to "dB (peak)". Best results were achieved in the range of 2 kHz (Koschinski & Lüdemann, 2013).

Different design configurations of the big bubble curtain were tested during the installation of 2.5 m diameter tripod foundation piles at the Borkum West II OWF. The best configuration was able to achieve a noise reduction of 11 to 15 dB (SEL) and 8 to 13 dB (peak) (Koschinski & Lüdemann, 2013). Additional tests, using a double ring of perforated pipes achieved even greater reductions of 17 dB (SEL) and 21 dB (peak). Greatest sound attenuation occurred when the nozzle pipes were set apart at a distance of 3 times the water depth which gave rise to two distinct bubble curtains.

It is noted that at Borkum West II OWF, the system was not effective at nine of the 40 locations due mainly to adverse sea and weather conditions. Other big bubble curtain configurations have been tested at several other OWFs in Germany and which have shown that noise attenuation using these systems can vary considerably depending on the actual configuration used as well as environmental factors such as type of seabed and tidal currents.

The deployment of these systems do not appear to cause significant delay to the construction program as they can be deployed alongside the preparatory works for piling (Koschinski & Lüdemann, 2013).

4.4.1.2 Little bubble curtains

Several variations of little bubble curtains exist including layered ring systems, confined bubble curtains and vertical hoses (small bubble curtains). The advantage of these types of arrangements is that, unlike large bubble curtains, there is no requirement for an auxiliary vessel to deploy the systems (Verfuß, 2014).

Due to weather constraints, only the lower part of a layered ring little bubble curtain system could be installed and tested during the piling of a 2.6 m pile for a tripod foundation in 30 m depth of water at the Alpha Ventus OWF. Nevertheless, noise reductions of up to 12 dB (SEL) and 14 dB (peak) were achieved but only in the direction of the tidal current flow. Elsewhere, ‘acoustic windows’ had developed due to gaps in the bubble curtain caused by the tidal current flows and which substantially reduced the efficiency of the mitigation system. On the back of this experience the system was re-designed and re-tested during the installation of tripiles at the BARD OWF. Underwater noise here was reduced by 13 dB (SEL) and 14 dB (peak) under the best configuration.

4.4.1.3 Casings

Casings are pile sleeves or pipes which enclose the pile as a barrier to noise propagation. The casings may be filled with foam or air bubbles to further improve efficiency. The IHC noise mitigation system (NMS) is a particularly sophisticated double skinned and insulated casing which has been used during the installation of all 30 monopile foundations of 5.7 m diameter at the Riffgat OWF. Estimates of the noise reductions achieved were 16 to 18 dB (SEL) and around 13 to 21 dB (peak). One downside of the use of this type of system is the storage and crane capacity on the installation vessel. Verfuß (2014) notes that as the weight of the casings increase with depth, applicability of these systems is limited.

4.4.2 Noise Exposure Reduction

Any impacts that could affect an individual will be lessened where the level of exposure to the noise is reduced. Many countries do not permit any high noise activities where a marine mammal is present within approximately 500 m. Such an identification tends to be passive, where either Marine Mammal Observers (MMOs) search for the presence of a surfacing animal, or by monitoring the underwater noise around the location of piling to listen for clicks or other sound evidence of the presence of a vocalizing marine mammal. A search is typically undertaken for 30 minutes prior to commencement of piling. Studies (e.g. Herschel et al., 2013) have shown that these methods are likely to underestimate the probability of a marine mammal being present, but there are limited options to accurately or confidently identify an animal. A marine mammal observation is less effective at night during hours of darkness, and sometimes piling restrictions during the night are applied.

It is assumed that an individual animal will flee from a high intensity sound source, and this is used to apply mitigation designed to reduce its exposure to noise. A so called 'soft start' procedure is frequently required with piling (Marine Management Organisation (MMO), 2014), where the pile is struck at a relatively low energy and speed at first before increasing the energy through the process, giving an animal time to leave the immediate area while the noise is relatively low. Sometimes this is done in combination with an acoustic deterrent device or 'seal scarer' (which is also effective for other species), which emits a noise designed to scare an animal from the immediate area of piling before it commences, but which itself is not dangerously loud.

4.4.3 Program Restrictions

Requiring no direct action to the noise source, all construction can be restricted to be outside of an environmentally sensitive period (Bailey et al., 2014), for example during spawning, migration or other time when the introduction of a stressor may be particularly damaging. As there may be multiple sensitive species in the region and each can have different sensitive periods in the year, this can lead to large parts of the year where any high intensity underwater sound activities are restricted. In the case of programs of long duration, this can lead to installation interruption and significant impacts to costs and timelines. The implications of revisiting a site with high impact disturbances in multiple seasons may also have unforeseen consequences.

4.5 Description of Impacts

4.5.1 Impacts During Construction

4.5.1.1 <u>Physical or Auditory Injury to Individuals</u>

There is no doubt that impact piling produces high intensity underwater sound levels. Research has shown internal injuries and temporary hearing loss to marine species following exposure to high noise levels under laboratory conditions (e.g. Halvorsen et al., 2012 and Lucke et al., 2009) and research from the Convention on Biological Diversity (United Nations Environment Programme, 2016) shows how nations around the world producing underwater noise within their waters propose to mitigate the effects. Commonly this relates to offshore petroleum prospecting or extraction activities, but the requirements can in principle be applied to any offshore activity producing potentially significant levels of underwater noise.

There are a variety of policies in place by the different nations, but all follow the basic principle of recognizing and reducing negative impact on local sensitive species. Mitigation methods range from noise control to exclusion of noisy activities from a particular area or time of year when there is specific environmental sensitivity. Research is ongoing to identify mitigations either through noise control or through the use of low noise alternative installation technologies, particularly due to requirements in areas such as Germany where strict noise limits are applied.

The highest noise levels produced during piling occur at close proximity to the pile. The hammer strike produces a vibration along the tube, which is transmitted from the metal into the water as a pressure wave, which then propagates away from the source. In general, the harder the pile is struck, the higher the noise level is in the water and the further it travels before dissipating into the background noise. Hammers used for installation of offshore wind turbine foundations are of a high enough specification that the noise levels they produce are sufficient to cause mortal injury to marine life, such as fish with swim bladders or in their larval forms (Bailey et al., 2010, Richardson et al, 1995, Popper et al, 2014), although this would typically be at ranges of 10 m from the pile or less (Natural Power, 2013). Further away, physical, internal injuries can occur, which will vary depending on the sensitivity of individual species (Finneran and Jenkins, 2012). Where the pressure wave has reduced to lower levels, there is still a potential to damage the hearing of an individual which, depending on the noise levels, duration and sensitivity of a species, can be either on a permanent or temporary basis (NMFS 2016, Popper et al., 2016).

4.5.1.2 Behavioral or Displacement Effects

Where underwater noise levels are sufficiently high enough to cause a disturbance to an individual, that individual may react. The reaction may be anything from a startle reaction to hiding or fleeing. This reaction is highly dependent on behavioral context as well as noise level, where the reaction and intensity will vary depending on the individual's species and desire to be in the area or ability to flee, as well as other biological imperatives. It has been found that porpoises can flee an area during piling (Dähne et al., 2013), returning some days later. Some evidence shows that marine mammal strandings have occurred near to navy sonar and explosive testing exercises, and although a connection was shown, the cause of these strandings has not been conclusively connected to the noise (EDA, 2013; Parsons et al., 2008; Moore and Barlow, 2013). The noise levels return instantly to ambient after the noise ceases.

High noise levels can also cause indirect impacts such as disrupting feeding, as either the animal may not feed under those conditions or the prey could be driven from the area or go into hiding.

The extent of the reactions will be dependent on context (Nedwell, 2007). Where a strong motivation to be in an area or to cross an ensonified area exists, such as for feeding, breeding or migration, then an animal's tolerance to noise would be expected to be greater than when an animal is less motivated. Additionally, different fish and marine mammal species have different sensitivity to received sound at different frequencies; thus, a sound audible to one species may be completely inaudible to another, and the potential range of effect for a less sensitive species will be smaller for an otherwise identical level of noise in the water.

Behavioral avoidance reactions are predicted in EIAs in the UK and although there is widespread use of behavioral response criteria and thresholds, there is low confidence in them for the reasons given above. This is further limited by the paucity of available data relevant to the environmental conditions present at the development location. For a while, research reported by McCauley et al. (2000) in respect of fish were used as behavioral response criteria to piling in UK underwater noise EIAs although they specifically related to a reaction of one species endemic to Australia in caged conditions exposed to seismic air-gun blasts.

At the time of writing, the most authoritative document containing criteria for the impact of noise to fish is Popper et al. (2014). This publication, together with Hawkins et al. (2014), makes it clear that the response of an individual or group is dependent on many variables. Consequently, Popper et al. does not recommend any numerical criteria for behavioral effects of fish to noise, instead providing general guidelines for the likelihood of a reaction of a species group "near" or "far" from the noise source.

It is partly because of this paucity of experimental data and confidence in predicting reactions for EIAs, but also the challenge in ground truthing during the actual construction period, that studies into behavioral reactions have not been required as consent conditions during construction of OWFs in Europe.

There are few studies available to demonstrate the extent of a behavioral reactions due to the introduction of OWFs. There is strong evidence from controlled experiments that impulsive noise will lead to reactions at noise levels that are much lower than would cause injury in both marine mammals (e.g. Hermannsen *et al*. 2015) and fish (McCauley *et al*. 2000; Mueller-Blenkle *et al*., 2010). There is also evidence for behavioral avoidance in harbor porpoises in the wild during piling (Carstensen *et al.* (2006). The hearing sensitivity of different marine mammal species and fish is highly variable however, and different species would therefore be expected to react differently to an otherwise identical noise stimulus (Southall et al., 2007; Popper et al., 2014).

It is these differences in sensitivity and in addition to the contextual complications that makes drawing conclusions relating to behavioral reactions challenging. There are too many variables and potential situational conditions for there to be confident general criteria with current knowledge. However, as a broad conclusion, it would be fairly safe to say that a behavioral reaction in fish and marine mammals using current impact piling techniques would be likely, although exceptions to these assumptions should not be ruled out.

4.5.2 Impacts During Operation

4.5.2.1 Impacts Due to Increased Background Noise Levels

Ambient noise levels in the underwater environment have been increasing over the last century (Slabbekoorn et al., 2010, Merchant et al., 2016), and this risks causing an impact on any marine species that, in some respect, relies on sound to survive (Van der Graaf et al., 2012).

Increasing the existing background noise level as a consequence of introducing noise to an environment can make it harder for animals to communicate. This effect, known as ‘masking’, potentially affects the ability of a species to find a mate and reduce the success of finding prey, for example, by inhibiting echolocation (Clark et al., 2009). Because relatively small increases in the background noise level could be sufficient to cause a masking effect, this could occur over very large distances.

4.5.2.2 Reduction in Populations in Vicinity of Operational Turbines

Once a wind turbine is installed, the near constant operation will produce mechanical noise which is transmitted through the structure into the water. Unlike the temporary nature of piling, this noise is present whenever the machinery is operational. While the noise levels are much lower than those during foundation piling, they are likely to persist for the lifetime of the turbine, which could be 20 years or more, and potentially get worse over time as the machinery ages. Operational noise levels may also vary over short timescales in response to different wind conditions.

4.6 Observed Environmental Effects from Monitoring and Research

4.6.1 Percussive Piling

Dähne et al. (2013) studied the distribution of harbor porpoises (*Phocoena phocoena*) before, during and after the installation of the Alpha Ventus OWF in German waters. The surveys undertaken showed that the fewest porpoises were detected during piling operations, and indicated a strong avoidance response 20 km around the pile being installed. The paper also showed that the longer the pile driving period, the longer the displacement of animals. Carstensen et al. (2006) also demonstrated a substantial reduction in harbor porpoise during the construction of the Nysted OWF in the western Baltic (Danish waters), with the detection rate of porpoises increasing from a matter of hours outside piling to days during construction.

A similar finding was reported by Russell et al. (2016) for harbor seals (*Phoca vitulina*) during the installation of the Lincs OWF off the eastern English coast. There was also a significantly reduced population of seals up to 25 km from piling activity, although recovery was very fast, with a normal distribution found again within two hours of the cessation of piling.

Underwater noise measurements were collected during impact piling operations to install 4.5 m diameter steel monopoles at the Robin Rigg OWF (Natural Power, 2013). The data were used to predict the ranges over which marine animals were likely to suffer mortality and physical injury. On the basis of pre-existing knowledge of the species hearing ability, the range over which fish and marine mammals were predicted to avoid the sound were also calculated.

These data, supported by Bailey et al. (2010), suggest that marine species may suffer mortality and physical injury out to a maximum range of 3 m and 40 m, respectively and that sound levels could elicit behavioral responses (avoidance) in fish (herring and cod) as far as 18 km from the sound source. Fish with comparatively poorer hearing ability (dab) (*Limanda limanda*) may perceive this sound level to 5.5 km. The ranges over which behavioral responses in fish were expected to occur were greater in deeper water areas compared to shallower water areas. Comparable results were calculated for marine mammals.

Study of fish reactions in the wild during noise exposure is harder than for marine mammals, as the detection methods for the presence of marine mammals (by vocalization or surfacing for air), are not typical for fish. Studies therefore tend to be in controlled environments, although by nature this may affect the subject's behavior. Mueller-Blekle et al. (2010) reported on the effects of exposure of cod and sole to recorded pile driving noise and observed a significant movement response at SPL levels above 140 dB (peak), although it was highly variable and there was evidence of habituation to the noise. This concluded that behavioral reactions could occur at distances of tens of kilometers from the piling, although this does not necessarily equate to avoidance, which depends on many motivational factors, as described above.

Underwater noise measurements taken at the Burbo Bank Extension OWF in 2016 (Mason et al., 2016) showed that during piling for 8 MW turbines, noise levels were in excess of background noise levels at distances of around 40 km from a 7.1 m diameter foundation pile. Although piling at a single wind farm may occur for a few hours per day during the installation of an OWF over a period of several weeks to months, subsequent wind farm constructions in the wider area could potentially lead to cumulative impacts over many years.

Predicting the impacts of underwater noise from OWF construction on sensitive receptors is required as part of the impact assessment process supporting lease applications. The following case study describes the assessments that are typically undertaken to inform predictions concerning the potential environmental impacts of OWF construction, using the Westermost Rough OWF as an example, and relates the subsequent measures made in the field to the predictions made in the ES.

Case Study 6: Physical or Auditory Injury to Individuals
Westermost Rough Offshore Wind Farms

Background

Westermost Rough (WMR) OWF is located approximately 12 km off the north-east coast of England in water depths ranging between 10 and 25 m. Offshore construction was started early 2014 with first power generated in September 2014. The wind farm consists of 35 Siemens SWT 6MW wind turbines with a total generating capacity of 210 MW.

This case study describes the findings of a licence monitoring study on the predicted impacts of underwater noise on fish and marine mammals during the installation of turbine foundations.

Rationale

The ES for the WMR OWF identified potentially significant impacts on fish and marine mammals from noise during piling (Nedwell et al., 2012). Consequently, a condition was placed on the wind farm's consent requiring monitoring to be undertaken during installation of the first four piles (as a minimum), which is typical in the UK sector. The diameter of the piles to be installed was 6.5 m, and the piling hammer used a maximum blow energy of 1600 kJ per strike; installation occurred in February 2014. The ES provided 'worst case' and 'most likely' scenarios for underwater noise propagation modelling, and the installed piles matched best with the 'most likely' scenario: the modelled pile diameter was 6.5 m and maximum blow energy was 2000 kJ.

A variety of different studies were referenced to acquire appropriate criteria for assessing the potential for injury to fish and marine mammal as follows:

Physical and Mortal Injury

Little recent research is available on the direct effects of noise levels high enough to cause injury or death to marine mammals for ethical reasons. A study by Parvin et al (2007) follows research by Yelverton et al (1975), which reported the effects of underwater explosive blasts on mammals. Mortal injury was anticipated when both marine mammal and fish species were exposed to underwater sound pressure levels of 240 dB re 1 μPa (peak to peak) and 220 dB SPL re 1 μPa (peak to peak), respectively. The WRM underwater noise EIA estimated that mortal injury could occur within distances of less than 10 m, and physical injury at less than 100 m, from the piling. More recent studies suggest that this may underestimate the tolerance of mammals to blast (Finneran and Jenkins 2012) but fish may be more sensitive (Popper et al., 2014).

Auditory Injury

This is broken down into temporary (i.e. recoverable) auditory injury, known as Temporary Threshold Shift (TTS), and permanent damage to the auditory system, where there is a long term reduction in hearing acuity for an individual, known as PTS. New authoritative documentation has been published recently, particularly by NMFS (2016) in respect of marine mammals, and Popper et al (2014) for fish. The WMR ES was produced before these documents were available and instead referred Southall et al (2007) for marine mammal auditory injury criteria, and Nedwell et al (2007), the dB_{ht} criteria, for traumatic auditory injury (for all species).

Field measurements

Measurements of the underwater noise produced during the piling were reported by Patricio et al (2014) and a comparison between the modelling results was made. Calculations of the 'source noise level' (i.e. the noise level at a standardized 1 m from the pile) showed that the modelling for the EIA was conservative, and the noise levels measured on site were somewhat lower. The source noise level was below the threshold for mortal injury proposed by Parvin et al (2007), meaning that, based on those thresholds, there was no risk of lethal injury to any species during piling and overall effects would occur over a smaller range than was predicted. This is not an uncommon finding: modelling in these situations tends to be based on the maximum blow energy that can be produced by a piling hammer, whereas over much of the piling process the blow energy is slowly ramped up and the maximum may not ever be reached, meaning the highest predicted levels are rare.

In terms of auditory injury, Patricio *et al* reported effects based on Southall et al for marine mammals. The EIA predicted injury threshold level to be reached from 15 m to 300 m from the pile for cetaceans (dependent on species) and to 5400 m for pinnipeds. The measurements showed that injury threshold values were reached between 200 m and 1500 m from the pile for cetaceans and to 2500 m for pinnipeds on average.

In respect of fish, Patricio *et al* used a different set of criteria from the EIA, as proposed by the Fisheries Hydroacoustic Working Group (2008). These relate to a general, non-specific 'injury' to the fish. Therefore, these values cannot be used for a direct comparison with the EIA for fish. However, whereas the EIA predicted traumatic hearing damage threshold levels to occur between 50 m and 600 m (depending on species), measurements demonstrated a risk of (non-auditory) injury threshold levels to occur from 2000 m to 4500 m, using the stricter alternative criteria, depending on the size of the fish.

Discussion

Conclusive study of the actual threshold levels for permanent hearing damage associated with the impacts of underwater noise generated by offshore piling is difficult, as many injuries are recoverable. Where they are not, the injuries would be very difficult to attribute to piling specifically as they tend to build up incrementally over time and would only be measurable some time in the future. No research could be found connecting any deaths of marine mammals to OWF piling. Only anecdotal evidence of some fish kill can be found. Measurements show that, based on existing noise impact criteria, injuries to marine life are certainly possible and auditory injury, both recoverable and permanent is likely.

How and to what degree injury is caused to marine species is a topic currently under study around the world, and new research is published regularly. There is frequently no international consensus on the thresholds to be used, although some studies do exist that are considered authoritative (NMFS, 2016 and Popper et al., 2014). There are usually a few years between production of an EIA and the actual installation of piles, and so it is common that new research is published in the interim, which is more appropriate for the assessment of potential impact. While in general the latest research would provide the most reliable assessment methodology or impact thresholds, data or measurements produced subsequently to verify the predicted impacts in an EIA should be assessed against the criteria on which the EIA based.

4.6.2 Operational Underwater Noise

It is expected that noise levels are much lower and less significant during wind turbine operation than construction. Consent conditions typically require noise measurements to be taken during the operational (post-construction) period of wind farms (e.g. Barrow OWF**)** (Edwards et al., 2007) in the UK. However, more recent agreement with stakeholders, based on increased confidence in relatively low noise outputs, has allowed some developers to prepare desk-based assessments in lieu of on-site measurements (e.g. for Gwynt-y-Môr OWF) (Barham, 2016), although measurements have still been required where new or larger turbines are installed (e.g. Gunfleet Sands 3 Demonstrator OWF) (6 MW turbines) (Collett and Mason, 2014)). At the latter site, the noise levels around a wind turbine were found to drop to the order of background noise around 100 m from the turbine, with a measured SPL of 115 dB (RMS) at 30 m, from an operational turbine, although measurements were only snapshots taken during wind speeds of up to 8 m/s.

Pangerc et al. (2016) studied Siemens 3.6 MW turbines at the Sheringham Shoal OWF in UK waters over 21 days. A measurement station was set up at 50 m from the turbines. The study found that the radiated sound was dominated by a clear tonal peak at 160 Hz 1/3rd octave band up to 126 dB re 1 µPa^{2}Hz^{-1} in winds in excess of 10 m/s, and an average broadband sound pressure level of up to 128 dB re 1 µPa. The majority of the sound energy measured was below 500 Hz.

Tougaard et al (2009) sampled noise levels around three OWFs; the largest turbines (2 MW) were installed at Middelgrunden OWF. The two other wind farms were Bockstigen-Valar OWF and Vindeby OWF, with turbine sizes 500 kW and 450 kW respectively. The authors used measurements under wind speeds of up to 13 m/s and found sound pressure levels in the range 109-127 dB re 1 µPa (RMS) at distances between 14 and 20 m at frequencies below 500 Hz. The same study also looked at data on harbor porpoise and harbor seal hearing sensitivities to estimate the "zones of audibility" (i.e. how far from the operational turbine an animal could hear the turbine over background noise in the water). It was estimated that seals would be able to hear the turbines at distances from 140 m to 6400 m, and porpoises no more than 73 m. The paper concluded that any significant behavioral response to the noise, let alone avoidance, is unlikely during the operation of the wind farm, but the possibility of behavioral effects around OWF should not be dismissed until greater knowledge of noise output from other turbines is available.

Thomsen et al (2006) review the findings of observations of fish behaviors in proximity to an operational turbine at Svante OWF. European eels (*Anguilla anguilla*) did not substantially change their swimming behavior when passing a single (220 kW) wind turbine at a distance of 0.5 km. When the rotor was stopped, the catch rates of cod (*Gadus morhua*) and roach (*Rutilus rutilus*) were significantly higher in the vicinity of the turbine (100 m) than at distances between 200 m and 800 m. These findings indicate an attraction for fish, possibly due to the reef effect. By contrast, during operation, the catch rate decreased by a factor of 2 within 100 m from the windmill under otherwise similar conditions. This could be interpreted as a displacement effect. However, no investigations of the variation in fish density were performed prior to construction, so the differences may be attributable to other factors.

Levels of underwater noise at Robin Rigg OWF were reported to be sufficiently low that lethal, physical injury and auditory damage to marine species (fish and marine mammal) would not occur (Natural Power, 2013). Perceived levels of underwater noise were considerably below those thought likely to cause a behavioral avoidance response and for the marine mammal species considered in the study (harbor porpoise, harbor seal and bottlenose dolphin), the noise encountered probably represented background noise. For the fish species studies, (cod, herring, and dab), the underwater noise data collected indicated that perceived levels were insufficient to cause any behavioral responses.

A case study at the Egmond aan Zee OWF (Scheidat et al., 2011) investigated the effects of the wind farm on harbor porpoises under normal operational conditions. The harbor porpoise population was thought to have significantly increased within the wind farm boundary, due to the increase in acoustic detections of this species relative to control areas.

Populations of fish were also found to increase within some wind farms, possibly as a result of the so called 'reef effect', and because of fishing restrictions implemented by some countries or reduction in fishing effort by some gear types, such as mobile fishing gear. (Scheidat et al., 2011, Attrill et al., 2012). Although this does not rule out the potential for noise to have a negative effect on species around wind farms, underwater noise caused by an operational OWF appears to have little overall effect, or is counteracted by the benefits afforded by the shelter and enhanced feeding opportunities. The increased presence of fish post construction is suggested as a reason for the possible increased population of harbor porpoise at Egmond aan Zee OWF, as indicated by an increase in acoustic detections of this species. It is worth noting that Tougaard et al. (2009) found that the operational wind turbines they sampled would only be audible to harbor porpoises at distances of 63 m or less, and that they would have to be much closer to encounter a theoretical 'disturbance'.

A study on harbor porpoises after completion of construction at Horns Rev 1 OWF in the Danish North Sea revealed no significant effect on the population present (Tougaard et al. 2006), whereas a similar study looking at the Nysted OWF (Carstensen et al, 2006) in the Danish Baltic Sea revealed a noticeable population decline. Both wind farms are of comparable size. The range of outcomes shows that these impacts remain difficult to predict and that results from one study are not necessarily transferable to others, without proper validation.

Brasseur et al. (2012) could not determine any effects on harbor seals (*Phoca vitulina*) at Egmond aan Zee OWF since it became operational, although it appeared that tagged seals extended their distribution towards the wind farm after construction. Southall et al (2007) notes that seals tend to be fairly tolerant of underwater noise, in comparison to porpoises.

4.7 Section Conclusion

Significant amounts of data from underwater noise monitoring have been collected, which has driven improvements in model predictions and the confidence provided by them. Based on numerical simulations, underwater noise generated from impact piling of turbine foundations can potentially cause mortality to some marine species within a few meters, physical injuries over tens of meters and lesser behavioral responses over tens of kilometers. Direct observations of the effects of underwater noise from OWF construction are limited as there are few studies which have correlated piling activity with behavioral aspects of marine species, particularly fish. In the cases reviewed, marine mammal species were showed behavioral responses that are broadly in line with the model predictions and generally returned rapidly, following the cessation of piling operations, although observations were inconsistent. Effects of seabed vibration have not been studied and are lacking in this review.

Once a wind farm is fully operational, each turbine will produce noise which can be detected and cause potential masking effects at variable distances depending on the sound levels produced and individual species sensitivities. Scaled up over a large area such as the North Sea, where around 10,000 turbines are proposed over the next few years, this will lead to a substantial area that could be adversely affected with respect to underwater noise. Research so far does not show that noise related to operational wind farms has a significant effect on the species studied, but there is still much work to be done in respect of the impact on many species in the wild (Williams et al., 2015). The acquisition of noise data, particularly in respect of new and larger noise sources will contribute to the overall dataset. Studies on the long term exposure to, and the cumulative effects of, low levels of underwater noise from operational OWFs on marine species are lacking.

5. BENTHIC ECOLOGY

5.1 Introduction

This section reviews OWF information and data relevant to benthic ecology, specifically macrofauna and flora larger than 1 mm size, inhabiting sediments or the sediment/water interface, including the subtidal and intertidal zones on the installed structures themselves. Appendix A presents the monitoring studies and other literature available that have been reviewed to inform this chapter.

Figure 5.1: Dense mussels (*Mytilus edulis*) with Plumose anemone (*Metridium senile*) attached to a turbine foundation at the Barrow Offshore Wind Farm

(Photographer: Fugro EMU Ltd)

5.2 Stakeholder Concerns

Benthic ecology refers principally to the groups of invertebrates, seagrass and algae living on or within the seabed substrates. They provide a wide range of ecosystem services including aeration and stabilization of sediments, processing and cycling of nutrients, food for higher trophic levels and habitat structure and refuge for a range of fish and shellfish species. On the outer continental shelf, several species are considered endangered or threatened and receive protection under the Endangered Species Act (ESA) and may therefore be subject to management. Many components of the benthic ecology are therefore highly valued and/or are subject to regulatory management and concern can be raised by various stakeholders and interest groups during scoping and impact assessment of proposed OWF developments. Table 5.1 below summarizes the typical concerns that have been raised by stakeholders in European countries where OWFs have been developed in relation to potential effects on the local benthic ecology.

Table 5.1: Typical Concerns Raised by Stakeholders During Scoping of Potential Effects of Offshore Wind Farm Construction and Operation on Benthic Ecology

<table>
<tr><th>Concern</th><th>Source</th><th>Pathway</th><th>Effect</th><th>Typical Mitigation</th></tr>
<tr><td colspan="5">Construction/decommissioning Phases</td></tr>
<tr><td>Temporary seabed disturbance</td><td>Seabed preparation, drilling, cable trenching, removal of infrastructure</td><td>Increased sediment instability, abrasion and compaction</td><td>Species removal, displacement or mortality.
Habitat disturbance</td><td></td></tr>
<tr><td>Changes to water and sediment quality</td><td>Seabed preparation, cable installation and drilling</td><td>Sediment plumes, release of sediment contaminants and deposition</td><td>Smothering and burial of species and habitats</td><td></td></tr>
<tr><td>Noise and vibration</td><td>Piling, drilling, trenching</td><td>Sound waves transmitted through the water column and sediment</td><td>Physiological damage, avoidance</td><td></td></tr>
<tr><td colspan="5">Operational Phase</td></tr>
<tr><td>Loss of habitat</td><td rowspan="2">Presence of infrastructure on the seabed</td><td>Footprint of turbines, scour and cable protection material on the seabed</td><td>Reduction in extent of habitat for the lifetime of the project</td><td></td></tr>
<tr><td>Introduction of new habitat</td><td>Species colonization</td><td>Increased epibenthic biomass and diversity. Increased risk of spread of invasive species</td><td></td></tr>
<tr><td>Heat and EMF emissions</td><td>Operational cables</td><td>Propagation through the sediment and water column</td><td>Re-distribution of species</td><td>Burial of cables</td></tr>
</table>

5.3 General Monitoring Rationale

Irrespective of apparent stakeholder concerns, the significance of impacts of OWF construction and operation on benthic ecology are commonly assessed as negligible or minor. This is because of the localized and temporary nature of the predicted impacts during construction, the small area affected in comparison to the wider wind farm site and the ability to micro-site or reposition infrastructure to avoid sensitive features, such as reefs if necessary. Horizontal directional drilling (HDD) has also been employed during the installation of export cables at landfall sites to avoid potential damage to valued coastal habitats such as saltmarsh, although this has not universally been the case.

Monitoring of the benthic ecology against previously collected baselines has usually been undertaken after construction of the wind farm has been completed. Monitoring during construction has only been undertaken infrequently and usually in relation to concerns surrounding potential effects of raised suspended sediments on a recognized sensitive receptor such as a local shellfish population or seagrass bed. At Lillgrund OWF for example, a feedback control program was initiated during construction to monitor ecological effects on local mussels and seagrass with the intention of limiting activities to lower the observed impact, should ecological threshold be exceeded.

The purpose of post-construction monitoring usually relates to confirmation of the predictions made in the ES and to better understand likely interactions between construction and operation activities and ecological components to help inform future policy and management decisions, as well as future wind farm design.

Trawls, sediment grabs, and seabed video surveillance are typically employed to investigate the different habitat and species components that comprise the benthic ecology and to detect and assess the changes that have occurred that are attributable to OWF construction and operation. Scientific and commercial divers have also been used to collect information on epibenthic communities colonizing the turbines.

Most studies have involved some degree of medium to broad scale survey campaigns to monitor for impacts of OWF construction and operation over the entire site and adjacent areas. In some EU states however, the focus of environmental monitoring has been to collect localized (individual structure level) information to improve understanding of the potential impacts of the introduction and colonization of the hard surfaces of the turbines and scour protection material and the consequential effects on the surrounding benthos and higher trophic interactions. Marine Management Organization (MMO) (2014) notes that through a combination of large and local scale studies, OWF monitoring in Belgium has indicated that major effects on benthos may become more pronounced as the wind farms grows older and bigger and food chain linkages may become established from hard substrate epifouling organisms to surrounding soft sediment communities to demersal and bentho-pelagic fish.

5.4 Typical Mitigation Measures

Specific measures to mitigate potential impacts on benthic ecology have not generally been required, reflecting the negligible or minor significance of the impacts that have typically been predicted during impact assessments following implementation of appropriate planning measures. The careful siting of wind energy lease areas and wind farms during strategic planning, site feasibility, and pre-application stages is usually sufficient to identify and map sensitive benthic receptors so that adverse impacts can be largely avoided. This knowledge is then typically used to inform impact assessment and appropriate mitigation design at an early stage, such as micro-siting of infrastructure, re-routing of cables and management of construction activities as well as the design of bespoke monitoring to investigate the status of local features of interest during construction and operational phases as agreed with the regulators.

The following case study describes benthic ecological studies that were carried out to characterize and map potentially sensitive stony reef features at the Westermost Rough OWF to inform micro-siting of inter-array cables and the placement of the feet of jack up vessels during the construction stage (Emu Limited, 2012).

Case Study 7: Benthic Ecology Studies to Inform Micro-siting and Construction Management
Westermost Rough Offshore Wind Farm

Background

Westermost Rough OWF is a wind farm located approximately 12 km off the north-east coast of England, in an area of highly mixed coarse cobble, sand and gravel seabed with topographically distinct stony reef features comprising cobble and boulders and possibly indicative of glacial features (eskers). Water depths on site vary between approximately 10 m and 25 m.

Offshore construction was started in 2014 and was completed in 2015 with first power generated in September 2014. The wind farm consists of 35 Siemens SWT 6MW wind turbines with a total generating capacity of 210 MW.

Consent for the construction and operation of the wind farm was granted in 2012 (Marine Licence L/2011/00305/1) but with the condition that appropriate pre-construction surveys would be undertaken "*to determine the location and abundance of [protected] Annex 1 habitat in the vicinity of the array and cable route. Should [protected] Annex 1 habitat be identified in the area of the proposed array the License Holder is required to undertake an assessment of the need to micro-site individual turbine structures, inter array cable or the export cable".*

In compliance with this license condition, the developer undertook detailed geophysical (MMT, 2013a & b) and seabed video surveillance surveys (Emu Limited, 2012) of the site and export cable route with particular focus on raised linear features identified in the acoustic mapping data. Detailed investigation using underwater cameras was used to ground-truth the acoustic data. The ground-truthing showed that some areas appeared to closely resemble protected Annex I 'geogenic reef', while in other places the resemblance was comparatively less.

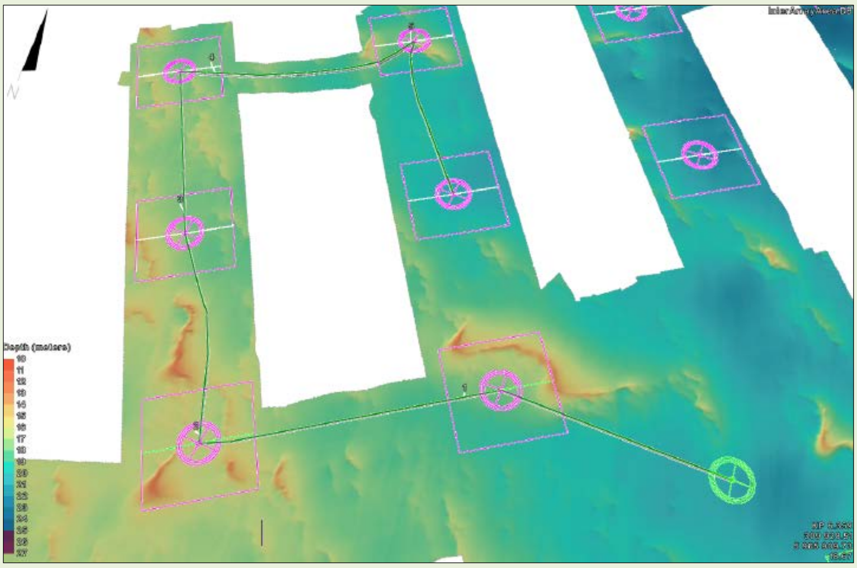


Figure 5.2. Example geophysical data at Westermost Rough Offshore Wind Farm showing distinct linear seabed features (eskers)
(source MMT, 2013a)

Methods

Drawing upon criteria for scoring the quality of geogenic reefs, in agreement with the regulator, the developer was able to identify and map three categories of potential Annex geogenic reef based on the topographic distinctness of the feature, the particle composition of the feature and the biological assemblages associated with the feature, as follows:

- Category 1 – bathymetrically distinct ridges, with a consistently high proportion of cobbles and/or boulders across the entire feature (typically ranging between 60% and 100% across the entire feature). These features were well defined from the acoustic and seabed video data;
- Category 2 – ridge features with comparable composition of cobbles and/or boulders as category 1

geogenic reefs, but comparatively less distinct within geophysical and video datasets with lower elevation compared to category 1 features;

- Category 3 – relatively low lying, with a varying proportion of cobbles and boulders (not consistent across the feature). Cobbles and boulders were generally embedded in or lying on sediment. These features are disjointed features with little relief, and are considered lower quality (in terms of structure and ecological functioning) than the Category 1 and 2 reef features.

Features classified as category 1, therefore, had the greatest resemblance to Annex I geogenic reef features. Category 3 reef, in contrast, had the lowest resemblance to Annex I geogenic reef.

Results

The total area of each category of reef recorded is presented in the Table 5.2.

Table 5.2: Total Areas of Each Category of Potential Annex I Geogenic Reef

Category of Potential Annex I Reef	Export Cable Route	Wind Farm Site
Category 1 (high resemblance)	(0.04 km^2)	(0.32 km^2)
Category 2 (medium resemblance)	(0.03 km^2)	(0.46 km^2)
Category 3 (low resemblance)	(0.45 km^2)	(0.42 km^2)
Total	**(0.45 km^2)**	**(1.2 km^2)**

Armed with a map of the distribution and extents of each category of potential Annex I geogenic reef, the developer was able to successfully negotiate and agree upon detailed construction methodologies and routes/foundation placements with the regulator and avoid potential adverse effects on potential Annex I stony reef features. A wide range of construction activities were permitted with the support of the habitat map including:

- Boulder removal;
- Inter-array and export cable routing including horizontal directional drilling;
- Placement of the feet and anchors of jack-up barges and construction vessels;
- Foundation drilling and turbine foundation placement; and
- Use of scour protection material.

Conclusion

In conclusion, the environmental information (habitat classification and mapping) provided during pre-construction surveys and mapping studies was used to enhance some aspects of the final construction design to avoid significant adverse effects on potentially protected features and supported confident statutory decision making and permitting of the wind farm construction and operation.

5.5 Description of Impacts

5.5.1 Impacts During Construction/Decommissioning

5.5.1.1 Temporary Seabed Disturbances

Typical wind farm construction requires some seabed preparation (or intervention) for foundations and subsea cables; this may include levelling (by dredging/cutting/excavation) and a gravel bed laid for stabilization purposes[2]. Subsequent fixing of turbine structures to the seabed results in permanent loss of original benthic habitat for the duration of the operation of the wind farm and is addressed in Section 3.5.2 below[3]. Potential impacts associated with decommissioning activities, including removal

[2] Technological advances inlcude the development of self-installing concrete gravity bases to provide foundations for large wind turbines in deeper water; these might reduce the need for seabed interventions in future developments

[3] Most existing wind farms have utilized monopile or gravity-based designs; where feasible, floating designs should have less impacts on benthic communities

of the turbines, scour material and cables are generally regarded as being similar or less than those for construction.

Feet of installation barges can penetrate up to 8 m into the seabed. For example, at the Greater Gabbard OWF, it was estimated that each jack-up can impact an area of approximately 350 m^2, excluding additional disturbance by smaller, support jack-up barges and tugs. Each installation will require at least one, main jack-up visit; however, worst-case assessments have allowed four visits per turbine. Subsequently, the disturbed area of seabed could be up to 1400 m^2 per turbine. Provided affected biotopes do not include sensitive/valuable types, it has generally been argued that such areas are unimportant within the scale of broader environment, and therefore that impact significance is negligible.

Although most of the benthos in the depressions is assumed lost during and immediately after construction, the impact is usually considered temporary. Depressions created are left to fill in naturally; slumping of the sides and drift will transport larvae and benthos from adjacent areas into the depression. In areas of mobile sands, infill should happen more rapidly compared to more stable seabed habitats. Migration by worms and crustaceans is expected to be relatively rapid, as often happens in dredged areas (e.g. Newell et al., 1998). However, until the depressions become filled to near the surrounding level with similar sediments, the benthic community will likely be different to undisturbed areas, an effect that could persist for several years.

Electrical cables are installed within turbine arrays and along export cable routes, typically using plough, cutting or jetting techniques[4], to burial depths of 1 m to 3 m. These activities cause disturbance to the seabed, and create suspended sediments.

Navigation, trawling and anchoring exclusion zones associated with OWF reduce other impacts on benthos. In terms of ecological benefits, it has been suggested that impacts to benthos by OWF development are minimal in comparison to activities such as the passage of trawl gear over the seabed (Wilhelmsson et al., 2010; Wilhelmsson, 2013). The conservation potential of OWF is discussed in section 1.6 of the Introduction above.

5.5.1.2 Changes to Water and Sediment Quality

Seabed intervention (dredging, cutting, excavation, ploughing, jetting, etc.), jack-up installation and anchoring of other vessels will cause sediments to become suspended in the water column. Depending on local hydrological conditions, suspended sediments may settle out close to origin, or be transported away from the area. Most assessments have considered that settling out of suspended sediments have the potential to smother benthos, cause stress through increased scouring and result in the dominance of tolerant opportunistic species and lower overall diversity. These effects may also have negative consequences for statutory nature conservation objectives where significant levels of suspended sediments could potentially interact with designated sites or features.

[4] Directional drilling may also be used, but this is expensive and only considered for banks and sensitive coastal habitats, such as saltmarsh

Specific hydrodynamic mathematical models are constructed for each wind farm and these are the primary tools used for the assessment of the dispersion and settling of suspended sediments. In most cases, it has been argued that smothering would not be significant because:

- Construction activities that generate suspended sediments would be intermittent, spread out over the duration of construction; and
- Resultant plumes would contain concentrations that are typically low and within background levels.

Marine sediments may contain a variety of chemically harmful substances, including arsenic, heavy metals, oil, organo-tin, PCBs and pesticides, which are effectively locked in inside undisturbed sediments. Seabed intervention causes disruption of sediment structure and can release these contaminants into the water column, making them available to animals and plants, with the potential to cause toxicological effects, or to transfer up the food chain to fish and marine mammals. The likelihood of this occurring depends upon the type and degree of sediment contamination; the highest levels of contaminants generally occur in silts of industrialized estuaries. Usually, in offshore environments that are remote from point sources of pollution, this issue is not a concern.

Impact assessments have generally applied a negligible classification to such impacts; monitoring of biotic and abiotic receptors has occasionally been undertaken. For example, the concentrations of contaminants in oyster tissues that were compared before and after construction of Kentish Flats OWF, UK. The post-construction levels of arsenic, copper, zinc, cadmium, and total PCBs were lower; levels of cadmium were largely unchanged; and levels of chromium, nickel and silver were higher than baseline, but this was mirrored by similar increases in samples collected at control sites outside of the wind farm area. The mean concentrations of lead and mercury were higher than those measured during baseline and at control sites. The report concluded that "*in all cases these were attributable to natural variation. In all cases the levels were within relevant guidelines and standards and in most cases well within the levels recorded from the North Kent area during previous surveys. It was concluded that the analysis of the oyster flesh revealed no evidence of any effect on contaminant loading attributable to the Kentish Flats construction program*" (Vattenfall, 2009).

5.5.1.3 Noise and Vibration

Construction activities such as pile-driving, vessel movements, anchor-handling, and seabed intervention such as blasting, dredging, cutting, etc. generate underwater noise and vibration. Pile –driving, which is commonly used during the installation of monopile or jacket-based turbine foundations, generates underwater noise at levels that have been observed to cause avoidance behavior in marine mammals (e.g. Richardson et al., 1995), and can potentially cause mortality and tissue damage in fish (e.g. Popper and Hastings, 2009). Marine invertebrates have been considered less susceptible than mammals and fish to loud noise and vibration as they do not generally possess air-filled spaces. Nevertheless, noise at these levels has been reported to cause short-term behavioral responses in marine invertebrates within a distance of approximately 10 m of the disturbance (McCauley, 1994; Brand and Wilson, 1996); bivalves withdraw their siphons, polychaetes retract their palps, and polychaete worms withdraw rapidly to the bottom of their burrows.

More recent work presented at the "4th International Conference on The Effects of Noise on Aquatic Life" in July 2016 included studies of marine invertebrates. Wale et al. (2016) showed that high levels of underwater noise indirectly caused single-strand breaks of DNA in cells of the gills and hemolymph of blue mussels. Solé et al. (2016) reported that low-intensity, low frequency noise damaged the structure of 37 proteins in statocysts (sensory receptors) of the Mediterranean common cuttlefish. They noted that the observed changes are known to affect the physiology and the function of the receptor, which may compromise cuttlefish survival and their role in oceanic ecosystems. The implication of recent research for benthic invertebrates at the population level needs further clarification.

Environmental statements for UK and EU wind farms have generally accepted that mortality of some benthos will occur during construction. Marine benthic invertebrates are sessile in nature or slow moving, and unlikely to flee even if they are able to detect the direction of sound; it has thus been argued that "soft start-up" is unlikely to be of any benefit. This also applies to those which are more mobile, such as many shrimps, lobsters, and crabs. Assessments have generally stated that mortality would be limited to a distance of a few meters, coincident with the area subject to permanent loss of seabed. The impact is generally considered to be of negligible significance.

5.5.2 Impacts During Operation

5.5.2.1 <u>Habitat Loss</u>

The foundations of the turbines and associated scour material and cable protection material occupy the seabed resulting in the loss of original seabed habitat directly below the footprint of these infrastructures until decommissioning. Typically, the total area occupied in this way is very small (< 1 % to a few %) compared to the total area of the license and the impact has invariably been judged to be negligible to minor.

In unperturbed systems, the composition and structure of soft sediment macrobenthic communities are highly dependent on the granulometry and organic content of the seabed, and on the local hydrography (Coates et al., 2011).

Throughout the operational lifespan of an OWF, benthic habitat loss may be extended by scouring – i.e. the local erosion of seabed material at the base of installed structures caused by complex vortex forces. The extent of scour will depend on wave heights, peak periods, tidal current velocities, water depth, and sediment characteristics (see Chapter 3 for a description of the development of scour).

There are two main options to address scour: either allow for scour in the design (i.e. deeper insertion of base structure into the seabed/increased size of the foundations), or install scour protection (e.g. placement of gravel/rock, composite rubber mat, or frond mattresses at the seabed to diffuse forces). Design choice determines the impacts that result. In designs where scour protection is not utilized, a cone of scour usually develops around each base (e.g. monopile) (see Chapter 3). Impacts range from change in sediment characteristics where benthos diversity, abundance and biomass might be affected, to deep blow-outs where benthos becomes largely denuded.

The placement of gravel or rock around the base of turbines has often been used as scour protection in UK and EU wind farms, causing a permanent loss of underlying soft-sediment habitat (which might have been lost or substantially altered anyway through the scour process). Moreover, Coates et al. (2011) note that a scour protection system, consisting of a filter and an armor layer, installed around wind turbine structures or around power cables to protect against erosion, does not eliminate the possibility of secondary erosion occurring around the scour protection systems.

The Oslo/Paris Commission (OSPAR) (2008a) provided context to the scale of potential scour-related habitat loss based on information on the size and nature of the European wind farms constructed, authorized and in planning at the time of their review. Assuming that all turbines in the OSPAR area (north-east Atlantic) had monopile foundations, and using the worst-case scenario of a 100 m scour pit diameter, they calculated:

- For 12 operational wind farms available at the time of the OSPAR review (total 467 turbines), the area of seabed affected by foundations and scouring or scour protection would be 3.67 km^2;
- For 31 authorized wind farms available at the time of the OSPAR review (total 2324 turbines), the area of seabed affected by foundations and scouring or scour protection would be 18.25 km^2; and
- For 47 wind farm applications available at the time of the OSPAR review (total 3792 turbines) the area of seabed affected by foundations and scouring or scour protection would be 29.78 km^2.

OSPAR (2008a) concluded that OWFs with monopile foundations have a relatively small area of impact in terms of foundations, scour pits, and scour protection when compared to other activities such as: active marine mineral extraction sites in the UK that cover 144 km^2; UK marine disposal sites that cover 310 km^2; and cuttings piles produced by the offshore hydrocarbon industry in the UK that cover 1605 km^2.

Impact assessments have also considered that the installation of a wind farm, with an array of many turbines, could alter near-field and far field hydrodynamics, and thereby impact macrobenthic communities (Wilhelmsson and Malm, 2008; Zucco et al., 2006). There is no specific research to correlate near and far field hydrodynamic changes and associated benthic effects at this time.

5.5.2.2 Introduction of New Habitat

Construction of a wind farm introduces new hard surfaces such as turbine and substation foundation structures, scour protection (specifically gravel/rock placement), concrete mattresses, articulated pipe, etc. Epifaunal colonization of hard surfaces starts almost as soon as the structures are installed, and development of ‘fouling’ epifaunal communities continues during the operations phase. Factors influencing the epibenthic invertebrate and algae assemblages on and around the artificial reef are salinity and temperature, water movement, light availability, depth, inclination of the surface and material and texture (Andersson, 2011).

The ES for Kentish Flats OWF describes the possible succession of biofouling on gravel armor: “opportunist species, such as encrusting worms and barnacles, would likely be the initial colonizers of the gravel deposits followed by other species characteristic of coarse gravel areas locally. Mobile epibenthic animals such as hermit crabs and common starfish may also rapidly colonize the gravel armor. Depending on the degree of subsequent stability and scour, later colonizers may include encrusting colonial invertebrates such as seamat and sea fir. These types of animals would attach to the surfaces of larger, stable gravel particles. Other mobile animals such as crabs may also seek cover in the interstitial spaces between the gravel particles. The gravel armoring may, thus eventually host a relatively diverse macrofauna characterized by encrusting and attaching species with mobile epibenthic animals with reduced infaunal biomass".

Fouling not only produces an increase in biomass, new habitats for mobile fauna are also created, providing shelter against strong currents and predators. This in turn creates an artificial reef (Hammar et al., 2008). Consequently, there can be increases in the number of shellfish and the animals that feed on them, including fish and marine mammals, resulting in a localized increase in biodiversity (Bailey et al., 2014) (Chapter 6 discusses apparent increases in fish abundance in wind farm sites and presents evidence of possible foraging of seals at turbines). The development of artificial reefs is usually considered a neutral or positive effect of OWF development. Assessment of the impact (beneficial or otherwise) should consider if the artificial reef results in increased production, or simply aggregation (i.e. a redistribution of abundance). Artificial reefs on turbine foundations differ from some other anthropogenic structures in that the turbines extend throughout the water column, enhancing biodiversity through depth-related zonation. Impacts associated with the loss of biodiversity and ecosystem services provided by OWF infrastructure should be assessed on decommissioning.

5.5.2.3 EMF and Heat Emissions

Electromagnetic Fields (EMF)

Electricity generated by the offshore wind turbines is a byproduct of bringing power onshore. 'Intra-array' power cables are used to connect turbines to each other and to offshore substations, while an 'export' cable delivers generated power to onshore facilities. Intra-array cables have a lower rating than export cables; e.g. the cables networking the Horns Rev turbines offshore Denmark have a 33 kV rating while the export cable is rated at 150 kV. The power cables for OWFs are usually buried to a depth of 1 m to 3 m beneath the seabed surface to protect it against damage due to mobile sediments, scour, trawl fishing, anchoring and other activities.

EMFs will be generated in the surrounding seabed and water by the transmission of electricity through submarine power cables. Conductive sheathing shields the external environment from the electric field and EMFs emitted from power cables into the marine environment are therefore the magnetic field (measured in tesla, T), and the resultant induced electric field (measured in volts per meter, V m^{-1}).

Magnetic (B) Field

Normandeau et al. (2011) noted that while Alternating Current (AC) transmission is currently the industry standard for OWF in Europe and those proposed in the US, Direct Current (DC) transmission would likely be used for future projects that are located further from shore. They modelled the expected EMFs from representative submarine power cables, describing a substantial difference in the magnitude of magnetic fields from DC transmission compared to those from AC transmission.

Figure 5.3A depicts the average and range of calculated fields for ten AC cables modelled by Normandeau et al. (2011). In general, the intensity of the field was roughly proportional to the voltage on the cables (ranging 33 kV to 345 kV), although they noted that separation between the cables and burial depth also influenced field strength. The predicted magnetic field was strongest directly over the buried cables[5] (averaging approximately 8 μT, with a maximum of approximately 18μT) and decreased with vertical and horizontal distance from the cables; the average predicted field strength was less than 2 μT at distance of 2 m from a point on the seabed directly above the cable. For context of scale, the earth's magnetic field ranges 25 μT to 65 μT; a reference value of 50 μT is often quoted in OWF ESs.

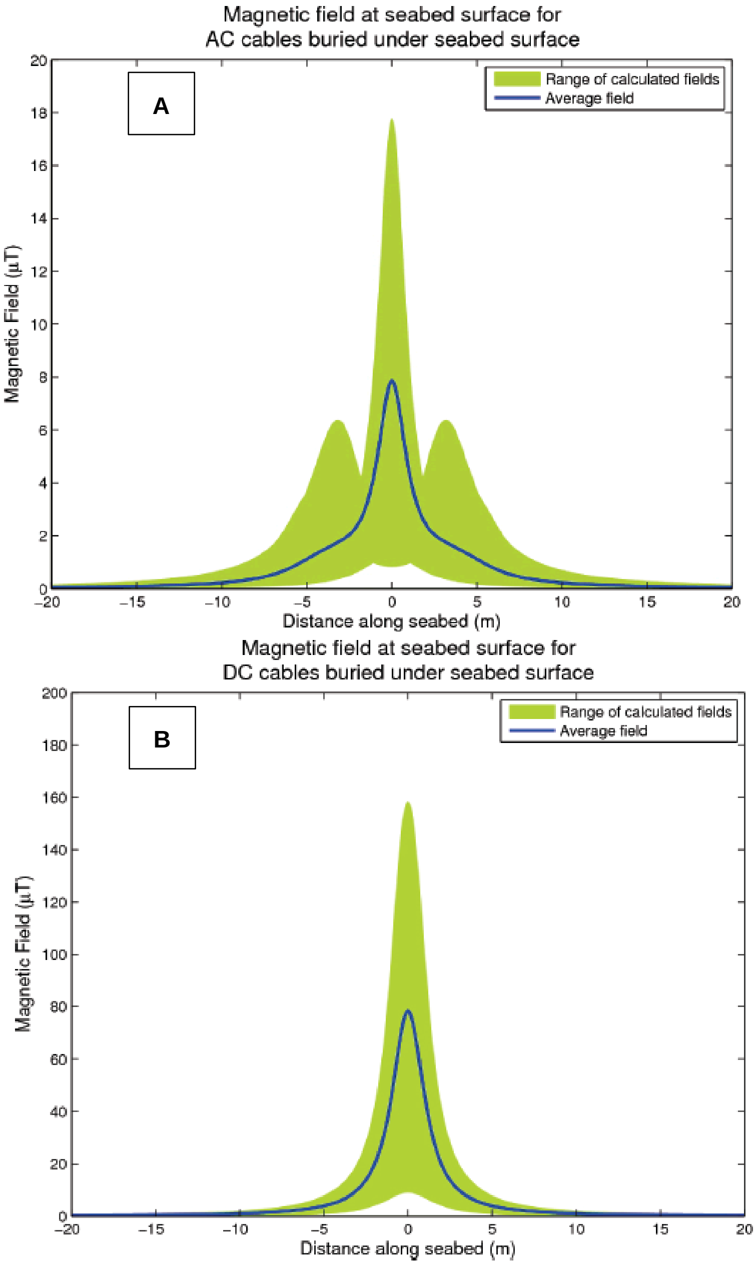


Figure 5.3: Modelled magnetic fields for ten projects using AC transmission (A), and for nine projects based on DC transmission (B)
(source: Normandeau et al. (2011)

5 The magnetic field appeared as a bimodal peak in two cases where the current was delivered along two sets of cable that were separated by several meters

Figure 6.2:Figure 5.3B depicts the average and range of calculated fields for nine DC cables modelled by Normandeau et al. (2011); in these examples, the burial depth was assumed to be -1 m. They note that “unlike the magnetic field from AC cables, the magnetic field from DC cables can influence the intensity of the local geomagnetic field, as well as its inclination and declination, thus the orientation of the cable relative to the geomagnetic field should be accounted for when considering the effects of DC cables. The DC magnetic field from cables running perpendicular to magnetic north will affect the intensity and inclination angle of the geomagnetic field, but not the declination angle. In contrast, the DC magnetic field from cables running parallel to magnetic north will affect the declination angle of the geomagnetic field as well as its intensity and inclination angle”. Magneto-sensitive species, such as harbor porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*) and Minke whale (*Balaenoptera acutorostrata*) are more likely to be able to detect EMFs from DC cables than from AC cables.

Sensitivity to EMF depends on a species’ ability to detect the field, and the species’ response to it. Increasing evidence shows that many marine species, both vertebrates and invertebrates, can sense the earth’s magnetic field and use this information for orientation and navigation. Animals that utilize magnetoreception to aid long-range migrations to feeding or breeding grounds have been studied in particular (Normandeau et al., 2011). Most research to date has concentrated on fish.

Impact assessments for UK and EU OWFs have generally noted a relative lack of research and information on invertebrate response to anthropogenic EMF. In their review, Normandeau et al. (2011) listed marine invertebrates for which information on sensitivity to electric or magnetic fields has been reported, including slugs, mussels, isopods, sandhoppers (amphipods), prawns, lobsters, crayfish, crabs, and sea urchins. Their review included physiological, toxicological and behavioral studies.

Certain benthic invertebrates (notably some Arthropoda and Mollusca) are known to be magneto-receptive. These species detect and use the earth’s magnetic field, in addition to visual information, to orient their movement. Boles and Lohmann (2003) demonstrated that spiny lobster (*Panulirus argus*) oriented reliably towards their capture site when displaced 12 km to 37 km to unfamiliar locations, even when deprived of all known orientation cues en route.

Lohmann and Willows (1987) showed that a nudibranch mollusk (*Tritonia diomedea*) derived directional information from the earth’s geomagnetic field and spontaneously oriented in patterns that reflected a behavioral response to a circa-lunar rhythm.

Lohmann et al. (1995) used artificial B-fields to demonstrate that spiny lobster (which undergo an annual migration and are capable of homing to specific dens even when hydrodynamic cues are disrupted, and when visual cues are obscured) altered their course when subjected to a horizontal magnetic pole reversal.

If anthropogenic EMF interfere with their perception of the geomagnetic field, magneto-receptive species may become disorientated (Fischer and Slater, 2010); depending on the magnitude and persistence of the confounding EMF, a trivial temporary change in swimming direction or a more serious impact on migration might result.

Induced Electric (iE) Field

An induced electric field is created by the flow of seawater or the movement of organisms through a magnetic (B) field. Induced electric fields are generally weak, but nevertheless ecologically important. Benthic fish such as skate, rays and catsharks use electroreception as their principal sense in locating prey.

The strength of anthropogenic E- and B-fields depends on the magnitude and type of current flowing through the cable, and on the construction of the cable; they rapidly diminish in strength with increasing distance from the source in seawater (Fischer and Slater, 2010).

In general, arthropods are not known to be electro-receptive. For example, Steullet et al. (2007) concluded that freshwater crayfish (*Procambarus clarkii*) from the southeastern United States does not have a high-sensitivity, specialized electric sense used in locating food. On the other hand however, Patullo and Macmillan (2007, 2010) reported that Australian freshwater crayfish (*Cherax destructor*) respond to low-level electrical signals, and provided evidence from controlled, laboratory experiments that they may use electroreception in hunting.

Heating Effects

Resistance can cause a power cable to increase in temperature when electricity passes through it. Any increase in temperature depends on the level of electrical current flow over time.

The effect of radiated heat from cables buried in the seabed was considered during planning of the 'Cross Sound Cable Interconnector' – a pair of 40 km long, high voltage (140kV) DC submarine cables traversing sand and clay sediments between New England and Long Island, New York. Concerns were raised that thermal radiation from the buried cable may impact on the surrounding benthos, e.g. by increasing incidence of shellfish disease. When it was assumed that the cables were buried at -1.8 m, calculations indicated an estimated rise in seabed surface temperature of 0.1 °C, and a rise in overlying water temperature of 0.000003 °C. If buried at -0.6 m, seabed surface temperature was calculated to rise by 0.15 °C (CSC, 2001). These increases are considered insignificant and well within natural temperature fluctuations.

In situ measurement of sediment temperature in relation to two buried power cables (33 kV and 132 kV) was studied at the Nysted OWF in Denmark (Meißner et al., 2006). The target burial depth of the cables was -1 m. Temperatures were measured at two test sites (directly over the cable, and 30 cm to the side of the cable) and compared to measurements at a control site (unaffected by heat emissions). Recording equipment included titanium poles each equipped with 16 thermosensors spaced 10 cm apart, so that temperature could be measured at predefined depths in relation to the buried cable. This equipment was placed at one site in relation to the 33 kV cable, and at another site in relation to the 132 kV cable. Results indicated that:

- Seabed temperature was generally higher in proximity to the 132 kV cable than in proximity to the 33 kV cable;
- The highest temperature was recorded by the sensor in closest proximity to the 132 kV cable;

- The maximum difference in temperature measured above the 132 kV cable and that measured at the control site was 2.5 °C; and
- Differences in temperature measured by the 'cable sensors' and that measured by the 'control sensors' decreased with decreasing depth. Temperatures measured on the seabed surface were hardly any different: (i) above the 132 kV cable, (ii) 30 cm to the side, and (iii) at distant control site were 12.1 °C, 12.2 °C and 12.3 °C, respectively.

OSPAR (2008a) noted that the majority of infauna inhabit the top 5 cm to 10 cm of the seabed in open waters, and the top 15 cm in intertidal areas, although some organisms will burrow deeper.

5.5.2.4 Chemical Contamination

During operations, there is a risk of pollutants leaching from antifouling paints and from accidental spills of hydraulic fluid, petrochemical fuel or lubricant oil from machinery or vessels performing installation, maintenance or decommissioning operations. Organic or metal pollutants associated with the infrastructure used for electrical signals, and metals associated with sacrificial anodes might be also released into surrounding marine waters (Tornero and Hanke, 2016). Therefore, the contaminants potentially discharged from marine renewable energy devices include metals such as aluminum, copper, and zinc, booster biocides such as diuron and irgarol, hydrocarbons such as BTEX and PAHs (e.g. naphthalene), and also chemicals used as dielectric fluids such as silicone fluids, mineral oils, biodiesel, and synthetic esters, coolants such as ethylene and propylene glycols, and electrolytes such as sulfuric acid (Tornero and Hanke, 2016). Under the U.S. Clean Water Act, values for Total Maximum Daily Load (TMDL) limits the amounts of pollutants entering marine receiving waters and offer criteria for assessment and compliance monitoring.

Impact assessments have generally predicted a negligible significance to such risks after management controls are implemented. The Scottish Marine Renewables SEA (Scottish Executive, 2007) states "*most of the priority habitats likely to be present in the study area for which there is relevant sensitivity information are not particularly sensitive to heavy metal contamination that could result from use of copper based antifoulants or from sacrificial anodes.*.

OSPAR (2008b) note that "*all chemicals, paints, coverings etc. used in the maintenance and repair should be approved for use in the marine environment and their ecotoxicological properties known. It is important that all storage areas for chemicals (whether in the nacelles, substation or on land, vessels or other structures) are appropriately bunded (such bunds should be a minimum 10% greater than the volume of all chemicals to be stored). All vessels and equipment should be checked and maintained to an approved standard and where necessary certified for the task to which they are employed. Such measures are required to reduce the risk of chemical pollution incidents. It is advisable that pollution control and remediation measures are described in a plan*". With adequate control in place, the risk should be minimal, or in the event of an accident, containable.

5.6 Observed Environmental Effects from Monitoring and Research

5.6.1 General Findings

Monitoring reports have generally concluded that there was no evidence that wind farm construction had strong broad-scale influences on benthos, supporting ES predictions of minor adverse, negligible or neutral impacts. Changes have usually been attributed to natural variations in sediment and benthic community conditions as illustrated by the examples below.

5.6.2 Loss of, and Disturbance to, Benthic Habitat

Leonard and Pedersen (2006) reviewed benthic data collected during 1999 to 2005 for the Horns Rev OWF that was constructed in 2002. Horns Rev (reef) is a shallow area in the eastern North Sea, offshore Denmark, formed by sediments deposited during earlier geological periods. These deposits are now covered by accumulations of marine sand that are constantly adjusting to hydrological changes – tidally influenced and dominated by waves. Migrating bed forms with medium to coarse sand characterize the area, with considerable variation in grain size distribution. Median grain size increased significantly from 350 µm (2001) to 509 µm (2005), but similar patterns were also recorded at control stations outside of the wind farm area. Leonard and Pedersen (2006) concluded that there was no evidence that Horns Rev OWF had affected hydrodynamic regimes that might have influenced sediment characteristics. They found in general no significant changes in benthic community structure, abundance or biomass between 1999 and 2005. Any changes that were recorded were considered to reflect "*natural variations and are not attributable to the wind farm construction*". Leonard and Pedersen (2006) noted "*the most significant effect attributable to the construction of the OWF was the loss of pre-existing habitats and the introduction of hard substrate habitats into a community that originally was dominated by infauna in sandy sediments*".

RSK (2009) compared data from two post-construction surveys (2007 and 2009) with those from one pre-construction survey (2004) at Barrow OWF in the UK. While there was a general increase in grain size overall, they noted that grain size increased at some stations, and decreased at others. As these changes were recorded at test (inside OWF) and at control stations (outside OWF), the authors point to natural fluctuations as the likely cause. Given a general inverse relationship between grain size and organic content, the authors note that the accompanying decrease in overall TOC was not surprising. Similarity analysis of benthos data indicated that many of the subtidal sites from 2004 were, as a group, more similar to themselves than to stations sampled in 2007 and 2009. They highlight that the locations of only 4 stations were consistent across 2004, 2007 and 2009, and that at these stations similarity analysis showed that communities were >40% similar between 2004 to 2007, decreasing to ~35% between 2004 to 2009. They state that "*statistical tests on the environmental variables which have been measured in 2004, 2007 and 2009 appear to show that they are not responsible for the defining the benthic communities present*". They conclude, on the basis of changes that occurred both at test and at control stations, that "there have been natural changes throughout the area, and that the changes at the sites within the area of possible influence are not caused by the construction or operation of the wind farm. Based on the conclusion above, it is not anticipated that further benthic surveys will be required for investigating the pre- and post-construction situation as Barrow OWF and no further surveys are planned".[6]

Burbo Bank OWF is a relatively small OWF located about 6 km offshore Liverpool, UK[7]. Construction commenced in 2006 and first power was generated in July 2007. Environmental baseline conditions

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[6] Conclusions of the report were challenged by MMO and by Natural England; comments and criticisms to which RSK responded in an Addendum

[7] A larger extension is currently under construction (http://www.burbobankextension.co.uk/en)

were surveyed in 2005. The first post-construction (i.e. operations) survey took place in 2007, the second in 2008 and the third in 2009/10. Bathymetry identified a general trend of sediment accretion during 2008, particularly in the central area of the wind farm (CMACS 2011); this change was apparently independent of wind turbine positions. Seabed elevations were typically around 50 cm, although they reached just over 1 m in a few areas. The accretion was assumed to be a function of a dynamic sedimentary environment – i.e. natural. The 2009 survey found that large volumes of material had then moved off site, such that there were widespread areas of slight (tens of cm) net sediment loss, compared to the previous year (CMACS, 2011). Granulometry revealed a clear decrease in grain size over the course of the monitoring program, particularly in the central part of the survey area, including the wind farm, which became relatively muddy.

Benthic grab monitoring data indicated a high degree of variability both between years and between individual survey stations in the same year at Burbo Bank (CMACS, 2011). Relatively high densities of invertebrates recorded during the baseline survey in 2005 decreased markedly in the 2006 survey (during construction), and then recovered slightly in 2007. The 2009 densities were about 25% lower, due to changes in the most abundant species of polychaete worms and bivalve mollusks. These trends in grab data were supported by the results of the 2 m beam trawl surveys. Despite these changes, (CMACS, 2011) concluded that there was no marked difference in overall invertebrate community composition between years. It was concluded that natural processes leading to sediment influxes coupled with bioturbation (sediment destabilization by deposit feeding invertebrates) are sufficient to explain the observed variability which was described as far back as the 1970s on Burbo Bank (CMACS, 2011). Supporting evidence is available from the bathymetric surveys above.

The Westermost Rough OWF comprises 35 turbines located approximately 12 km from the shore at its nearest point. The seabed is dominated by highly heterogeneous gravelly sand, gravel and cobbles with patches of boulder and small areas of low lying stony reef. Comparison of pre-construction benthic data with data collected during the first year of operation at Westermost Rough OWF revealed a shift in community structure characterized by a change in some of the sub-dominant species and differing abundances of the principal characterizing fauna (PMSL, 2016). Total numbers of species were higher during the first year of operation, with a greater range of epifaunal taxa recorded, compared to pre-construction values. It was noted that temporal and spatial variability is likely to be naturally high in these coarse mixed sediments and that higher level biotope classifications were broadly consistent between years. Similar species differences also occurred at reference sites supporting natural variability over OWF effects. PSML (2016) concluded that "*observed differences between pre and post construction surveys are likely to reflect natural small scale spatial and temporal variability and are unlikely to be solely attributable to construction of the wind farm or indicate significant anthropogenic impacts*".

The Gunfleet Sands 1 and 2 OWFs located in the Outer Thames Estuary, UK, were constructed in two phases, starting 2008 and ending 2010. The export cable was installed using two methodologies. Most of it was installed by plough, however, a small section (about 300 m) closest to the offshore substation was installed by jetting with an ROV. The planned burial depth was 1 m to 3 m. There was a significant increase in organic content of sediment samples collected at export cable route sites between 2007 (pre-construction) and 2010 (post-construction), but not at other locations. CMACS (2012) suggests that this could be related to sediment disturbance by cable laying activities. The export cable route was characterized by muds; the wind farm area was generally sandy. Benthic surveys in 2011 found that the most species-rich sites were those on the export cable route where mud content was higher. However, they also noted that community composition at these sites had not changed significantly since 2007. Sites on top of the sand bank had lower levels of species richness (CMACS, 2012).

Monopiles were installed at Gunfleet Sands by pile-driving. No scour protection was installed (except at one site where the target depth could not be reached) because the monopiles were designed to resist the development of scour pits. Post-construction surveys found that scour was more intense than predicted in the EIA. Scour at six turbines and at one substation were measured. The average area of scour was about 40 m by 31 m; scour depths were deeper than predicted, ranging 7.6 m to 8.0 m from the surrounding bed; no significant scour was associated with the cable route. Scour wakes extending about 340 m to 370 m from two turbine sites were noted (see section 3.6.3.2). Multi-dimensional scaling (MDS) plots indicated that stations closest to monopiles were well clustered together amongst other sampling stations within the wind farm both between and within years, suggesting that scour effects had not shifted community composition away from that typical of the wider wind farm area. However, CMACS (2012) acknowledges, "*in practice, scour monitoring stations are positioned no closer than approximately 60 m from a turbine*". CMACS (2012) concluded that benthic community diversity within each treatment area, as measured by the Shannon-Wiener index, has not changed significantly between years.

Following construction of the two turbines at the Gunfleet 3 demonstrator site, only a single post installation benthic ecology survey of the export cable route was required to fulfil licence conditions (Natural Power, 2013). Data collected approximately 7 months after the offshore cable installation were compared with baseline data collected 2 years previously. This revealed a significant difference in communities between years, characterized by an increase in juvenile bivalves, but no difference between treatment and reference areas within years. Natural Power (2013) concluded that the observed changes were a result of natural variation and that this reflected similar observations at other OWF sites.

No major differences in the composition of benthic fauna of the Egmond aan Zee OWF and reference areas were found a few months following completion of construction. Overall, species diversity and biomass of benthic communities of the sandy seabed between the turbines were well within the range of reference values. Furthermore, no significant difference in the settlement of bivalves between the wind farm site and reference areas were found. The exclusion of commercial fisheries activities from the wind farm was attributed to apparent correlations between bivalve abundance and sediment type. All analyses indicated that there were no short term effects of the wind farm construction, although it was acknowledged that further monitoring would be required to determine longer-term effects.

Other OWF reviewed during this study (e.g. Kentish Flats, Robin Rigg, Lynn and Inner Dowsing, Rhyl Flats, and North Hoyle) reached similar conclusions: that any broadscale fluctuations of parameters measured/calculated during monitoring programs could not be attributed to the construction/operation of the OWF; localized effects on benthic ecology, e.g. disturbance through seabed intervention, was followed by a phase of recovery. An example of a typical 5 year licence compliance benthic ecology monitoring campaign at North Hoyle OWF is presented in the following case study and as summarized in nPower (2008).

Case Study 8: Benthic Ecological Monitoring
North Hoyle Offshore Wind Farm

Background

North Hoyle Offshore Windfarm (NHOWF) is Wales' first OWF, situated in Liverpool Bay, approximately 6 km off the North Wales coast at Prestatyn. The wind farm, owned by NWP Offshore Ltd, features 30 Vestas 2 MW turbines.

Consent for the project was granted in August 2002. Offshore construction commenced in March 2003 and was completed in March 2004, with partial operation from November 2003. A program of offshore environmental monitoring was undertaken prior, during and following the completion of construction works, as summarized in Table below.

FEPA Ref Year	Phase	Year
Year 1	Pre-construction	2002/3
Year 2	Construction (Phase 1)	2003/4
Year 3	Post construction	2004/5
Year 4	Post construction	2005/6
Year 5	Post Construction	2006/7

Methods

A total of 17 sampling stations were identified for annual benthic grab surveys to monitor impacts of the NHOWF on the subtidal benthic invertebrate communities. These 17 sites were initially surveyed in 2002 prior to construction and again in 2003 after installation of wind farm monopiles and cables. In 2003, three new sites were added within the turbine array, which were monitored during the subsequent surveys.

Surveys were undertaken at the same time of the year (September) to maximize comparability between years. Grab sampling was undertaken by means of a standard 0.1 m^2 Day grab, and triplicate grab samples were taken at each station. Samples were subsequently washed over a 1 mm mesh sieve and all the fauna retained was identified to the highest possible taxonomic level and enumerated. Sessile colonial epifauna were recorded as present/absent.

In addition to the grab sampling, a total of 22 beam trawl sample stations were selected within and around the NHOWF to assess the demersal fish and epibenthic communities. Sampling was undertaken by means of a standard 2 m beam trawl with a 4 mm square mesh cod end, with a chain matrix. Trawls were carried out at 1 m/s speed along a 300 m track. All commercial fish were measured, with elasmobranch species also being sexed. All other species of fish as well as epibenthic invertebrates were counted; sessile colonial invertebrates were recorded as present/absent or weighted. Subsampling was adopted when very large hauls were obtained.

Data analysis was undertaken using the statistical package Quest Research's Plymouth Routines in Multivariate Ecological Research (Primer-E) (v5). The whole faunal dataset was analyzed, including colonial organisms which were assigned a value of 1 for analytical purposes.

Results

Assessment of the results from grab samples analysis indicated great variation in the number of taxa and abundance of benthic organisms, both within and outside the wind farm, which were interpreted as being associated with natural variability of environmental factors such as the nature of the sediment and/or recruitment and survival of benthic organisms.

Specifically, changes of benthic community in 2003 and 2004 were associated with a large reduction in faunal diversity and abundance. The subsequent 2005 and 2006 surveys, however, showed a recovery of faunal diversity and abundance, with levels comparable to those recorded during the 2002 pre-construction survey. Statistical analysis revealed changes in community structure across the development and the control sites, although slightly less consistently. Therefore, the report concluded that there was strong evidence that both temporal variation and short-scale spatial variability in benthic communities were affected more by natural processes than by the construction and operation of the NHOWF. However, the report also acknowledged that a degree of uncertainty remained in determining whether these changes were solely associated with natural variability.

The temporal changes of biotopes identified during the initial 2002 survey were not considered indicative of a shift in community composition, rather a reflection of changes in the abundance of selected species, which determines the split between very similar biotopes, as reported in the classification adopted in the study.

A total of 32 fish species were recorded in the trawl samples over the five years of survey. The abundance showed a threefold increase between 2001 and 2006, with no spatial pattern of distribution, rather a general increase in fish numbers at each trawl site.

The results from the 2006 beam trawl monitoring survey supported the results from the previous surveys which identified the fish and epifaunal communities within and around the NHOWF as being typical of the Irish Sea. The main fish and epifaunal communities identified was the flatfish plaice / dab (*Pleuronectes-Limanda)* assemblage, which is found within the 20 m contour of Liverpool Bay and is typical of such shallow and sheltered soft-bottom environments. Some of the communities identified within the NHOWF, as well as to north and west of the development, hosted abundant hydroids, bryozoans and softy corals such as *Alcyonium digitatum*, which are typical of coarse and stony grounds, and showed similarity with the Thickback Sole-Hermit crab (*Microcheirus-Pagurus*) assemblage which is found beyond the 20 m contour of the Irish Sea.

Conclusion

Overall, results of the five years of surveys showed no evidence to suggest that the construction and operation of the NHOWF had altered the fish and benthic communities of the area. The faunal assemblages remained unchanged over time and no significant change in the species diversity and composition from the baseline data of 2001 was observed. Changes in the abundance and distribution of some of the most abundant species were recorded throughout the windfarm site, the near-field and the control sites, and as such they were attributed to natural variability.

To date, the majority of available longer term (i.e. 3 years or more) post construction monitoring relates to comparatively small OWFs of around 30 to 40 turbines in size. Post construction monitoring for the larger OWFs in the UK, for example Greater Gabbard (140 turbines), London Array (175 turbines) and West of Duddon Sands (108 turbines) are not complete and so evidence as to the longer term effects of habitat loss and seabed disturbance as a result of their construction and operation on benthic ecology is not yet available. However, some studies have been completed during the first year of operation of these larger OWFs, the findings of which are briefly reviewed below.

A significant reduction in the fines content of seabed sediments was reported one year after construction of the Greater Gabbard OWF (CMACS, 2014) compared to pre-construction data collected approximately 4 years previously. However, comparison with longer term datasets collected approximately 8 years previously, and during the initial EIA investigations, showed that fines levels were similar suggesting a degree of natural variability in this regard. CMACS (2014) considered that the amount of fines settling on the seabed in this area is strongly influenced by the high energy wave environment and winter storms along this part of the coastline. Differences in species composition were also observed between years but were insufficient to support a wind farm effect. Natural variability related to the observed fluctuations in sediment composition was attributed to observed faunal differences.

Significant temporal and spatial changes in the benthic community structure of predominately shallow water mobile sand bank habitats were recorded 1-year post construction at the London Array OWF (MarineSpace, 2015). The temporal differences were attributed to changes in the abundance of common species, representative of the local sand bank habitats, rather than any changes in species identities. No gross changes in biotope type occurred over time although boundaries had altered. No explanation was offered as to the observed spatial differences other than that this was due to the effects of natural variability given that a universal change, across the entire study area, had occurred.

Small but insignificant changes in sediment composition were observed one year following construction at the West of Duddon Sands OWF (NIRAS, 2016). Seabed sediments retained their respective pre-construction classifications including muddy sand and sandy mud. Changes in sediment composition noted across the array were reflected within the reference area suggesting natural variation. Macrobenthic communities were noticeably different between the two sampling occasions. Key differences included a decline in characterizing species such as the brittlestar *Amphiura filiformis*, the horseshoe worm *Phoronis* sp. and the bivalve *Kurtiella bidentata*. However, similar changes were also observed at reference stations suggesting that the observed changes were due to natural variation.

5.6.2.1 Uncertainty

Uncertainty about the characteristics and scale of natural variation has plagued many monitoring programs in efforts to assess potential impacts of OWFs using before-after comparisons mainly because baseline monitoring was limited to very short timescales. The first phase of Thorntonbank OWF was constructed in 2008. Coates et al. (2013) compared 2005 to 2012 monitoring data for the OWF against 18 years' historical data (1980 to 1998) obtained from two Belgian research institutes. They concluded that long-term data of soft sediment macrobenthos showed clear inter-annual variability in average macrofaunal abundance on the Thorntonbank and neighboring Gootebank (a control area). Densities on the Thorntonbank were highest in 1986 while Gootebank densities were highest in 2008. Minimum densities occurred for both sandbanks in 1998; the authors cite evidence that the likely cause was extremely cold winter temperatures and the negative North Atlantic Oscillation index in 1995/1996. A temporary change in macrobenthic community composition was recorded on the Thorntonbank (compared to the control area) after construction of six gravity-based foundations there in 2008. Subsequent data show that the community entered a recovery phase. Coates et al. (2013) emphasize the "*utmost importance of collecting samples during or straight after construction to determine the direct effects of any works carried out*".

Temporal fluctuations in species numbers at the Alpha Ventus OWF were reflected in the reference areas suggesting that the construction and subsequent 2 year of operations did not have a significant effect on epifaunal species richness in the wind farm site over and above the natural variation. However, abundance and biomass values of epifauna did differ after two years. Furthermore, all infaunal community measures within the wind farm differed from those at the reference areas suggesting wind farm effects or an effect associated with the exclusion of commercial fisheries although it was concluded that further seasonal monitoring would be required to confirm potential effects.

For most of the cases investigated, the UK OWF construction monitoring reports did not reveal conclusive data on the scale/nature of habitat loss, in reference to the ES Project Description. An exception to the above was the report for Walney OWF. Project engineers realized shortly before installation that a plough (for installing the export cable) would be unable to penetrate sediment along a section of the route, and they instead opted for a vessel-mounted backhoe plough (BHP). Management of change (MoC) in consultation with relevant authorities required a benthic camera study to assess the extent of any impacts due to the changed method. Unlike the plough, which creates a cut in the seabed, inserts the cable, and closes the cut in a single operation, the BHP places excavated sediment to one side of the cable trench until the cable has been laid, after which the sediment is used to backfill the trench over the cable. The survey obtained seabed imagery along four transects across the trench, confirmed seabed conditions after trenching and backfilling, and produced a graphical representation of seabed disturbance to allow spatial scale of any impacts to be understood. The survey found that impacts were not visible at distances greater than 26 m from the trench. However, suspended sediment levels were higher after cable installation, and this was associated with the operation of the BHP. Although the report did not comment on the magnitude or significance of differences (compared to plough), and did not state if the authorities were satisfied that changes remained acceptable, the detail of the MoC and the findings of the survey provided useful information in the monitoring report.

The integrity of intertidal communities was monitored during construction of the Robin Rigg OWF wind farm (Entec, 2008; 2009a & b). Sensitive and legally protected reef areas (*Sabellaria alveolata*) in the intertidal zone, landfall of the export cable triggered a need for intertidal monitoring. Monitoring records showed that the intertidal reef had been damaged in several places possibly by construction vehicles that had been driven over it highlighting a potential failure in construction management. The need for a clear, tested management plan, linked to a monitoring and non-compliance system, should be included in construction monitoring; such information is relevant to future mitigation and monitoring requirements. The following case study reviews the intertidal monitoring that has taken place at the Robin Rigg export cable landfall site (Entec, 2008; 2009a & b).

Case Study 9: Intertidal Benthic Monitoring **Robin Rigg Offshore Wind Farm**
Background Robin Rigg OWF is Scotland's first OWF, located at Robin Rigg, a sandbank midway between Galloway and Cumbrian coasts in the Solway Firth. The windfarm first generated power for test purposes in September 2009, and was completed in April 2010. The wind farm comprises 58 MW Vestas Turbines, and is connected via an offshore substation using two export cables which operate at 132 kV. These cables come ashore near Seaton, Cumbria and continue for approximately 2 km inland to an onshore substation. As part of the application process for permission to develop the Robin Rigg wind farm, an EIA was required, together with a Marine Environmental Monitoring Program (MEMP). The latter was developed in conjunction with Robin Rigg Management groups (RRMG). The remit of the MEMP was to record any changes to the physical and biological environment potentially associated with the construction and operation of the windfarm. The present case study focuses on the intertidal area of the cable landfall, which is known to host large colonies of the honeycomb worm *Sabellaria alveolata* (*Sabellaria* reef) which is nationally and internationally (Europe) protected. **Methods** Intertidal ecology surveys were conducted by simple walk-over surveys along the length of the corridor and along the edges of the reef noting the presence of common species. Digital photographs of the shore were taken. Information regarding the location of the *Sabellaria* reef was then plotted onto Ordnance Survey (OS) maps to allow temporal comparison between surveys. An initial survey was conducted in 2004 on the intertidal area of the cable landfall to establish a suitable route across the shore which would minimize any disturbance to the *Sabellaria* reef. A corridor of sandy ground was identified between patches of *Sabellaria* reef which would allow a cable route to be laid without disturbing the reef. A subsequent survey was conducted in 2008 prior to commencement of work in order to re-map the

location of the *Sabellaria* reef. A further survey was conducted in 2009 after the installation of the first cable, with a view to re-mapping the location of the *Sabellaria* reef and sandy corridor to aid the positioning of the second cable.

Results

Results of the surveys showed that the position of the corridor between the *Sabellaria* reefs had changed very little between the initial 2004 survey and the subsequent 2008 and 2009 surveys, with the areas of *Sabellaria* reef to the north and south of the corridor remaining in good conditions.

However, possible track and plough marks of the cable installation construction machinery had had obvious physical impacts on the beach and on the reef itself in some locations. In addition, in many places the tracks had been filled with transient sand, making the *Sabellaria* reef, unlikely to re-establish on these tracks, as the in-fill material would be unsuitable. The remedial action outlined in the report was replenishment of the tracks with cobbles in order to provide a suitable substrate on which the reef could re-establish itself.

Figure 5.4: **Physical impacts of export cable installation on the lower shore at Robin Rigg Offshore Wind Farm**
(source: Entec, 2009b)

During the last survey, in 2009, it was also noted that the *Sabellaria* reef on the mid shore had diminished in some places. This was attributed to the particularly cold winter of 2008/2009. *Sabellaria alveolata* is at its northern limit in the Solway Firth and, being particularly vulnerable to frost, is killed by freezing temperature. The cold winter of 2008/2009 is likely to have resulted in freezing temperatures at low water when the reef is exposed, thus killing off the *Sabellaria* worms. *Sabellaria* reef in the mid-shore is more likely to be affected by cold temperatures, as it is exposed more often by the retreating tide. Conversely, the reef on the lower shore is more protected by the relatively warm sea water.

Management intervention during construction of OWFs has been undertaken to mitigate potential adverse effects on valued benthic receptors but has generally been limited to the monitoring of suspended sediment values against agreed thresholds at which it is judged that the receptor in question becomes intolerant (see Chapter 3). However, it may be argued that monitoring of the responses of the benthic receptors themselves could provide more relevant feedback to inform construction operations and to establish clear cause-effect relationships. Such feedback monitoring has been employed at Lillgrund OWF where a range of species parameters were monitored to provide feedback to mitigate for potential adverse impacts of sediment spill during dredging OWF operations as explained in the following case study (Vattenfall, 2010).

Case Study 10: Feedback Control Monitoring of OWF Dredging Activities
Lillgrund Offshore Wind Farm

Background

The Lillgrund OWF comprises 48 turbines located 9 km offshore of the Swedish south coast in the Baltic Sea. Construction commenced in 2006 and was completed in December 2007. The turbines were installed using gravity base foundations for which pre-dredging of the seabed was required prior to placement. In recognition of the potential risk of significant impacts on benthic ecology as a result of sediment spill from the dredging, a program of feedback control monitoring was initiated. This program monitored established ecological thresholds which, if exceeded, may have resulted in direct action to modify construction activity to lessen the impact.

Methods

Two receptors were identified as suitable faunal and floral representatives of the local benthos for feedback control monitoring. These included seagrass (*Zostera marina*) and mussels (*Mytilus edulis*). Three seagrass variables were selected for feedback monitoring including 'shoot density', 'shoot biomass' and 'carbohydrate levels of the rhizomes' It was decided that a reduction of these variables by more than 25% over baseline values would initiate mitigation. These variables were selected on the basis that they have shown a rapid response in experiments with artificial shading, while statistical power analysis indicated that only a limited number of replicates is required to determine statistically significant changes.

Parameters for monitoring of mussels included 'sediment coverage' and 'coverage by mussels' as determined by video screening.

Baseline seagrass data were collected in May to June and August to September. The monitoring was conducted in the corresponding months during the construction. Before, during and after monitoring of mussel and sediment coverage was conducted using seven transects, each 500 m in length positioned with reference to numerical predictions of the sediment transport and currents in the area.

In addition, the benthic sediment fauna along the buried cable route was examined for the combined effects of physical disturbance and EMF emissions. The researchers developed a Benthic Quality Index for comparison of benthic communities pre and post installation.

Figure 5.5: **Seagrass bed (*Zostera* sp.)**
(source: Vattenfall, 2010)

Results

Monitoring of sea grass beds during the installation of turbine foundations and inter-array cable at the Lillgrund OWF showed an initial increase in shoot density, shoot biomass and rhizome carbohydrate compared to baseline values followed by a period of decline over the subsequent year. During this time, divers noted a general disappearance in vegetation at monitoring stations together with the appearance of other species. Similar observations at other sites within the region and outside of the likely influence of construction suggested a general decline in eel grass probably caused by general sea temperature changes, large quantities of smothering filamentous algae and heavy blooms of cyanobacteria not related to OWF construction activities. Declines at stations within impacted areas were less than those observed at reference stations supporting the view that observed effects were not linked to the construction of the wind farm.

Monitoring of mussels during dredging for wind farm foundations at Lillgrund OWF identified healthy populations throughout predicted impact areas for the duration of the activity. No evidence of sediment spill covering the seabed was observed.

Similarly, no significant effects on benthic fauna were recorded following installation of the Lillgrund OWF export cable to 1 m depth burial depth below the seabed. Values for the modified Benthic Quality Index (BQI) at stations within areas impacted by the cable installation were not significantly different from their baseline values. Comparison of other primary variables was inconclusive and any observed negative results were attributed to environmental factors such as temperature and oxygen fluctuations together with wind and wave erosion.

Conclusions

No negative construction effects were noted during the feedback control monitoring and no evidence of sediment spill was recorded. Observed declines in seagrass were attributed to regional declines, outside of the influence of the OWF.

5.6.3 Electromagnetic Fields and Heat Emissions from Power Cables

Potential impacts of EMFs on marine benthic invertebrates depend upon the characteristics of the fields produced by the cable, the sensory abilities of a species, the life functions that its EMF senses support, and its biology (e.g. life cycle stage).

In their comprehensive review, Normandeau et al. (2011) conclude that there is no direct evidence of impacts to invertebrates from EMFs generated by submarine power cables; Fischer and Slater (2010) concluded the same. However, Normandeau et al. (2011) noted that few marine invertebrates had been studied for this purpose, and that studies had focused on the behavior of mobile adults; their larval stages are less studied. Thus, any discussion of potential impacts of anthropogenic EMFs on marine benthic invertebrates requires considerable speculation that may possibly overlook a number of potentially more sensitive species.

Malm (2005) found no abnormalities in assemblage structure during a visual survey of benthic communities along, and on, an OWF power cable, suggesting that EMF and heating effects did not influence assemblage structure. Similarly, Love et al. (2016) observed no statistical difference between invertebrate assemblages along energized and un-energized cables, although the densities of two species (sand star and black crinoid) were statistically different between energized and un-energized cables.

Mainwaring et al. (2014) excluded EMF from their study of the sensitivity of blue mussels to anthropogenic pressures on the rationale that "*Mytilus species are not known to be affected by electromagnetic fields*". In their study of benthic communities before, during and after construction of Horns Rev OWF in Denmark (Leonard and Pedersen, 2006) state "*Impacts from … electromagnetic fields … on the benthic communities are considered as negligible or non-detectable*" and were therefore excluded from the study.

5.6.4 Colonization of Hard Surfaces, Reef Effect and Invasive Species

Coates et al. (2011) reported on a "small-scale" study focused on the benthos in the immediate vicinity of a single turbine at Thorntonbank, offshore of the Belgian coast. Their aim was to determine if any smaller scale changes had occurred since the installation of the turbine foundations. Benthic samples were collected at seven stations along each of four radii stretching away from the turbine: the north-west (NW) and south-east (SE) radii were perpendicular to the direction of the main current; north-east (NE) and south-west (SW) were parallel to it. Benthic samples were collected along these radii at distances of 1, 7, 15, 25, 50, 100, 200 m from the gravity based structure.

Coates et al. (2011) highlighted the following findings:

- Lower median grain size and higher macrobenthic abundance were detected in closer proximity to the turbine;
- High chlorophyll a concentrations, lower median grain size, and high abundance of soft-sediment species were recorded in samples collected along north-east and south-west radii, parallel to the flow of tidal currents; and
- Samples collected along the north-west and south-east radii (perpendicular to the currents) were mainly dominated by tube building amphipods, known for stabilizing soft substrates.

The authors emphasize that this provides a clear indication of a shifting macrobenthic community, and suggest that the changes in abundance and species composition could be due to:

i. Tidal currents that decrease in speed around the bottom of the gravity-base structure resulting in sheltered areas promoting the settlement of larvae;
ii. Changes in sediment characteristics (smaller median grain sizes), although not statistically significant, caused by changing hydrodynamics;
iii. Higher production of particulate organic matter (POM) by epifauna on the turbine structure, and deposition of this on the seabed, providing additional source of food for benthos; and
iv. seabed depressions caused during construction acting as traps for settlement of larvae and POM.

The authors further suggest that this illustrates the importance of focused, small scale monitoring plans together with research on seabed morphology, to determine the effects of OWF structures on soft sediment macrobenthos.

Degraer et al. (2012) highlighted the link between hard-substrate epifouling organisms and adjacent natural, soft-sediment macrobenthic and epibenthic communities. They observed an enrichment of the benthos close to the wind turbines, extending to a distance of at least 50 m from the erosion protection layer; a gradient from strong effects close to the scour protection to scant effects at 100 m distance. Invertebrate densities reached approximately 55,000 individuals/m², with juvenile starfish (*Asterias rubens*) overwhelmingly dominating the macrobenthos nearby the wind turbine foundation in some instances. Excluding the juvenile starfish, densities ranged ~2,000 ind./m² (at 100 m) to ~9,000 ind./m² (at 15 m). They also noted an increase in species richness from 10 spp./0.1 m² (at 100 m) to 23 spp./0.1m² (at 25 m), and consequently a significant change in community composition from the natural *Nephtys cirrosa* community to a community closely related to the rich, nearshore *Abra alba* community. Degraer et al. (2012) repeated the observation of Coates et al. (2011) supporting the findings that these patterns were particularly visible in directions parallel to the prevailing tidal currents.

Barrow OWF surveyed monopile epifauna during the construction phase approximately 8 months after installation. They found that all surveyed monopiles had been colonized, and that communities were at varying stages of development. Factors proposed to account for differences included age-in-water, water depth (light attenuation) and turbidity, and tidal streams or wave action; the report did not provide substantial discussion of these factors. The construction report did not address invasive species, although operations monitoring did (see below).

Other studies (e.g. Bunker, 2004; EMU, 2008a, 2008b) have also shown that epifaunal colonization of wind farm structures starts soon after installation, that there are clear zones/bands, that a process of succession occurs that can be affected by storm events etc., and that the type of structure (e.g. monopile or gravity base) and natural factors influence the community composition and growth.

The new hard substrate habitats available after construction will be colonized by species that were not present, or at least not abundant, in the pre-development area.

After construction of the turbine foundations at Alpha Ventus OWF in German waters, species diversity and biomass of the fouling assemblage increased steadily and within two years, there were 100 times more hard bottom species growing on the foundations than in former soft sediments, and biomass had reached more than 20 kg/m^2 in the shallow subtidal mussel accumulation. The foundation structures were densely colonized by young brown crabs (Lüdeke, 2015). Fouling communities that inhabit the bases can add a large amount of weight to the structure.

The blue mussel is a dominant invertebrate species on rocky substrates in the North and Baltic Seas, and is often seen in high densities on turbine foundations. The extent of biofouling of hard surface structures at the Egmond aan Zee OWF increased during 2007 to 2009 (Bouma and Lengkeek, 2009; Bruijs, 2010). A clear zonation in fouling communities was identified at three monopiles. An upper, mussel-dominated zone extended to a depth of about 15 m; although this zone extended deeper on one monopile. Below the mussel-dominated zone, the community comprised soft fouling species in a relatively thin layer. Increased drag by currents/wave action caused clusters of mussels to occasionally loosen and detach.

As noted previously, hard-substrate epifouling organisms encrusting turbine foundations and scour protection tend to spread into and enrich surrounding soft-sediment macrobenthic and epibenthic communities. Wilhelmsson and Malm (2008) compared fouling assemblages on turbine foundations to those on nearby natural hard substrate including rocks and boulders. Assemblage composition on the foundations was significantly different to that on nearby boulders, noting that species number and Shannon-Wiener diversity were significantly lower on the turbine foundations. It was also indicated that the turbine-based assemblages might affect assemblages of invertebrates and algae on nearby boulders.

Burial of power cables is not always possible, especially in rocky areas. Alternate methods to protect seabed cables include the placement of rock/concrete mattresses, or the use of articulated pipe. Magnetically sensitive species, such as some species of crustaceans and mollusks, may be present amongst existing or newly colonizing organisms. There is no clear evidence yet that the distributions of potentially magnetically sensitive species significantly affect the composition of assemblages growing on or close to submarine power cables.

5.6.4.1 Invasive Species

There is a worldwide concern about the spread of invasive species and recent studies have illustrated the potential role of OWFs as ‘stepping stones’, creating new pathways for current-mediated dispersal (Adams et al., 2014). Most OWFs are, or will be, located near-shore in shallow waters, in proximity to intense anthropogenic activities. Recreational boating can be responsible for the spread of alien invasive species, especially on a local scale, that will ultimately determine the extent of the economic and environmental impact of a non-native species (Johnson and Carlton, 1996; Lodge et al., 1998; Ashton et al., 2006). The proliferation of marinas and recreational vessels has become increasingly implicated in the spread of marine non-native species (Ashton et al., 2006), with examples in the UK of non-indigenous bryozoans initially recorded in marinas which then spread into natural rocky shore environments, becoming invasive alien species (Ryland et al., 2011).

Kerckhof et al. (2011) studied colonization by non-indigenous species of OWF structures in Belgium, and demonstrated that the new artificial hard substrata do offer opportunities for non-indigenous species (introduced as well as range-expanding species from the Atlantic to enter the southern North Sea. Or, if already present, to expand their population size and hence strengthen their position in the southern North Sea. They note that obligate intertidal hard substrata species, for which other offshore habitat is rare to non-existing, are at particular risk.

Leonard and Pedersen (2006) studied fouling of Horns Rev structures, and found two species, the initial colonizers including the amphipod *Jassa marmorata* and the marine midge *Telmatogeton japonicas*, that had not previously been recorded in Danish waters. They also noted records of *Caprella mutica*, a non-indigenous or alien species introduced from the Japanese Sea. Occasionally some of these species were recorded in samples of soft-sediment benthos and they raise concern that threatened species such as Ross worm (*Sabellaria spinulosa*) or whiteweed (*Sertularia cupressina*), might experience additional pressure from invasive species.

Other assessments of epibiota on hard surfaces at UK and EU OWFs have identified the following alien species native to the Pacific Ocean or Gulf of Mexico:

- Acorn barnacle (*Elminius modestus*) at Thorntonbank (Kerckhof et al., 2009, 2010) and at Kentish Flats (EMU, 2008b);
- Giant barnacle (*Megabalanus coccopoma*) at Thorntonbank (Kerckhof et al., 2009, 2010);
- Slipper-limpet (*Crepidula fornicata*) at Thorntonbank (Kerckhof et al., 2009, 2010) and at Egmond aan Zee (Bouma and Lengkeek, 2009);
- Pacific oyster (*Crassostrea gigas*) at Egmond aan Zee (Bouma and Lengkeek, 2009);
- Asian sea squirt (*Styela clava*) (a non-marine species) at Kentish Flats (EMU, 2008); and
- Marine midge (*Telmatogeton japonicus*) at Thorntonbank (Kerckhof et al., 2009, 2010).

Some alien species (e.g. Pacific oyster *Crassostrea gigas*) or leathery sea squirt (*Styela clava*) that are classified as problematic (OSPAR, 2010) or as having deteriorating effects (JNCC[8]) have been found at wind farms sites, although not as major components of the faunal community.

Adequate anti-fouling controls and ballast water management for OWF construction and operation and maintenance vessels are typically required to mitigate for the introduction of potentially invasive species. Additional controls including risk assessment may be required in relation to OWF infrastructure fabricated on shore and subsequently towed to site.

5.7 Section Conclusion

The monitoring reports reviewed to date have recorded change in the subtidal benthic ecology following OWF construction which has been related to natural variation, as indicated by reference data or has been inconclusive with regards to establishing cause – effect relationships. The only exception is the Robin Rigg OWF case previously cited, where physical damage outside of the planned methodology was inflicted during the installation. Where planned installation measures are adhered to, no significant adverse effect attributable to the construction and operation of OWFs has been reported. In particular, the monitoring has shown no significant subtidal impact as a result of the installation and operation of cables to date. However, it should be noted that inadequate survey design and the short duration of the monitoring programs have limited conclusions in some instances.

Seabed disturbances to coarse sediment shores, including to a high value intertidal *Sabellaria* reef have been reported and this has resulted in the persistence of longer term physical impacts of greater significance. Development of, and adherence to, project environmental management plans linked to monitoring and non-compliance systems should be included in construction monitoring, in order to prevent similar impacts occurring in the future.

There is limited evidence of potential organic enrichment and a shift in the infaunal and epifaunal composition at the base of the turbines. Further study is warranted with regard to the likely extent of enrichment effects and associated change in benthos over time. The planned studies at Block Island under the RODEO initiative may provide useful data in this regard. Similarly, the colonization of the hard structures of OWF infrastructure is often considered a positive impact, regarding biodiversity enhancements, however, potential ecosystem linkages, as a result of enhanced feeding opportunities for higher tropic levels over the life of a project remain unclear. Impacts of decommissioning of OWF infrastructure should consider effects on biodiversity and ecosystem services.

Finally, the potential use of OWFs as ‘stepping stones’ for non-indigenous invasive species to expand their range is of concern. The extent to which OWFs contribute to the increased spread of these species is uncertain and should be accounted for and addressed in any project plan where this is deemed a risk factor.

[8] http://jncc.defra.gov.uk/page-1722, accessed on 16 October 2016

6. FISH AND SHELLFISH ECOLOGY

6.1 Introduction

This section reviews information and data relevant to impacts of OWF (OWF) construction and operation on fish ecology.

For the purposes of this review, this section covers fish species and assemblages commonly found in European coastal waters and addresses aspects of ecology related to migration movements, spawning, and nursery habitat and responses to underwater noise and habitat change. This section does not cover commercial fishery issues or related socio-economic aspects. Appendix A presents the monitoring studies and other literature available that have been reviewed to inform this chapter.

Figure 6.1: Whiting (*Merlangius merlangus*) aggregating around the foundation of the North Hoyle Offshore Wind Farm meteorological mast

(Photographer: F. Bunker, source: CMACS, 2004)

6.2 Stakeholder Concerns

OWF construction and operational activities have the potential to introduce anthropogenic generated sound sources into the local underwater environment as well as the potential to disturb seabed sediments. This could lead to interaction with fish and shellfish communities and disrupt life cycle aspects such as migration, over-wintering, spawning, use of nursery areas, and feeding. Many species are particularly valued by stakeholder groups due to their nature conservation designation and/or their commercial value. Consequently, there is concern as to the potential effects of OWF construction and operation which is invariably raised during consultation and scoping exercises. Table 6.1 below summarizes the typical concerns that have been raised by stakeholders in relation to potential effects on fish and shellfish.

Table 6.1 Typical Stakeholder Concerns Relating to Fish and Shellfish Ecology

Concern	Source	Pathway	Effect	Typical Mitigation
Construction/decommissioning Phases				
Generation of underwater noise and vibrations	Piling and drilling of foundations	Noise as sound waves and particle motion transmitted through the water column and seabed sediments	Physiological damage, mortality or avoidance	Temporal restrictions. Soft starts*
Changes to water and sediment quality	Seabed preparation, cable installation and drilling	Sediment plumes, release of sediment contaminants and deposition	Temporary avoidance. Smothering of fish nests and eggs on the seabed	Temporal restrictions
Operational Phase				
Operational noise and vibration	Turbines	Noise as sound waves transmitted through the water column	Avoidance	
Heat and EMF emissions	Operational cables	Propagation through the water column	Avoidance	Burial of cables
Habitat loss, new habitat	Infrastructure	Placement of infrastructure on the seabed	Reduction in total area of critical fish habitat. Attraction (reef effect)	

Note:
***** - Soft starts are generally regarded as embedded mitigation as this is the usual procedure during initial piling prior to full energy piling

6.3 General Monitoring Rationale

Most operational OWFs have been monitored in terms of their impacts on fish and shellfish ecology or have been subject to measures to limit potential construction impacts.

The general intention of the monitoring undertaken to date has been to improve understanding of the potential impacts as predicted during the impact assessment process and to reduce uncertainty concerning the responses of sensitive fish and shellfish receptors. The need to better understand the potential impacts of noise generation on fish on the one hand and the provision of new habitat and fish aggregation effects of the turbine support structures on the other has driven much of the monitoring effort to date. Consequently, the weight of the current monitoring effort has been focused on investigating post-construction effects, such as the potential aggregation of fish and shellfish around structures and the effects of EMF, as these have been regarded to be longer term/permanent effects, lasting for the duration of the development and have also been associated with the greatest uncertainty. In contrast, impacts that occur during the construction have received comparatively less attention. This is because of the generally short-term nature of the impact, the ability of mobile fish receptors to avoid adverse areas, and the application of agreed mitigation measures which avoid significant adverse interactions between noisy construction activities and fish and shellfish assemblages.

6.4 Typical Mitigation Measures

The significance of predicted impacts of wind farm construction on fish and shellfish ecology have largely been assessed as negligible to minor during impact assessments, mainly as a result of the perceived mobility and wide ranging nature of fish, so that adverse areas can be avoided or because the area was not considered to support valued species or critical habitat. Where moderate or major impacts have been assessed, the associated impacts have typically been subject to mitigation measures, commonly in the form of a temporal restriction to piling to avoid potential adverse impacts on identified sensitive life cycle stages. Indeed, seasonal pile-driving restrictions have been frequently imposed during the construction of wind farms in the UK and the Netherlands to limit the impact upon fish spawning grounds for commercial species and fish larvae. Belgium and German wind farms have had noise thresholds which must not be exceeded together with noise limitation procedures to lessen the effects of noise on fish and marine mammal populations. Table 6.2 presents examples of the measures that have already been undertaken, or have been agreed to be undertaken, to mitigate the impacts of OWF construction and operation on fish and shellfish ecology.

Table 6.2: Summary of the Measures Agreed to Mitigate the Potential Underwater Noise Impacts of Offshore Wind Farm Construction on Fish and Shellfish Ecology

Offshore Wind Farm	Mitigation Type(s)	Duration	Receptor of Concern
Kentish Flats	Seasonal restriction on installation of the export cables - herring spawning season	N/K	Herring (*Clupea* sp.)
Rhyl Flats	Retrospective piling restriction Apr to mid-May for spawning sole	~1.5 months	Sole (*Solea solea*)
Thanet	Fish spawning restriction **lifted** following survey and modelling	N/K	N/A
Greater Gabbard	Timing restriction on piling (Feb to mid-May) and cable installation (Oct to Feb) for spawning fish	~3.5 months	Demersal Fish
	Soft-start procedures		
Gunfleet Sands II	Piling restriction – Herring spawning season	N/K	Herring
Ormonde	Piling restriction	~1.5 months	No specific species mentioned
	Soft-start procedures		
Walney	Piling and seismic survey restriction	~ 3 months	Whiting (*Merlanguis merlangus*), Sole, Plaice (*Pleuronectes platessa*) & Sprat (*Sprattus sprattus*)
West of Duddon Sands	Piling and seismic survey restriction	~2.5 months	Cod (*Gadus morhua*), Whiting, Plaice
	Soft-start procedures		
Gwynt y Môr	Piling restriction (only piling for substation allowed during spawning)	~1.5 months	Sole
Westermost Rough	No piling or seismic activities between mid-August and the end of October	~1.5 months	Herring
Burbo Bank Extension	Piling restriction – dover sole spawning	~1.5 months	Sole
	Piling restriction – fish migration	~1.5 months	Salmon smolt (*Salmo salar*) and sea trout smolt

Offshore Wind Farm	Mitigation Type(s)	Duration	Receptor of Concern
			(*Salmo trutta*)
	Restriction on project total foundation numbers – to reduce potential impacts on adult salmon migration	n/a	Salmon
Humber Gateway	Herring larvae surveys during piling (September to October)	~1 month	Herring
Rampion*	Piling restriction – black bream spawning	~2.5 months	Black Bream *(Spondyliosoma cantharus)*
	Piling restriction – herring spawning	~1.8 months	Herring
Galloper	Piling restriction – peak sole spawning season	~1.5 months	Sole
	Piling restriction – peak herring spawning season	2 months	Herring
Walney Extension	Piling restriction - cod spawning season	~ 1.5 months	Cod
	Piling restriction – Herring spawning season.	~ 2 months	Herring
Egmond aan Zee Prinses Amalia	Piling restriction	6 months	Fish eggs and larvae
German sites	SEL must not exceed 160dB (re 1 µPa) and the Peak Level (L_{peak}) must not exceed 190 dB at a distance of 750 m	Construction	Marine mammals
Belgium sites		Construction	
Moray Firth wind farms* Beatrice*	Possible piling restriction not exceeding 16 days depending on the findings of site specific survey findings	~0.5 months	Herring

Notes:
N/K - not known
* - not yet constructed

Potential impacts of EMF emissions have generally been assessed as negligible or minor, as they have been regarded to be highly localized while the mobile nature of the receptors suggest that they are able to move away from affected areas. Monitoring and research conducted to date has not recorded any significant behavior modification due to EMF emissions, such as avoidance or attraction to operational cables or significant changes in migration behavior. Cables are also generally buried where the geology allows to do so, which is generally accepted as suitable embedded mitigation. Any residual EMF effects are considered to be negligible where burial of cables to 1.5 m depth or greater below the seabed can be achieved.

Measures to mitigate underwater noise impacts during OWF construction in Europe are now generally well established, but vary by country. Mitigation measures are typically applied should scoping consultations and/or pre-application investigations identify valued or sensitive receptors within the influence of potential impacts. In addition, the monitoring and research conducted to date supports a developing understanding regarding post-construction impacts on fish and shellfish ecology, although long-term monitoring campaigns have yet to be completed and so conclusions in this regard cannot be reached without caution. For example, the presence of aggregations of fish at turbine locations suggests that operational noise is not a significant issue, at least with regards to those species observed within operational wind farm sites. However, the lack of long-term study means that the effects of lasting exposure of fish and shellfish to low levels of noise from operational turbines is not known. Nevertheless, the development and agreement of during-construction mitigation measures in the pre-application stages are becoming commonly practiced in Europe and has provided regulators and stakeholders with the requisite comfort levels for confident permitting decisions to be. In the US, research and consensus opinion may be needed to identify and agree the duration of the sensitive periods during which disturbance activities should be avoided and the importance of outreach programs and inter-agency liaison cannot be underestimated.

6.5 Description of Impacts

6.5.1 Impacts During Construction/Decommissioning

6.5.1.1 Adverse Underwater Noise and Vibrations

Fish can detect underwater sound, and use this to interpret their environment, identify prey or predators, or in behaviors such as aggression, defense, territoriality, courtship, and mating. An auditory system is particularly important for aquatic vertebrates when visual perception is restricted (Wysocki and Ladich, 2005). The detection of sound is crucial to the lives of fish, and anything that interferes with their ability to detect biologically relevant sounds, could affect their behaviors and even the survival of individuals and populations.

Fish possess two principal sensory organs for the detection of underwater vibrations: the lateral line system, and the inner ear. The lateral line system is stimulated by low frequency vibration (generally below 150 Hz) – water flow relative to the body – enabling fishes to sense, for example, the motion of nearby fish and prey. Fish can also detect the acoustic field when located close enough to the source.

In addition to the lateral line, fishes have a bilateral pair of inner ears that lie inside the cranium on either side of the head. The inner ears of fishes are complex structures that share many physiological features with those of other vertebrates. The inner ears have two major sensory functions: one, the “vestibular” sense, which is related to posture and balance, and the other “auditory” sense is hearing. Hearing is based on the detection of oscillatory movements at a range of frequencies (Popper et al., 2003).

Elasmobranchs (e.g. sharks and rays) lack a swim bladder; they maintain buoyancy with oil that they store in their large livers, or control their depth using dynamic lift. Teleost fishes on the other hand have a swim bladder, or other gas-filled organ, that helps them to maintain buoyancy so that they can conserve energy when swimming. The swim bladder may also enhance the auditory sense of teleosts due to the high compressibility of gas compared to water; a volume of gas exposed to oscillating pressure changes will display larger pulsations than a comparable volume of water (Popper et al., 2003). If the swim bladder is somehow connected and able to mechanically transmit pulsations to the inner ear, it may provide an auditory gain. The proximity of the swim bladder to the inner ear is therefore important; in some fishes it is located further away from the inner ear than in others. Fish having a fully functional swim bladder, e.g. herring and cod, tend to be much more sensitive to noise. Any damage to the swim bladder can also be expected to have consequences for hearing, although swim bladder damage is usually fatal.

Fishes can be divided into three groups depending on their utilization of the swim bladder as an accessory hearing organ (Popper et al., 2003). So called ‘hearing specialists’ either have a bony connection between the swim bladder and the inner ear, or possess gas-filled vesicles in close or direct contact with the otoliths. Species lacking a swim bladder constitute the other extreme; fishes with a swim bladder but lacking specialized connections (e.g. salmon) fall in between. The latter two groups are referred to as 'hearing generalists' (Popper et al., 2003). Hearing specialists (e.g. herring and shad) are able to detect higher frequencies of sound than generalists can.

The two components of underwater sound (vibration and pressure) change significantly with distance from the source. In the near field, extending one wavelength of sound frequency from the source, vibration is the dominant component, and is used by fish to detect the motion of predators and prey. In the far field, extending from one wavelength outwards, pressure is the prevailing component. Fish species that can detect both pressure and vibration are generally considered to be more sensitive to underwater noise.

In general, fish can detect sound within the range of about 30 Hz to 1 kHz, although there are some species that can detect less than 20 Hz, and others that can detect over 20 kHz ((Thomsen et al., 2006) and citations therein).

Noise and vibration can impact directly on fish physiology and affect their behavior. Direct physiological impacts include:

- Injury;
- Temporary threshold shift; and
- Auditory masking.

Loud noise or intense vibration can cause injury in fishes. A distinction is usually made between physiological effects that are not life threatening (e.g. external bleeding at the base of fins), and those that are (e.g. burst swim bladder or massive internal bleeding); the latter are considered "injury" (Popper et al., 2003).

Temporary threshold shift (TTS) is a temporary shift in the auditory threshold – otherwise known as auditory fatigue. It may occur suddenly after exposure to a high level of noise within the hearing range of the animal. The recovery time for TTS varies.

Hearing is limited by detection thresholds. A "masked" threshold occurs when another sound ("noise") partly hides ("masks") the sound of interest (the "signal") and raises its threshold for detection (Popper et al., 2003). Anthropogenic noise can therefore make it more difficult for fishes to detect sounds of interest through masking.

Some fish species respond behaviorally to sound by attraction to the source (e.g. Culik et al., 2001). Fish may also respond to loud noise by attempting to avoid or flee from it. The spatial extent of the zone of responsiveness cannot be calculated, because available threshold levels vary widely (Thomsen et al., 2006). While behavioral response, such as moving away from a primary feeding area, would not be considered an injury, it could potentially lead to physiological effects that result in deterioration in health, or even death. Therefore, the physiological and ecological consequences of behavioral responses need to be considered.

Offshore construction activities such as acoustic sonar surveys (which may include low-frequency, high-energy methods, such as air guns, to high-frequency, low-energy methods, such as multibeam echo sounding or sidescan sonar systems), pile-driving, vessel movements, anchor-handling, and seabed intervention (e.g. blasting, dredging, cutting, ploughing, rock placement) generate underwater noise, and vibration. With the exception of high-frequency acoustic sonar surveys (which are often at or above 100 kHz), construction-related noise is generally low frequency, i.e. in the range of several 10's to 3000 Hz, which is within the hearing range of most fish.

Pile-driving, which is commonly used for the installation of monopile- or jacket-based turbines, is usually the noisiest activity during the construction of OWFs and has been the focus of most underwater noise impact assessments. Piling generates underwater noise at levels observed to cause avoidance behavior in marine mammals (e.g. (Nedwell et al., 2003a); Richardson et al., 1995), and may potentially cause mortality and tissue damage in fish (e.g. Popper and Hastings, 2009). The underwater sound levels recorded during piling are such that they should be regarded as capable of causing significant effects on marine mammals and fish (Nedwell et al., 2003a).

Foundation piles for turbines are usually about 20 m to 30 m long. Pile-driving generates single pulses between 50 ms and 100 ms in duration, with approximately 30 to 60 blows per minute, it usually takes between 1 to 2 hours to drive one pile into the seabed (Nedwell et al., 2003a). Multiple piling events could occur simultaneously during the construction of an OWF. Potential impacts on fish hearing depends on their sensitivity, the generated sound spectra and intensity, and on the length of exposure. For construction of the Kentish Flats OWF, UK, (constructed in 5 m water depth and approximately 10 km from shore) the pile driving operations were anticipated to take between 2 and 3 hours per pile, resulting in a total of 60 to 90 hours for all of the turbines over an anticipated 4-month construction period.

The level of noise produced by piling depends on factors such as the diameter of the pile, water depth, local geology and material properties. Piling the 4 m diameter pile at North Hoyle produced subsea noise levels of 260 dB re 1μPa @ 1 m; most energy was found around 200 Hz, with additional peaks at 800 Hz and 1.6 kHz (Nedwell et al., 2003a). Piling the 4.75 m monopiles at Barrow OWF yielded similar maximum levels. Measurements at the Utgrunden 1 OWF near Bergkvara, Sweden, showed maximum levels of approximately 210 dB re 1μPa at 30 m from the piling site, decreasing to approximately 180 db at 320 m distance (Maxon and Nielsen, 2000). For a comprehensive review of underwater noise levels arising from OWF construction, please see Chapter 3.

For comparison, noise levels produced by seismic airguns range from 210 dB re 1μPa @ 1 m for an average airgun array to 259 dB re 1μPa @ 1 m for a large array (Richardson et al., 1995). Boats and ships generate noises with source levels and dominant frequencies of 152 dB at 6.3 kHz for an inflatable with an outboard motor, 162 dB at 630 Hz for a tug/barge travelling at 18 km/h, and 177 dB at 100 Hz for a large tanker (Vella et al., 2001). Measurements of cable trenching at North Hoyle indicate a source level of 178 dB re 1 μPa @ 1 m (Nedwell et al., 2003a). Side-scan sonar mounted on a ROV can generate 210 dB re 1 μPa at 1 m (Edgetech 2000). Cumulative anthropogenic noise occurs during offshore construction because there are usually several vessels working together with piling and seabed intervention activities.

Based on their measurements of piling noise at North Hoyle OWF and using a threshold criterion of 90 dB_{ht}, (Nedwell et al., 2003a) calculated the distance at which salmon, cod, and dab (*Limanda limanda*) would significantly avoid the noise were 1400 m, 5500 m and 1600 m from source, respectively.

(Knudsen et al., 1997) recorded flight or avoidance responses in juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout exposed to infrasound (10 Hz) in tanks. Fish did not habituate after even 20 exposures. (Bui et al., 2013) also noted a strong flight response by Atlantic salmon to infrasound, where swimming speeds tripled compared to that of controls.

Correlating fish responses to OWF construction piling noise in the field is difficult as fish are difficult to track in open waters, although some acoustic studies have attempted this. The effectiveness of embedded mitigation such as soft starts are therefore difficult to verify although intuitively one may expect fish to move away from affected areas as adverse noise increases.

6.5.1.2 Changes to Sediment and Water Quality

Marine sediments may contain a variety of harmful substances, including arsenic, heavy metals, oil, organo-tin, PCBs and pesticides, which are effectively locked in in undisturbed sediments. Seabed intervention causes disruption of sediment structure and can release these contaminants into the water column, making them available to animals and plants, with the potential to cause toxicological effects, and transfer up the food chain to fish and marine mammals. The likelihood of this occurring depends upon the type and degree of sediment contamination, with the highest levels of contaminants generally occurring in silts of industrialized estuaries. In addition, dredging, cutting, excavation, ploughing, jetting, jacking-up, and anchoring will cause sediments to become suspended in the water column. Depending on local hydrological conditions, suspended sediments may settle out close to origin, or be transported away from the area. Mobile species, such as fish, are able to avoid unfavorable water quality and it is therefore generally not considered a direct risk to their health. Potential impacts to fish more typically acknowledged include:

- Physiological effects through clogging of fish gills;
- Smothering of the eggs of demersal fish spawners such as herring by settling of suspended sediments;
- Reduced visibility that could interfere with the feeding efficiency of predators such as mackerel; on the other hand, the situation might benefit prey species; and
- Habitat loss and direct mortality of burrowing and sand-dwelling non-migratory species such as sandeels (Ammodytidae).

In general, ESs for UK and EU OWFs have used hydrodynamic mathematical models as the primary tools for assessment of the dispersion and settling of suspended sediments. In most cases, it has been argued that smothering would not be significant because:

- Construction activities that generate suspended sediments would be intermittent, spread out over the duration of construction; and
- Resultant plumes would contain concentrations that are typically low and within background levels.

Herring spawn preferentially over gravel, where the eggs stick to the particles and can form large mats of several egg layers. The ES for Greater Gabbard OWF noted that the eggs need to be well oxygenated during development and "*it is conceivable that increased levels of suspended sediment may lead to increased deposition … that may smother any eggs that were present… however, the maximum deposition of sediments from wind turbine foundations and cable laying would amount to very much less than 1mm of sediment and this would not be expected to settle to any great extent over gravel beds which exist because they are present in hydrodynamic areas where finer sediments do not settle preferentially*".

The ES for Rhyl Flats OWF noted that fish likely to use the area as a nursery or for spawning are likely to be most at risk from suspended sediments. Sprat, sole, plaice, and whiting were known to spawn in the vicinity, while inshore waters were generally known to be important for spawning of herring, whiting and plaice. The ES predicted only minor impacts because construction impacts are temporary in nature, and fish demonstrate avoidance behavior, thus in most cases are able to avoid impacts".

The ES for Sheringham Shoal OWF calculated that the area of direct habitat loss due to construction plus the area of indirect habitat loss due to smothering was less than 1% of the estimated spawning ground for herring (*Clupea sp.*) and concluded "*the magnitude of effect is therefore considered to be extremely small*". They further argued that "*the majority of fish species found in the … study area are considered to be tolerant of the moderately high levels of turbidity commonly encountered during storm events, and the short term increases in suspended sediment concentrations predicted during the worst case scenario (i.e. trenching) are not considered to rise above background levels for a significant period. On this basis, the magnitude of effect is not considered significant as the maximum areas affected are highly localized. The potential impact of increases in suspended sediment or smothering on the natural fish resource is considered to be of negligible significance*".

6.5.2 Impacts During Operation

6.5.2.1 Operational Noise and Vibration

Underwater noise from operating turbines is generated in the generators and gears in the nacelle and is transmitted through the tower to the foundation from where it emits into the surrounding water (Tougaard et al., 2008). Underwater acoustic measurements at offshore wind turbines have been made in Sweden, Denmark, and Germany (reviewed by Madsen et al., 2006). Although the turbines differed in size, foundation type, and depth, the recorded sounds were tonally similar, i.e. they were generally dominated by a series of pure tones below 1 kHz, and in most cases below 700 Hz, which did not seem to change with varying wind speed (Madsen et al., 2006). However, there was considerable variation in noise levels, with turbine type and wind speed playing major roles. Third-octave levels of the noise from various types of turbines measured about 100 m from the foundation ranged from 100 dB re 1 μPa RMS to 120 dB re 1 μPa RMS (Tougaard et al., 2008). It cannot be excluded that future, larger turbine constructions could be noisier. The number of turbines and transmission-loss properties (which depend on water depth and bottom type) also influenced the calculated detection and masking ranges, which vary considerably between OWFs (Wahlberg and Westerberg, 2005).

Krãgefsky (2014) reports that the sound frequency generated by an operational turbine is within the general perception range of fish, although the intensity is low and does not cause immediate physical harm to fish. Low intensities notwithstanding, the long-term effects of exposure to low level operational noise remains unknown. The estimated distance at which fish can perceive sound emitting from an operational turbine is below 10 m for a hearing generalist without a swim bladder and below 1 km for a fish with normal hearing capability. A hearing specialist may, however, perceive operational noise at a distance of up to 10 km.

Ingemansson Technology (2003) reported that sound levels increased with the number of active turbines in a wind farm. Additive effects might result where individual sound source levels are high enough to propagate into adjacent ranges. The interference pattern created by the signals from several wind turbines will create a complex sound field (Madsen et al., 2006).

Underwater noise from operational turbines is potentially important because it is present almost continuously during the lifetime of the wind farm. Under favorable conditions (low background noise, low transmission loss), the sound may be audible to seals, odontocetes, and fish at distances up to some kilometers from the turbines (Tougaard et al., 2008). Due to the low intensity and low frequencies of the noise, the impact on marine mammals is considered marginal, but a significant impact on fish cannot be ruled out. Although it is unlikely that fish would be physically harmed by operational noise, there is the potential of creating a masking effect over a wide area.

The effect of the acoustic near-field also need to be taken into consideration. Thomsen et al. (2006) state that in close proximity to the wind turbine, the particle motion component will be much higher for the respective sound pressure values. This is relevant to fish species that are primarily sensitive to particle motion (vibration), e.g. dab and salmon. They conclude that in a range of probably less than a hundred meters around a single turbine, hearing generalists, which are primarily sensitive to particle motion, will perceive much higher relevant impulses. The *zone of masking*, i.e. the area where wind turbine noise might reduce the maximum detection distance between signaler and receiver, could extend as far as the *zone of audibility* in some cases (Wahlberg and Westerberg, 2005; Thomsen et al., 2006).

6.5.2.2 Electromagnetic Fields and Heat Emissions

EMF and heat emissions are byproducts of electricity transmission through the power cables associated with the offshore wind turbines. Intra-array power cables are used to connect turbines to each other and to offshore substations, while an export cable delivers generated power to onshore facilities. Intra-array cables have a lower rating than do export cables; e.g. the cables networking the Horns Rev turbines offshore Denmark have a 33 kV rating while the export cable is rated at 150 kV. The power cables for OWF are usually buried to a depth of 1 m to 3 m beneath the seabed surface to protect against damage due to mobile sediments, scour, trawl fishing, anchoring, and other activities.

EMF will be generated in the surrounding seabed and water by the transmission of electricity through submarine power cables. Conductive sheathing shields the external environment from the direct electric field, and EMF's emitted from power cables into the marine environment are therefore the magnetic field (measured in tesla, T), and the resultant induced electric field (measured in volts per meter, V m^{-1}).

Magnetic (B) Field

Normandeau et al. (2011) noted that while AC transmission is currently the industry standard for OWF in Europe and those proposed in the US, DC transmission would likely be used for future projects that are located further from shore. The authors modelled the expected EMFs from representative submarine power cables, describing a significant difference in the magnitude of magnetic fields from DC transmission compared to those from AC transmission.

Figure 6.2A depicts the average and range of calculated fields for ten AC cables modelled by Normandeau et al. (2011). Figure 6.2:B depicts the average and range of calculated fields for nine DC cables modelled by Normandeau et al. (2011); in these examples, the burial depth was assumed to be -1 m.

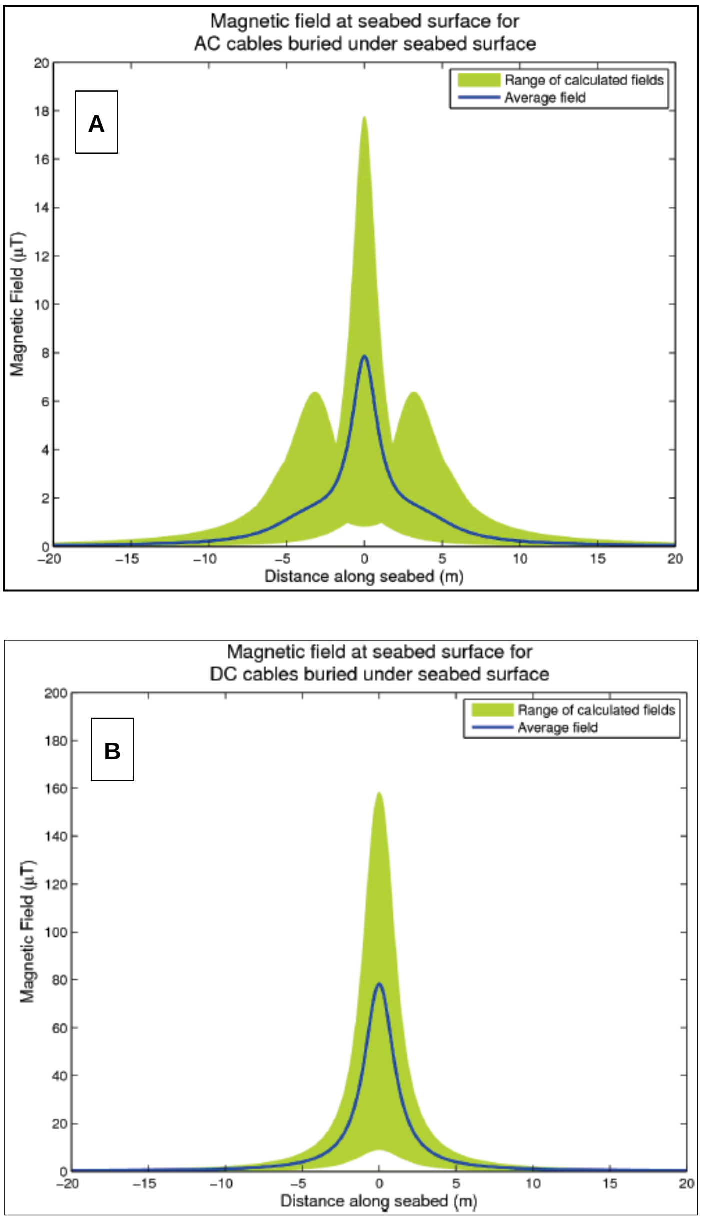

Figure 6.2: Modelled magnetic fields for ten projects using AC transmission (A), and for nine projects based on DC transmission (B)

source: Normandeau et al., 2011

In general, the intensity of the field was roughly proportional to the voltage on the cables (ranging from 33 kV to 345 kV), although they noted that separation between the cables and burial depth also influenced field strength. The predicted magnetic field was strongest directly over the buried cables[9] (average approximately 8 μT, maximum approximately 18 μT) and decreased with vertical and horizontal distance from the cables; the average predicted field strength was less than 2 μT at distance of 2 m from a point on the seabed directly above the cable. For context of scale, the earth's magnetic field ranges 25 μT to 65 μT; a reference value of 50 μT is often quoted in OWF ESs.

They note that "unlike the magnetic field from AC cables, the magnetic field from DC cables can influence the intensity of the local geomagnetic field, as well as its inclination and declination, thus the orientation of the cable relative to the geomagnetic field should be accounted for when considering the effects of DC cables. The DC magnetic field from cables running perpendicular to magnetic north will affect the intensity and inclination angle of the geomagnetic field, but not the declination angle. In contrast, the DC magnetic field from cables running parallel to magnetic north will affect the declination angle of the geomagnetic field as well as its intensity and inclination angle".

Figure 6.3 shows the magnetic field outside an industry-standard AC 13 kV submarine cable buried -1 m under the seabed surface. Magneto-sensitive species are more likely to be able to detect EMFs from DC cables than from AC cables.

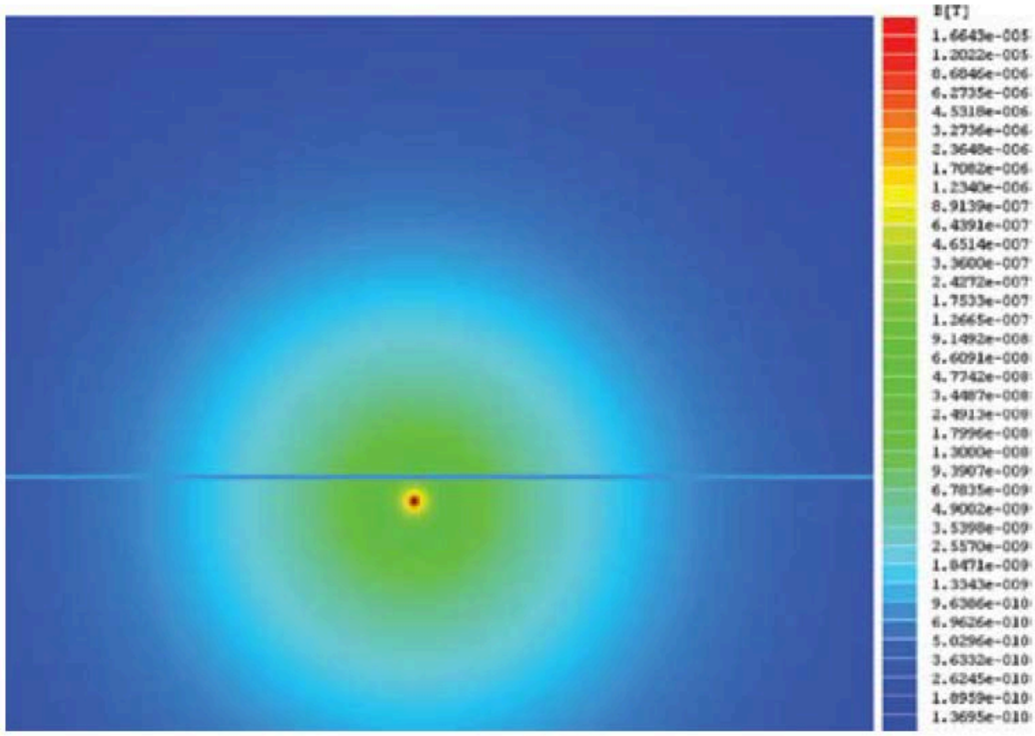

Figure 6.3. The magnetic field outside an industry standard 13 kV subsea cable with AC buried to 1 m; the seabed surface is shown as the horizontal blue line
(Source,:Centre for Intelligent Monitoring Systems, University of Liverpool, UK in Boehlert and Gill, 2010)

[9] The magnetic field appeared as a bimodal peak in two cases where the current was delivered along two sets of cable that were separated by several meters

Sensitivity to EMF depends on a species' ability to detect the field, and the species' response to it. Increasing evidence shows that many marine species, both vertebrates and invertebrates, can sense the earth's magnetic field and use this information for orientation and navigation. Animals that utilize magnetoreception to aid long-range migrations to feeding or breeding grounds have been studied in particular (Normandeau et al., 2011). Most research to date has concentrated on fish.

If anthropogenic EMFs interfere with their perception of the geomagnetic field, magneto-receptive species may become disorientated (Fischer and Slater, 2010). Depending on the magnitude and persistence of the confounding EMF, a trivial temporary change in swimming direction or a more serious impact on migration might result.

Induced Electric (iE) Field

An induced electric field is created by the flow of seawater or the movement of organisms through a magnetic (B) field. Induced electric fields are generally weak, but nevertheless ecologically important. Benthic fish such as skate, rays, and catsharks use electroreception as their principal sense in locating prey. Sharks, such as hammerheads, can detect flounder buried under 15 cm of sand. It can also be used to locate mates and for orientation (Boehlert and Gill, 2010).

The strength of anthropogenic E- and B-fields depends on the magnitude and type of current flowing through the cable and on the construction of the cable. Both E- and B-fields rapidly diminish in strength with increasing distance from the source in seawater (Fischer and Slater, 2010).

Although marine teleost (bony) fish do show physiological behavioral reactions to electric fields, elasmobranchs (cartilaginous fish such as sharks and rays) are more than ten-thousand fold as electro-sensitive. Elasmobranchs possess ampullae of Lorenzini, i.e. specialized jelly-filled pores, which are able to detect low levels of electrical potential. Electrical fields detected by the ampullae are converted into physiological signals and transmitted to the brain by primary afferent nerves for processing. Ampullary receptors are sensitive to weak electric field gradients, and are most sensitive to frequencies below 50 Hz.

It is understood that anthropogenic electrical fields can interfere with electroreception and thereby compromise detection of other fish or prey, communication and the ability to orientate. Gill and Taylor (2001) showed that dogfish (Squalidae) in laboratory tanks avoided 10 μV cm^{-1}, which was the maximum electric field expected from 3 core cables rated at 150 kV, 600 A AC. Although there have been many studies of fish, most have been laboratory-based physiological or behavioral studies. The extent to which EMF from submarine cables affects electro-receptive fish in their natural environment remains rather unclear, as discussed below.

6.5.2.3 Reef Effects

The construction of OWFs introduces new hard surfaces. Examples may include the turbine and substation foundation structures, scour protection (specifically gravel/rock placement), concrete mattresses, articulated pipe, etc. Epifaunal colonization of hard surfaces starts almost as soon as the structures are installed, and development of fouling epifaunal communities continues during the operations phase of the OWF. Factors influencing the epibenthic invertebrate and algae assemblages on and around the artificial reef are salinity and temperature, water movement, light availability, depth, inclination of the surface and material and texture (Andersson, 2011).

The ES for Kentish Flats OWF in the UK describes typical succession of biofouling on gravel armor: “opportunist species, such as encrusting worms and barnacles, would likely be the initial colonizers of the gravel deposits followed by other species characteristic of coarse gravel areas locally. Mobile epibenthic animals such as hermit crabs and common starfish may also rapidly colonize the gravel armor. Depending on the degree of subsequent stability and scour, later colonizers may include encrusting colonial invertebrates such as sea mat and sea fir. These types of animals would attach to the surfaces of larger, stable gravel particles. Other mobile animals such as crabs may also seek cover in the interstitial spaces between the gravel particles. The gravel armoring may, thus eventually host a relatively diverse macrofauna characterized by encrusting and attaching species with mobile epibenthic animals with reduced infaunal biomass”.

Fouling not only produces increasing biomass; new habitats are created that provide shelter against strong currents and predators, providing new habitat for mobile fauna, thereby creating an artificial reef (Hammar et al., 2008). Consequently there can be increases in the number of shellfish and the animals that feed on them, including fish and marine mammals, resulting in a localized increase in biodiversity (Bailey et al., 2014). The development of artificial reefs is usually considered a neutral or positive effect of OWF development. Assessment of the impact (beneficial or otherwise) should consider if the artificial reef results in increased production, or simply aggregation, i.e. a re-distribution of abundance. Artificial reefs on turbine foundations differ from some other anthropogenic structures in that they extend throughout the water column, enhancing biodiversity through depth-related zonation.

Natural reefs are habitats that offer bathymetric relief and are usually characterized by higher diversity of algal, invertebrate, and fish species than their surroundings (Kellison and Sedberry, 1998). An artificial reef is a purposefully or accidentally deployed anthropogenic structure that offers bathymetric relief and, like natural reefs, are characterized by high taxonomic diversity relative to their surroundings
(Bohnsack et al., 1994).

Construction and deployment of artificial reefs is practiced worldwide to manage fisheries, protect and facilitate the rehabilitation of habitats, and/or to increase the recreational value of an area. Artificial reefs generally support higher abundance and biomass of fishes compared to surrounding soft sediments, and even (in some cases) compared to adjacent natural reefs. Reasons why fish are attracted to reef habitats may include better protection and food availability, and the availability of reference points on the reef for spatial orientation (Wilhelmsson et al., 2010). Factors thought to influence the development of artificial reef communities include natural reef availability, mechanisms of natural population limitation, fishery exploitation pressure, life history dependency on reefs, and species specific and age-specific behavioral characteristics (Bohnsack, 1989).

The amount of vertical profile is also known to affect the abundance and diversity of demersal and pelagic fish present on artificial and natural reefs. Beets (1989) reported that benthic artificial reefs associated with midwater fish aggregating devices (FADs) attracted significantly more species and nominally more individuals than benthic artificial reefs without FADs; FADs are structures that create floating artificial habitats suspended at the surface, slightly below the surface, or in midwater between the surface and the bottom (Kellison and Sedberry, 1998). The authors suggested that fouling organisms and pelagic fishes associated with the FAD might indirectly affect the benthic fish community by enhancing benthic productivity: fecal materials, uneaten food particles, and occasional fish carcasses may fall as ‘organic rain’, increasing nutrient supply to the benthos below the FAD and thus increasing benthic productivity (Kellison and Sedberry, 1998). OWF turbine bases provide vertical structures that extend throughout the water column, thereby providing hard surface over a selection of depths, which may cater for different life stages and species of fish. Leonhard et al. (2011) noted that “*full understanding of the potential ecological consequences of deploying OWFs therefore requires knowledge of not only the artificial reef effect but also on ecosystem effects at species, population, habitat and community level, at appropriate temporal scales*”.

Habitat complexity is also known to influence fish community establishment on artificial reefs. The complexity of reef structures can be increased by addition of cavities that offer protection from predators and shelter from water currents, enhancing juvenile recruitment, diversity of species and abundance (Shulman, 1984; Hixon and Beets, 1989). Kellison and Sedberry (1998) investigated the effect of cavity hole presence and diameter on the recruitment and retention of fish to benthic artificial reefs. Units with no holes and units with small or large diameter holes offered different amounts of shelter to reef fishes. They found significantly greater fish diversity and abundance on units with holes than on those without. During the study, fish species such as black sea bass (*Centropristis striata*), spadefish (*Chaetodipterus faber*), gray triggerfish (*Balistes capriscus*), and a species of hake (*Urophycis* sp.) were often observed inside the units with holes. However, they found that the lengths of fishes associated with the benthic units were not significantly related to hole diameter. Surveys at oilrigs, on the other hand, have shown that growth rates and densities were higher, and fish were larger, around these artificial structures compared to those in nearby natural habitats (e.g. Love et al., 1999).

Many of the OWFs in the EU and UK are located in relatively shallow waters (< 40 m) and at comparable depths to those for the US east coast Wind Energy Areas. These shallow areas are generally highly productive and act as important nursery and/or feeding grounds for a number of fish species (Leonhard et al., 2011). The hard surfaces of turbine foundations and scour protection devices provide new habitats that are rapidly colonized by species different to those normally associated with sandy sediments, resulting in an increase in faunal diversity and biomass. Fish communities can form around artificial reef units within the first 12 months after deployment and remain relatively stable thereafter, although timeframes may vary (Jensen, 2002).

Thus, an increase in habitat diversity caused by the installation of turbine foundations and scour protection may attract fish, and may locally enhance fish species diversity. For some species, the reef effect might be counteracted by underwater noise and EMF generated by operation of the OWF (Leonhard et al., 2011). Noise and vibrations from rotor blades and generators are transmitted through air and the foundation to the underwater environment, while EMF are generated by power transmission through the array and export cables. Fish species sensitive to such noise or EMF might avoid exposure. Westerberg (as cited in Wilhelmsson et al., 2010) studied fish distribution patterns around a single wind turbine in Sweden and reported that cod and some pelagic species were more abundant 50 m from the turbine compared to 200 m to 800 m away; however, this pattern was only noted while the turbine was not running. There were no data for fish distribution patterns during turbine operation. Leonard and Pedersen (2006) on the other hand reported that noise and vibrations from the turbine generators at Horns Rev apparently had no impact on fish and other mobile organisms that had been attracted to the hard bottom substrates for foraging, shelter and protection.

6.6 Observed Environmental Effects from Monitoring and Research

This section presents the findings of site specific fish and shellfish monitoring campaigns and relevant research and highlights observed changes in fish and shellfish ecological conditions attributable to OWF impacts.

6.6.1 General Findings

Comprehensive post-construction sampling campaigns at the Egmond aan Zee OWF over 5 years did not detect any significant effects of the wind farm on fish and shellfish communities at the scale of the Dutch coastal zone but did record potential local benefits for some species. For example, localized increases of cod, edible crab, (*Cancer pagurus*), bib (*Trisopterus luscus*), bullrout (*Myoxocephalus scorpius*), sea scorpion, (*Taurulus bubalis*) and common dragonet (*Callionymus lyra*) were recorded around the turbines in summer compared to the surrounding natural sandy seabed. It was postulated that the greater abundances may be attributed to reduced commercial fishing pressure close to the turbines and associated positive population effects. In contrast, fewer sole, dab, plaice, and whiting were recorded compared to baselines. This was attributed to the marginal reduction in the extent of preferred sandy seabed habitat for these species due to the presence of wind farm infrastructure on the seabed. Additional tagging and telemetry studies of cod and sole showed that they utilized an area of seabed that was larger than the wind farm with no apparent avoidance behavior. Sole were seemingly not attracted to the turbine foundations although juvenile cod showed strong attraction with no apparent avoidance of operational turbines. No larger adult cod were recorded in the wind farm.

Monitoring campaigns conducted at the Barrow OWF 2 years after construction and at the Robin Rigg OWF 3 years after construction recorded notable differences in fish abundances from baseline conditions and between monitoring occasions but attributed this to natural seasonal changes which reflected normal fish migrations. No significant differences in the abundance of species attributable to windfarm construction or operation were detected. The principal species noted within the wind farm site were comparable to those in the reference area suggesting no significant broad-scale effects on the species composition of assemblages.

High seasonal and inter-annual variations in fish and shellfish abundances were also recorded during the monitoring at the Lynn and Inner Dowsing OWFs, which included 3 years of annual post-construction monitoring data. Temporal changes in fish and shellfish catches were again attributed to natural population fluctuations over the wider area. No gross temporal or spatial changes in species composition were recorded.

Similarly, no significant spatial or temporal differences in the composition of trawl catches were recorded 2 years post construction at Burbo Bank OWF. Statistical analysis demonstrated strong similarities in species composition between the wind farm, far field and reference sites in all pre-, during, and post-construction survey years. No evidence of fish aggregation was found. It was noted that '*the capture of elasmobranch species including small spotted catsharks, thornback rays (Raja clavata) and starry smooth hounds within and in close proximity to the wind farm suggested that these electro-sensitive predators were not excluded'*. The monitoring concluded that there had been no evidence of any major impact attributable to the wind farm and no evidence of an artificial reef effect was found.

Five years of post-construction monitoring at North Hoyle OWF similarly concluded that there was no evidence to suggest significant OWF influences on fish and shellfish with assemblages remaining unchanged from baseline conditions. Instead, observed differences in spatial distributions and abundances of conspicuous species were attributed to variations in natural processes and abiotic and biotic factors and were thought to exert greater influences on species distributions than any wind farm effects. Apparent increases in the abundances of species around the wind farm was also reflected at far field and reference sites and no evidence of an aggregating effect of the turbines was reported. It was acknowledged that the monitoring in this instance was insufficient to assess fish aggregation around turbines, although visual monitoring proved that gadoid species of fish were seen feeding on fauna that had colonized the foundations.

Trawls, gill nets, and potting were all used at the Teeside OWF to detect changes in local fin fish and shellfish populations following the construction and first year of operation of the wind farm (Natural Power, 2014). The abundance of fish (predominately whiting) and crustaceans, (predominantly *Nephrops* and swimming crabs) in trawls was found to have significantly increased at reference areas, with only small increases within the wind farm site. Changes in composition of trawl catches between sampling occasions were attributed to natural variation due to similar changes occurring within reference areas. Despite increases in the abundance of edible crab and lobster at reference stations, numbers within the wind farm site were slightly lower than pre-construction values. This was contrary to predictions made in the ES and was thought to be due to the positioning the pots within the center of the turbines and not sufficiently close to the foundation and rock scour material where the lobsters were thought to colonize. Nonetheless, commercial fishermen were noted to have re-located potting gear close to the operational wind farm (within 1 km) and in locations where none had been laid previously. Whether this activity is maintained in the future is not known. The function of the OWF as a fish aggregating device (FAD) was not known and would require sampling closer to the turbines than could be achieved during that specific campaign (Natural Power, 2014).

Post-construction fisheries monitoring data derived from commercial size triple rig otter trawl and bass trawls from Kentish Flats OWF (Vattenfall, 2009) found that catch per unit effort (CPUE) values inside the wind farm area were generally higher than in the control area; this was the case for most of the species studied, regardless of the fishing method used. However, this pattern was attributed to natural factors as similar distribution was recorded prior to operations. It was further noted that monitoring of the faunal colonization of the subsea structures did not record any fish around the turbines, although the foundations and surrounding seabed were colonized by various invertebrate communities. This is at odds with findings from other UK OWFs where shoals of fish (often juvenile gadoid species such as whiting) have been recorded in very close proximity to the turbines. Additional monitoring using a smaller beam trawl, and which may have been able to sample closer to the turbines at Kentish Flats OWF, revealed a comparable catch composition between years as presented in the following case study (Emu Limited, 2008).

Case Study 11: Fish Ecology Monitoring
Kentish Flats Offshore Wind Farm

Background

Kentish Flats OWF is a wind farm located approximately 10 km off the north coast of Kent, UK, on a large, flat, and shallow plateau. Water depth on site is approximately 5 m.

The wind farm consists of 30 Vestas V90-3MW wind turbines with a total capacity of 90 MW. Construction was completed in August 2005, with commissioning and testing of all turbines completed by September 2005.

Figure 6.4: Beam trawling at the Kentish Flats Offshore Wind Farm
(source Fugro Emu Limited)

As part of the application process for permission to develop the Kentish Flats site, a full EIA was required. A baseline ecological survey was conducted in 2002 prior to commencing the construction work in order to provide baseline data on the physical and biological conditions of the site. The data acted as basis for comparison with subsequent data from environmental monitoring programs, required as part of the Food and Environment Protection Act (FEPA) License (No. 31780/03/0).

Three post-construction monitoring surveys were subsequently conducted, the first in 2005, the second in 2006 and the third in 2007.

Methods

Benthic fish populations were assessed by means of beam trawl sampling using a heavily armored 2 m Lowestoft beam trawl. The trawl was made of galvanized steel, with the 5 mm knotless mesh net protected by a heavy trawl chaffing net at the cod end, and by chain meshing running from the Beam. This allowed trawling on highly heterogeneous seabed sediment comprising of shells and cobbles. The Beam trawl was towed over a distance of 500 m to 1000 m depending on the nature of the seabed and the amount of material retained within the trawl.

A total of ten stations were surveyed by beam trawling, to include: three within the primary impact area, defined as the site hosting the turbines; four within the secondary impact area, defined as the area outside the turbine site, along the tidal axis within a single tidal excursion; two within the cable corridor and one within the reference area outside the maximum tidal excursion from the development site.

Upon recovery, the Beam trawl was emptied into fish crates. All fauna were identified on site and abundance estimated. Representative samples of the fauna were retained for subsequent laboratory analysis and confirmation of nomenclature. Fish length was measured and recorded.

Results

Temporal variations of the benthic communities from the beam trawl samples were assessed with respect to the mean number of species, their frequency of occurrence within the survey area, and mean abundance, taking into account that this type of sampling provides semi-quantitative results. A summary of the fish species primarily responsible for the temporal differences is presented in Table 6.3.

Table 6.3: Summary of fish species recorded during post construction monitoring occasions at Kentish Flats Offshore Wind Farm

Species (Common Name)	Frequency of Occurrence (Average Abundance)			
	Year of Survey			
	2002	2005	2006	2007

Aphia minuta (transparent goby)	0	0	70% (0.9)	0
Clupea harengus (herring)	56% (0.7)	30% (0.6)	0	0
Platichthys flesus (flounder)	56% (9.8)	0	10% (0.1)	0
Scyliorhinus canicula (lesser spotted dogfish)	0	60% (1.8)	20% (0.4)	30% (0.3)
Trispopterus minutus (bib/pouting)	56% (2.2)	60% (0.8)	30% (0.3)	0
Merlangus merlangius (whiting)	100% (9.2)	90% (2.4)	10% (0.1)	20% (0.3)
Limanda (dab)	100% (0.7)	60% (2.5)	60% (1)	40% (1.5)
Agonus cataphractus (pogge)	78% (3.4)	70% (2.2)	40% (1.8)	10% (0.3)
Gobiidae (common goby)	78% (3.1)	80% (10.4)	100% (7.1)	20% (0.8)
Pleuronectes platessa (plaice)	89% (5)	80% (1.3)	50% (1.2)	60% (1.8)
Solea (Dover /common sole)	78% (4.1)	80% (4.2)	70% (4.3)	70% (2.4)

The species composition of samples from the beam trawls showed little temporal fluctuations across the survey area. The most evident temporal trend was associated with a gradual decline of the mean number of fish species since the study begun, the values in 2007 being nearly half of those reported in 2002. The crustaceans and the mollusks exhibited small temporal variability, with an overall increase in diversity, in all sample areas, since the study began. The average similarity of beam trawl samples collected in 2007 was higher than that of the 2002 samples. With regard to the reference area, trawl samples were obtained from a single sampling station. In addition, no samples were obtained at this station in 2002, therefore temporal comparisons within the reference area were limited, and an overall pattern of temporal variability could not be extrapolated.

It is worth noting, however, that mobile epibenthic fauna forage the seabed, seek reproductive partners and shelter from predators, hence a patchy and variable distribution is to be expected when sampling, particularly when compared to the sessile epibenthic fauna which colonize all available suitable hard substrata within the range of their mobile larval stage. Fish populations are highly mobile and wide ranging. Adult populations are also highly variable both temporally and spatially as demonstrated through comparison of annual data collected under fisheries monitoring programs.

Conclusion

When taking into account all the results of the benthic monitoring program, it was evident that patterns in the benthic ecology of the Kentish Flats area remained broadly unchanged when compared to the baseline data, with the recorded changes most likely due to natural variability associated with the hydrodynamic conditions of the area and recruitment success of biological communities.

Commercial shellfish stocks have been the subject of targeted monitoring due to the high value of the associated fisheries to local economies and the potential sensitivities of the species in question. The following case study reviews initial monitoring efforts conducted at Westermost Rough OWF to assess changes in local crustacean fisheries due to the construction of the wind farm (Roach & Cohen, undated).

Case Study 12. Commercial Shellfish Monitoring

Westermost Rough Offshore Wind Farm

Background

The Westermost Rough OWF is located approximately 12 km off the east coast UK in the North Sea. It comprises a total of 35 turbines, each of 6 MW capacity. The project was constructed in 2014 and 2015 over a period of around 20 months during which commercial fishing within the OWF boundaries was excluded.

The OWF is located on hard and rough ground which supports an important crustacean fishery. In recognition of concerns of potential impacts on local crustacean fisheries, a comprehensive campaign of monitoring was undertaken. This case study reviews the results of the first monitoring study undertaken in 2015 and immediately after the completion of the construction of the OWF (Roach & Cohen, undated) Further survey work is planned to understand potential longer term effects and will be reported in due course.

From Cohen & Roach, undated

Methods

Methods used during the post construction survey were similar to those of the pre-construction survey conducted 2 years earlier in 2013. The study area was divided into four areas including the turbine array and export cable route and corresponding control areas. Fleets of 25 pots, resembling the typical gears used by the commercial fishery, were laid in representative areas. Figure 6.5 shows the sampling locations where the fleets of pots were laid.

Pots were hauled twice a week during June, July, August, and September and the catch recorded in terms of species composition, sex and condition. Size metrics were also recorded and related to respective minimum landings sizes. The focus of the campaign was the valuable lobster (*Homarus gammarus*) stock, although edible crab (*Cancer pagurus*) and velvet swimming crab (*Necora puber*) stocks were also studied as important shellfish resources in the area. In addition, other species such as fish were also recorded. The data were used to calculate catch per unit effort (CPUE) and landings per unit effort (LPUE). Data were further subject to statistical analyses to determine the significance of any differences between years and between treatments.

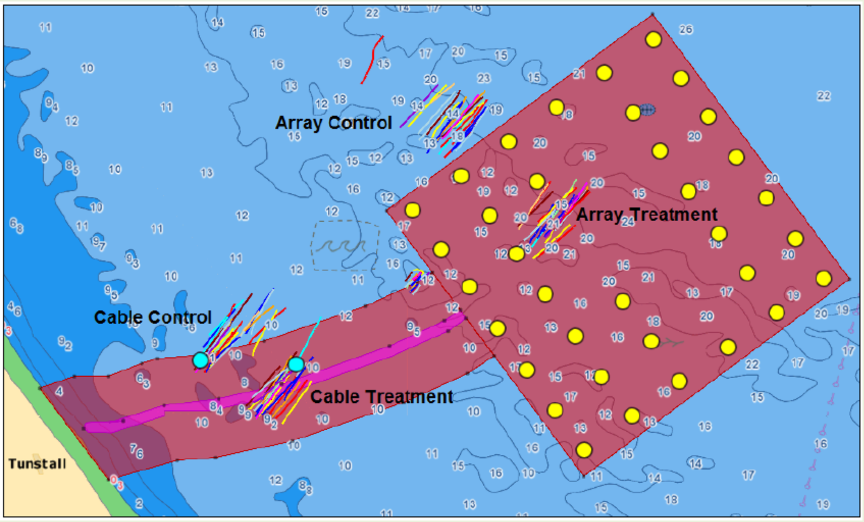

Figure 6.5 Westermost Rough Offshore Wind Farm Shellfish Survey. Location of pot fleets

(source: Roach & Cohen, undated)

A 20 month fishing exclusion, as a result of the construction works, provided opportunity to assess effects on shellfish size and abundance in the absence of fishing pressure. Comparison with pre-construction data collected 2 years previously in 2013 was undertaken to assess temporal change.

Results

Lobsters caught in the OWF site during construction were larger and more abundant than those in adjacent control areas where fishing had continued throughout the construction period. Both catch and landings per unit effort were elevated within the OWF compared to reference conditions and a greater proportion of the catch was above the minimum landing size in the OWF. The authors note that the effects of construction on the pre-existing adult lobster population do not appear to have been deleterious, or at least the effects, if present, were less than those exerted by the current fishing pressure. The 20-month period during which construction of the OWF was ongoing provided a temporary escape from fishing pressure for the lobsters there (Roach & Cohen, undated). The presence of fewer smaller lobsters in the OWF was highlighted as possible evidence of an OWF effect to which smaller individuals may be sensitive or less resilient than larger individuals. Once fishing resumed, CPUE and LPUE of lobsters reduced markedly in the OWF to levels comparable with those at the control area. This was possibly due to the intense fishing activities, over and above normal levels, that took place within the OWF site for a short time after it was opened to fishing the OWF.

Lower edible crab CPUE in the OWF during the construction period compared to the control area was attributed to the presence of greater numbers of lobsters at this time. Crabs may be deterred from entering pots if already occupied by a lobster or may leave a pot if lobster subsequently enters. Such interactions could lead to edible crabs being under recorded and unrepresentative of the actual abundance present. The removal of larger lobsters from the OWF following the resumption of fishing was thought to have resulted in a relative subsequent increase in edible crab CPUE.

The installation and operation of the export cable was not thought to have significantly affected shellfish populations. The pre-cable installation clearance of boulders under which lobsters could shelter was suggested as a possible cause of a higher proportion of smaller lobsters below minimum landing size along the export cable route compared to the adjacent control site.

Catches of edible crab were greater within the vicinity of the export cable route compared to the adjacent control site, although the reason for this was unclear. However, size distributions of edible and velvet swimming crabs were comparable between the site of the export cable and the treatment area suggesting little or no impact on these populations (Roach & Cohen, undated).

Comparison with pre-construction data showed no significant differences in lobster and velvet swimming crab abundance suggesting no significant adverse effects of the construction of the OWF on these populations. However, the abundance of edible crab was significantly reduced compared to baseline conditions, although it was not possible to attribute a cause at this time.

Numbers of juvenile cod were noted to be greater inside the OWF relative to other areas under investigation. The potential for the OWF to have an attractive effect on juvenile cod, as well as the associated effects on juvenile lobster abundance through cod predation of pre-settlement planktonic juveniles of lobster in the area, was noted.

Conclusion

No adverse effects attributable to the construction of the OWF were noted. Major changes were observed on the re-opening of the OWF to fishing. Several fishery trends were documented and which will require further continued monitoring to understand contributory factors. Surveying over a longer period of consistent fishing effort is required to identify fishing impacts from other potential causes of change (Roach & Cohen, undated). The aggregation of juvenile cod within the OWF may confound future conclusions.

Monitoring of commercially important intertidal cockle beds is required to establish the effects of the installation of two export cables at Race Bank OWF (UK) and to monitor the rate of post construction recovery of cockles (GoBe, 2016). A preliminary baseline survey has been conducted based on a traditional BACI design to establish the spatial variability of cockle abundance and biomass and associated substrate conditions within treatment and control areas. The collection of the cockles was undertaken by the local fishery management organization as part of their annual cockle assessment program and within an agreed sampling array. Sediment samples were also collected for particle size distribution analysis. Construction within the intertidal area at Race Bank OWF commenced in April 2016 and is expected to continue through 2017 (GoBe, 2016). The current data provides a baseline for comparative assessment and monitoring of cockle recovery.

6.6.2 Construction Noise

The most important source of noise introduced into the underwater environment during construction is piling, although other sources also exist including drilling, seabed preparatory works, trenching, and vessel movements. Potential effects may include startle, avoidance, physiological damage, and mortality with associated consequences for feeding, spawning, migration, and use of nursery and over-wintering areas. This section reviews the research and monitoring that has been undertaken to investigate the potential effects of construction noise on fish and shellfish ecology.

Wardle et al. (2001) suggested that there was only minimal disturbance to fish (saithe, whiting, and cod) when a seismic airgun was fired in close proximity. Mueller-Blenkle et al. (2010) on the other hand showed that cod and sole responded to relatively low received sound pressure levels from pile-driving (sole: 144 to 156 dB re 1μPa peak; cod: 140 to 161 dB re 1 μPa peak, particle motion between 6.51×10^{-3} and 8.62×10^{-4} $m \cdot s^{-2}$ peak). In response to the stimulus both species increased their swimming speed, with signs of swimming away from the source. Cod showed a significant freezing response at onset and cessation of noise playback. The authors also noted a high variability in behavioral reactions across individuals, and a decrease of response with multiple exposures, suggesting some degree of habituation. They concluded that "*the costs imposed by some mitigation measures ... go some … way to addressing a real problem*". Leonhard et al. (2011) suggested that increased abundance of sand eel in the impact area at Horns Rev OWF in 2004 might have been due to shifts in predator (e.g. cod and sole) abundance, which may have temporarily reduced during the construction phase.

On the basis of their measurements, Nedwell et al. (2003a) concluded that "*piling in particular should be regarded as capable of causing significant environmental effects, and planning of piling operations should take account of the effects of its noise on sensitive species*".

During pile-driving at Gunfleet Sands OWF, Nedwell et al. (2009) measured noise levels at potential herring spawning sites. Noise surveys were undertaken by Subacoustech Environmental in conjunction with a fisheries survey by Brown and May Marine Limited over a period of about 5 weeks from the period immediately prior to spawning. In general, the levels measured during the piling indicated that the range at which a behavioral avoidance effect on herring might be expected was about 5 km. It was thought unlikely that there would be an effect on spawning herring beyond these ranges. Brown and May Marine (2009) concluded that the presence of spawning herring on their known spawning grounds during piling activities indicated that spawning was not disrupted by the piling activities; probably because the grounds were located sufficiently distant from the noise source. However, Nedwell et al. (2009) caution that the routes that herring used to approach the spawning ground were unknown, and therefore it cannot be certain that fish were not affected. They further note that herring were unlikely to be prevented from reaching their desired spawning location as they could typically avoid the immediate area around the piling operation, given sufficient space.

A Dover sole spawning survey was agreed to be conducted to coincide with piling operations at the Walney OWF. The purpose of the monitoring was to assess the local spatial and temporal distributions of Dover sole and the potential impacts that piling operations may have on local spawning populations. Monitoring of sole abundance was conducted at three distances from the piling activity (750 m, 1500 and 2500 m) and on three occasions corresponding to pre-, during, and post-piling stages.

Highest catch rates were recorded at the monitoring station located closest to the piling. In addition, catch rates of sole were greatest during piling. This somewhat counter-intuitive observation mirrored the pattern for other flat fish species that were caught as by-catch during the same monitoring exercise. However, by-catch rates of other types of fish, such as round fish and elasmobranchs, demonstrated little variation between the three piling stages. No explanation for these observations was offered.

On this occasion, the comparatively low number of Dover sole (*Solea solea*) caught caveated conclusions concerning potential impacts but suggested that piling had no major impact on by-catch species. The monitoring also observed that "*the presence of* [Dover sole] *hyaline females and spent individuals within the catch suggests that Dover sole spawning may have taken place while the survey was conducted, but not in the area surveyed, given that no running individuals were caught".*

Construction phase monitoring of fish did not detect any significant effect at North Hoyle OWF, UK. The study was able to obtain ten years (1993 to 2003) of trawl survey data from the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) providing useful baseline information on temporal trends in the relative abundance of demersal fish. CEFAS have been surveying fish in the area using a consistent sampling protocol since 1989. Catch Per Unit Effort (CPUE) data suggested that no major deviations in demersal fish populations had occurred during construction; 13 of the 17 species were caught in numbers that were within the ranges for the previous 5 years. Dab, plaice, scaldfish (*Arnoglossus* sp.), and pogge (*Agonus cataphractus*) all showed higher CPUE during construction than in the previous 5 years. They did find that sole was much reduced in numbers during construction, but argued that this was '*widespread*' and that there was "*no suggestion of any particular relationship to the wind farm development*". They also did not record any Thornback rays (*Raja clavata*) during the autumn period of construction, suggesting that "*this is perhaps not surprising in view of the time of year, as they are thought to migrate offshore after the summer*". Calculations based on noise measurements during piling at North Hoyle OWF indicated that strong avoidance reaction by a range of species would be likely at ranges of up to several kilometers (Nedwell et al., 2003a).

Hydroacoustic measurements of fish abundance prior to the construction of the Alpha Ventus OWF showed no unequal distributions of pelagic fish inside and outside to the wind farm prior to construction. The composition of pelagic assemblages inside the windfarm was found to be very similar to that of surrounding areas. However, comparatively lower abundances of pelagic species were recorded within the boundaries of the wind farm during the construction. Up to 50% (summer) and 40% (winter) decreases in fish abundances were recorded inside the windfarm during construction compared to outside. The high noise intensities that occurred during the pile driving was considered to be the principal factor scaring fish away from the wind farm, although other, less significant noise producing construction activities were also implicated.

Nedwell and Brooker (2008) recorded underwater noise levels during drilling operations for pin piles used to secure a quadropod base in Strangford Lough, Northern Ireland; source level noise was calculated to be 162 dB re 1 μPa @ 1 m. This level is comparable with small vessel noise and considerably lower than the levels of noise generated by impact piling or vibro-piling. This level is also lower than levels that may cause fatality, physical injury or audiological injury to fish and marine mammal species. In terms of behavioral thresholds for selected species, data indicated that the

90 dB_{ht} strong likelihood of disturbance level was not exceeded at any range from the drilling operation; the 75 dB_{ht} behavioral avoidance range extended to a maximum of 3 m from the drilling, while the 50 dB_{ht} low likelihood of disturbance range extended to a maximum range of 115 m. Nedwell and Brooker (2008) concluded that species of fish and marine mammal are unlikely to be disturbed by the drilling noise unless they are in the close vicinity of the drilling operation. They also noted the importance of assessing the spectral levels of underwater noise when estimating its impact on marine animals.

Harding et al. (2016) measured oxygen consumption (as a proxy for active metabolic rate and stress) in marine-phase Atlantic salmon (*Salmo salar*) exposed to pile driving noise playback during laboratory studies and found that exposure did not result in changes in oxygen consumption, indicating that their salmon did not perceive the pile driving noise as a stressor. Although laboratory-based physiological experiments are not necessarily reflective of behavioral response in nature, they cite evidence from another study in support of their findings. Nedwell et al. (2003b) measured underwater noise from vibropiling and impact piling during construction activities near Southampton, and at the same time, observed the reactions of caged brown trout (*Salmo trutta*) on CCTV. Nedwell et al. (2003b) observed no changes in the behavior of brown trout even at distances less than 50 m from the source. In this study, the source level was approximately 194 dB re 1 µPa, and the transmission loss rate was about 0.15 dB/m. Harding et al. (2016) note that, compared to other teleost fish, Atlantic salmon lack specialist hearing mechanisms which reduces its ability to distinguish specific acoustic cues from background noise. The physiological and behavioral responses of fishes with more specialist hearing may be different.

6.6.3 Changes in Water and Sediment Quality

Impact assessments have generally indicated a negligible classification for potential impacts of changes to water and sediment quality, drawing upon the findings of hydrodynamic models of potential plume dispersion and sediment settling to support conclusions. Consequently, very few water and sediment quality monitoring studies relating to offshore wind impacts on fish and shellfish have been conducted, although some verification studies have been performed (see Chapter 3). Due to the presence of local commercial oyster fisheries, the developer of Kentish Flats OWF agreed to compare the concentrations of contaminants in oyster tissues before and after construction. The post-construction levels of arsenic, copper, zinc, cadmium, and total PCBs were lower; levels of cadmium were largely unchanged; and levels of chromium, nickel and silver were higher than baseline, but these findings were mirrored by similar increases in samples collected at control sites outside of the wind farm area. The mean concentrations of lead and mercury were higher than those measured during baseline and at control sites. The report concluded that "*in all cases these were attributable to natural variation. In all cases the levels were within relevant guidelines and standards and in most cases well within the levels recorded from the North Kent area during previous surveys. It was concluded that the analysis of the oyster flesh revealed no evidence of any effect on contaminant loading attributable to the Kentish Flats OWF construction program*".

Araújo et al. (2000) compared seasonal changes in fish assemblages with water quality parameters in the Thames River estuary, and found that temperature, salinity, dissolved oxygen, ammonia nitrogen and water flow changed seasonally, whereas pH and suspended solids (ranging between 18 and 486 mg/l) showed relatively low seasonal change and did not markedly influence the seasonal fish community. Fish in the North Sea and Irish Sea are generally considered to have a high tolerance to suspended sediment, and therefore direct impacts on fish through gill clogging have not been considered significant in ES for UK OWFs.

The UK authorities apparently changed their mind on the need for monitoring of suspended sediments during construction of the London Array OWF. The proponents first submitted a planning application in 2005. Annex 1 of their FEPA License dated 18 December 2006 stated "*a coastal and sediment monitoring plan and suspended sediment plume monitoring plan should be developed prior to the onset of works. This monitoring should include the use of fixed sediment meters over a period of at least four weeks during the pre- construction, construction and post-construction phases at suitable locations to measure near-field, far-field and neutral (control) effects of sediment release". And further requires that "if the use of jetting the export cable in the inter tidal zone is agreed, the license holder will be required to carry out monitoring of suspended sediments concentrations within the area of jetting*". However, construction of the project was delayed when one of the shareholders pulled out and it was some time before new shareholders were found. Since the initial FEPA License had an expiry date of 31 December 2010, a new FEPA License was required. Annex 1 of the subsequent FEPA License dated 25 February 2011 states that "*there are no requirements for monitoring suspended sediment concentrations*" suggesting regulators had bene persuaded that in this instance, SSCs from OWF activities at London Array were inconsequential.

6.6.4 Operational Noise

Wahlberg and Westerberg (2005) reviewed and assessed the impact of turbine-generated noise on fish. They concluded that, although there was no evidence that operational noise could cause temporal or permanent hearing loss in fish even within a few meters from a turbine, it could potentially affect fish behavior at ranges of several kilometers. They predicted that Atlantic salmon and cod could detect noise from turbines at a distance of 0.4 km to 25 km at wind speeds of 8 to 13 m/s. However, they note that data on fish behavior in response to turbine noise was insufficient to conclusively determine the degree to which this actually reduces the fitness of the fish and suggest that any extrapolation of their calculations, based on one OWF on the Swedish Baltic coast be done with caution.

Based on data from a single 1.5 MW offshore turbine at Utgrunden OWF in Sweden, Thomsen et al. (2006) calculated that dab and salmon (Salmonidae) might detect operational noise from a turbine at relatively short distances of about 1 km. The zone of audibility for cod and herring will be larger, perhaps up to 4 km to 5 km from the source. They caution that these ranges are only applicable for the area where their measurements were made (i.e. the Baltic Sea); they point out that ambient noise in the North Sea is generally higher than in the Baltic and therefore the detection ranges might be smaller.

The responsiveness of fish to operational OWF noise was studied using ultrasonic telemetry and fishing at the Svante OWF in Sweden (now decommissioned) (reviewed in Thomsen et al., 2006). It was shown that European eels (*Anguilla anguilla*) passing a 220 kW wind turbine at a distance of 0.5 km did not substantially change their swimming behavior. However, when the rotor was stopped, the catch rates of cod and roach were significantly higher within 100 m of the turbine than at distances between 200 m and 800 m. Not only do these findings describe avoidance of turbines when operating;

they also indicate that fish are attracted towards the turbine under conditions when turbine noise is reduced, possibly due to the reef effect. However, Thomsen et al. (2006) point out that these differences could be due to other factors, as no data on variation in fish density were performed prior to construction.

Marmo et al. (2013) modelled the emission of noise (6 MW turbine) by three foundation types (jacket, monopile and gravity foundation) and compared output levels to hearing and behavioral response thresholds of several marine mammal and fish species. At lower frequencies, the monopile produced the highest sound pressure level (SPL) of the different foundations, with levels of 149 dB re 1 µPa within 5 m of the foundation. At higher frequencies, the jacket produced the highest SPL with 177 dB re 1 µPa at 700 Hz and 191 dB re 1 µPa at 925 Hz within 5 m of the jacket. The authors found that different wind farm layouts (diamond and square) had negligible influence over the spread of the sound field. Noise from a monopile design was audible above the background noise for at least 20 km from the wind farm in all wind conditions. The gravity foundation was masked at low frequency (< 100 Hz) at a wind speed of 5 $m \cdot s^{-1}$, but became audible at 10 $m \cdot s^{-1}$ and 15 $m \cdot s^{-1}$, while the jacket was only audible above the background noise at frequencies higher than 400 Hz (Marmo et al., 2013). The authors concluded that "*Atlantic salmon and European eels are able to detect the presence of monopiles at greater ranges than gravity bases, though this may not affect their behavior. Allis shad and sea trout appear to be unable to detect noise produced by operational wind turbines, except at close range (< 100 m)*".

Anthropogenic noise stimuli, such as ship noise, have been shown to be a stressor in a number of fish species. Wysocki et al. (2006) showed that ship noise elicited a cortisol stress response in different fish species, regardless of their hearing sensitivities. Cortisol has detrimental effects on growth, sexual maturation and reproduction, immunological function, and survival in fish, and the level of stress can serve as an important health indicator for populations (Wysocki et al., 2006). Interestingly, no elevation was recorded when fish were exposed to continuous Gaussian noise in their experiments.

While very loud sounds of relatively short exposure, such as those produced by sonar, piling, and explosions, have attracted substantial attention in noise assessments, Slabbekoorn et al. (2010) argue that the greater impact on fish will be from more moderate sounds of longer duration that could potentially affect whole ecosystems. Anthropogenic sounds, such as those produced by vessels, could potentially impact much larger areas and involve much larger numbers of fish. They state that fish populations have come under threat for a number of well-known reasons including fisheries, habitat degradation, and chemical pollution, and that anthropogenic noise is potentially becoming another threat to fish. They note a lack of data and motivate the need for studies of noise dependent distribution and reproduction as well as investigations of masking of sounds used for communication, orientation, or detection of predators and prey; stating "*we believe that anthropogenic masking effects on predator–prey relationships could be widespread*".

Simpson et al. (2015) exposed European eels (*Anguilla anguilla*) to recordings of ships passing through harbors, and found that eels exposed to such noise were 50% less likely and 25% slower to startle to an "ambush predator", and were caught more than twice as quickly by a "pursuit predator", generally supporting this hypothesis for some fish species

6.6.5 Electromagnetic Field Emissions

A limited number of studies have documented physiological and developmental effects after exposure to EMF (Claisse et al., 2015); e.g. suppression of melatonin (a stress-related hormone) levels in juvenile salmon (Woodruff et al., 2012), or developmental changes in teleost embryos which led to subsequent behavioral differences in the fish four days after hatching (Lee and Yang, 2014). However, most of the research associated with OWF is focused on behavioral response to EMF exposure.

Magneto- and electroreception in fish has been studied for decades and several reviews on aspects related to submarine power cables have been recently published (e.g. Gill and Bartlett, 2010; Normandeau et al., 2011; Gill et al., 2014; Claisse et al., 2015).

Elasmobranchs have anatomical structures (ampullae of Lorenzini) which are able to detect electric fields. They use electroreception to detect prey, predators, and mates. Bedore and Kajiura (2013) reviewed literature on bioelectric fields and noted that the electric potentials of invertebrates (14 μV to 28 μV) did not differ from those of elasmobranchs, (18 μV to 30 μV). Teleost fishes on the other hand produced significantly larger potentials (39 μV to 319 μV), which were at a frequency range detectable by elasmobranch predators (<16 Hz). Median sensitivity in various elasmobranchs has been documented at 5 $nV{\cdot}cm^{-1}$ to 48 $nV{\cdot}cm^{-1}$ with maximum detection distances of 22 cm to 44 cm. Kalmijn (1982) showed that dogfish and blue sharks at sea exhibited apparent feeding responses to dipole electric fields (5 $nV{\cdot}cm^{-1}$) designed to mimic prey.

While elasmobranchs may be attracted to weaker anthropogenic fields, they can be repelled by stronger ones. A limited number of studies suggest avoidance may occur when encountering fields of ~4000 $nV{\cdot}cm^{-1}$ to 10000 $nV{\cdot}cm^{-1}$, although avoidance thresholds are likely to be species specific (Claisse et al., 2015). Electric fields have been successfully employed to prevent or deter fish movement. For example, ecological applications include preventing fish entrainment in intake systems of hydropower dams (Noatch and Suski, 2012). Safety-wise, a personal protective device that generates an electric field in seawater has been developed to deter shark attacks on divers (Smit and Peddemors, 2003), while the use of electric barriers to protect an area (a beach or part of a beach) against shark attacks has also been investigated. Research on electric deterrents for beach protection was first initiated in South Africa in the 1960s with the installation of a submarine cable (CARDNO, 2015).

It has been suggested that EMF from subsea power cables could impede migration of fishes near the seafloor (Gill et al., 2012; Noatch and Suski, 2012; Claisse et al., 2015). Based on the calculations of Normandeau et al. (2011), a magneto-sensitive fish may be able to detect the magnetic (B) field generated by a DC power cable at a distance of 20 m; and the induced electric (iE) fields could be detected at a distance of 10 m. Detection distances would also be dependent on factors such as cable burial depth and the cable's orientation relative to the earth's magnetic field (Claisse et al., 2015).

It is not presently clear if magnetic fields generated by undersea cables would impact the navigational capabilities of fish, as the available evidence seems inconclusive.

Gill and Bartlett (2010) reviewed the potential impacts of EMF from marine renewable energy developments on three fish species of conservation importance, Atlantic salmon, sea trout and

European eel (*Anguilla anguilla*). Atlantic salmon and European eel can use the earth's magnetic field for orientation and direction finding during migrations, while sea trout juveniles respond to both the earth's magnetic field and artificial magnetic fields, suggesting that EMFs from subsea cables may interact with migrating eels (and possibly salmonids) if their routes take them over the cables, particularly in shallow waters (< 20 m). Gill and Bartlett (2010) noted that all three species were likely to encounter EMF from subsea cables, either as adults or as juveniles, particularly within shallow, coastal waters adjacent to their natal rivers. The biological significance of such effects was undetermined.

For fish to be affected by anthropogenic EMF, they would need to be located near enough to the cables to encounter it. Sturlaughsson (2016) studied the swimming depth of sea trout *Salmo trutta* in Icelandic waters, and concluded that tagged fish were feeding close to the surface much of the time, with some time being spent at greater depths. They acknowledged that the fish feeding close to the surface could also have been feeding close to the bottom when in shallow water. Sturlaughsson (2016) noted that other studies have found similar patterns. Tagged sea trout in the coastal waters of Iceland in 1995 spent the vast majority of their time within the uppermost 5 m. In Alta Fjord in northern Norway, tagged sea trout spent more than 50% of their time between 1 m and 2 m below the water surface, and more than 90% of their time in water no deeper than 3 m; however, deeper dives (to a maximum of 28 m) were also recorded, usually at the end of the sea migration. In the coastal waters of northern Germany, 64% of tagged sea trout migrated within the uppermost water level at approximately 1.5 m, with occasional dives to 13 m water depth (reviewed by Sturlaughsson, 2016). Although fish species swimming near the water surface might be less affected by power cable EMF than demersal fish, their exposure would also depend on the water depth. Figure 6.3 describes the spread of EMF emissions into overlying water even when the cable is buried 1 m below the seabed.

Love et al. (2016) monitored the occurrence of fish near energized 35 kV submarine power cables at inshore waters (10-14 m depth) in southern California, and compared those data to the occurrence of fish at a concrete pipe and over a sandy seabed. Average magnetic fields emitted by the cables (Cable A = 73.0 μT, Cable B = 91.4 μT) were higher than measurements recorded at the pipe (0.5 μT) and at the natural habitat (0 μT). Overall, their study indicated that there were no biologically significant differences in fish communities between energized cables, concrete pipe, and sandy seabed. However, as only one elasmobranch individual was recorded during the 38 survey days, the consistency of fish communities across energized cables, concrete pipe, and sandy seabed could not be confirmed for other elasmobranchs. The relative paucity of elasmobranch records was interesting, considering that shallow habitats of southern California are known to support a rich diversity of elasmobranchs. (Love et al., 2016) acknowledge that their study was not designed to study the behavior of fish species when they encounter EMF from an energized cable during, for instance, migrations.

Westerberg and Lagenfelt (2008) used coded acoustic tags and an array of moored receivers to study the response of migrating European eel (*Anguilla anguilla*) to a 130 kV AC power cable in the Baltic Sea. Sixty eels were tagged and the migration speed was measured in a strait. Eel swimming speed was significantly slower around the cable than away from it. No details on eel behavior during movement over the cable were recorded, and the possible physiological mechanisms underlying this effect are unknown. In terms of environmental impact assessment, Westerberg and Lagenfelt (2008) note "*the effect of the cable on eel was small. There was no evidence that the cable was an obstruction to migration. Just two of the 60 eels turned back somewhere in the middle interval containing the cable and this can be explained by chance rather than caused by the cable. Other eels turned back south of the cable and some migrated north directly after the release. Even if a delaying effect on migration was demonstrated, the delay caused by the passage was about 40 minutes on average and would hardly influence fitness in a 7000 km migration*".

Gill et al. (2009) used mesocosm experiments to study the response of elasmobranch fish to anthropogenic EMFs of the type generated by OWFs. The study was conducted in a shallow, sheltered coastal water location that resembled an actual OWF situation. Two sections of high current, 3-phase low voltage, 135 kV power cable, which produced EMF similar in characteristics to an OWF cable, were buried to 0.5 m to 1m depth in the sandy seabed, 10 m to 15 m from the sea surface. One mesocosm – the 'live' mesocosm - was placed over the energized cable; the control mesocosm was placed over the un-energized cable. Ultrasonic telemetry was used to monitor the real-time movements of individually identifiable elasmobranch fish. The overall analysis showed that there were significant differences between the numbers of individual fish within the EMF zone (i.e. 2 m either side of the cable); significantly greater numbers of catshark were recorded within the EMF zone of the live mesocosm when the cable was switched on.

Kimber et al. (2011) found that catsharks (Scyliorhinidae) were either unable to discern, or showed no preference for artificial and natural electric fields of the same strength. Kimber et al. (2011) suggested that catsharks might therefore expend energy "hunting" for anthropogenic electric fields associated with undersea power cables. Panagopoulos et al. (2015) state that all types of anthropogenic EMFs/EMR, in contrast to natural EMFs/EMR, are polarized, and are therefore more bioactive than natural non-ionizing EMFs/EMR. It is unclear if migrating elasmobranchs can distinguish between anthropogenic and natural EMF.

DONG Energy (2006) reported on their studies of fish migration/movement in relation to the 132 kV export cable at Nysted OWF in Denmark. They collected data over several years using pound nets for both baseline and post-construction monitoring. Their data from 2003 and 2004 indicated significant impacts of EMF on four species: Baltic herring, common eel, Atlantic cod, and flounder. Their results suggest that migration of some species across the cable trace may be impeded; although they note that the results do not suggest that the migration is completely blocked.

Post-construction surveys at Gunfleet Sands OWF noted that "*the changes post construction appear to be minor, with thornback ray (considered in the ES to potentially be affected by EMF) being the most abundant species caught post construction*". The monitoring study did not discuss the possibility that thornback ray might have been attracted into the area by anthropogenic EMF. Thornback ray were more abundant inside the windfarm than at control sites in 2011, but in 2012 were 22% of the catch at both windfarm and control sites.

The three year Kentish Flats OWF monitoring program recorded a number of elasmobranch species, including the thornback ray and smooth hound which can potentially be affected by EMF associated with wind farm subsea cables within the wind farm site. The catch per unit effort (CPUE) for thornback rays indicated an increase in numbers year on year during summer months. It was concluded that there were no discernible differences in populations between wind farm and reference areas, so that it is unlikely that the observed increase is due to the operation of the Kentish Flats wind farm.

Dedicated elasmobranch monitoring surveys at the Sheringham Shoal OWF (Brown & May Marine, 2010; 2016) noted the conclusions of the Marine Management Organization (MMO) in the UK that while subtle effects such as attraction, inquisitiveness and feeding responses are likely, no significant effects on elasmobranchs have been recorded and that there is no evidence to date that EMFs significantly impact elasmobranchs at the population level. The elasmobranch surveys conducted at the Sheringham Shoal OWF are summarized in the following case study (Brown & May Marine, 2010; 2016).

Case Study 13. Monitoring Electro-sensitive (Elasmobranch) Species

Sheringham Shoal Offshore Wind Farm

Background

Sheringham Shoal OWF is located approximately 21 km offshore of the Norfolk coast UK in the southern North Sea and comprises 88 wind turbines with a generating capacity of 317 MW. Construction started in late 2009 with first power generated in 2011. Power from the OWF is exported to shore through two submarine export cables.

In compliance with licence conditions, and in response to concerns relating to potential EMF effects on electro-sensitive species, a series of elasmobranch surveys were conducted within the vicinity of the export cables to detect any change in populations between pre-construction and operational stages of the OWF. The following reviews the results of 3 surveys, conducted over 4 years to monitor elasmobranch populations following the construction of the OWF.

Methods

A pre-construction survey was undertaken in August 2010 (Brown & May Marine, 2010). Post construction surveys were subsequently undertaken in November 2012 and in August of 2013 and 2015 (Brown & May Marine, 2016). In addition, commercial fisheries landings data for the region was collected.

Sampling for elasmobranchs was conducted using baited (with squid) longlines of 100 m length and comprising 100 hooks each. Triplicate lines were set at each of ten treatment stations positioned along the export cable route. Six additional stations were subsequently added to the array in 2015 for use as reference stations. Figure 6.6 shows the locations of the treatment stations along the export and the reference stations.

Longlines were left to soak for at least two hours prior to recovery and recording of the catch. All fish caught were recorded. The stomach contents of lesser spotted dogfish (*Scyliorhinus canicula*) were also recorded.

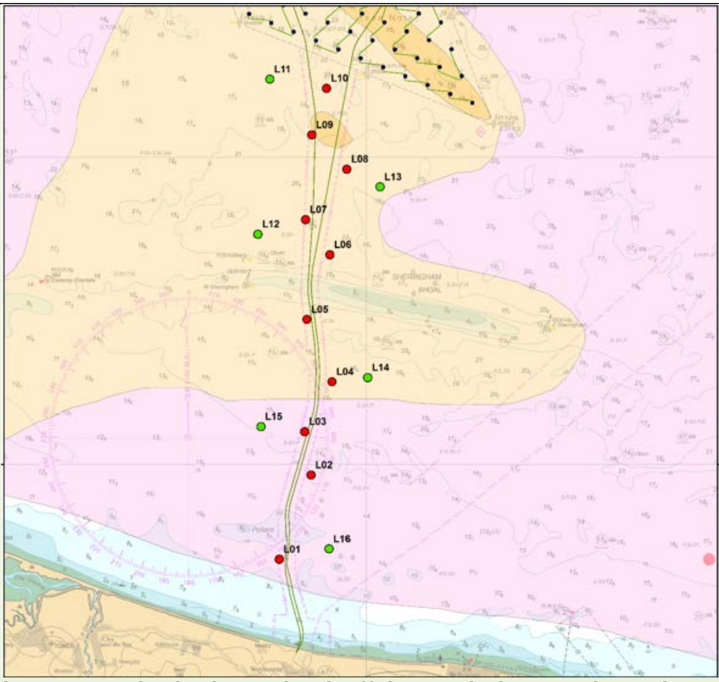

Figure 6.6. Sheringham Shoal Offshore Wind Farm Elasmobranch Monitoring Sampling Array
(source: Brown & May, 2016)
Red points – treatment stations
Green points = reference stations

Logistical constraints, primarily relating to the presence of static commercial gears, prevented all longlines from being deployed on some occasions. The numbers of samples actually collected over the course of the monitoring period ranged between 18 (2012) and 42 (2015).

Results

Table 6.4 presents a summary of the catch composition for each survey occasion and shows elasmobranch abundance had clearly reduced over the intervening years since the pre-construction survey but that numbers had increased in 2015. Brown & May (2016) suggested that this result should not necessarily be considered indicative of any deleterious effects and that it was almost certainly due to natural temporal variability in the abundance of individuals of species and population sizes. The variable nature of elasmobranch populations in the regions was highlighted by the commercial catch data.

Table 6.4. Summary of fish catch data at Sheringham Shoal Offshore Wind farm (source: Brown & May, 2016)

Common Name	Scientific Name	Pre-Construction	Post-Construction		
		August 2010	November 2012	August 2013	August 2015
Elasmobranchs					
Tope	*Galeorhinus galeus*	0	0	0	1
Starry smoothhound	*Mustelus asterias*	62	0	1	12
Lesser spotted dogfish	*Scyliorhinus canicula*	48	0	0	14
Thornback ray	*Raja clavata*	39	0	0	4
Common smoothhound	*Mustelus*	20	0	0	
Spotted ray	*Raja montagui*	5	0	0	1
Other fish					
Whiting	*Merlangius merlangus*	0	245	0	9

Dab	*Limanda*	2	0	1	2
Tub Gurnard	*Chelidonichthys lucerna*	2	0	0	1
Sea scorpion	*Taurulus bubalis*	0	0	0	1
Seabass	*Dicentrarchus labrax*	3	0	0	11

The results of the stomach contents analysis undertaken in 2015 showed that dogfish captured along the route of the export cable had recently fed with food items readily identifiable. Important prey was found to be similar to those found within the stomachs of dogfish captured during the pre-construction survey and included hermit crabs (Paguridae) together with sipunculids, unidentified crustaceans and polychaete worms. The fact that elasmobranchs had apparently recently fed within the vicinity of the operational export cable suggested no significant adverse effect on populations (Brown & May, 2016).

Conclusions
The authors highlighted that other OWFs have elasmobranch monitoring conditions attached to their marine licenses. These monitoring studies have also shown elasmobranchs to be present and apparently feeding unhindered within and around OWFs and associated electrical infrastructure. The findings of the current study matched those undertaken elsewhere and reflected the temporal variably in populations as indicated by commercial landings data.

6.6.6 Reef Effects

Results from preliminary studies in Denmark, the Netherlands, Japan and Sweden on fish abundance in a wind farm area as a whole (i.e. not only considering aggregations around turbines) indicated either
increased species abundances (e.g. sand eels, cod, whiting, sole), or no effects (reviewed by Wilhelmsson et al., 2010), although some studies have been statistically weak.

Seven years of post-construction monitoring studies at Horns Rev OWF indicated that fish species were attracted towards the wind farm foundations resulting in higher diversity inside the wind farm area compared to areas outside (Danish Energy Agency, 2013). In general, the abundance and diversity of fish increased close to the turbines. Many of the species inhabiting the wind farm structures were found to be common to the wider region, which comprised predominately shallow sandy substrates, although a few species such as the goldsinny wrasse (*Ctenolabrus rupestris*), the lumpsucker (*Cycloplerus lumpus*), and the eelpout (*Zoarces viviparous*) only appeared inside the wind farm area and within the survey area after the construction of the wind farm. It was noted that these species are typical “reef fish”, which were primarily found very close to the turbine foundations. Fish were found to be feeding on the fouling communities that had developed on the wind farm structures. Important prey items included the crustacean (*Jassa marmorata*) and the common mussel (*Mytilus edulis*) which were preyed upon by pouting (*Trisopterus luscus*) and goldsinny wrasse respectively.

Stenberg et al. (2015) used gillnets to study fish abundance and distribution at Horns Rev OWF. Overall catch rates in the control location compared to the impact areas indicated a positive effect of the OWF on fish abundance. This positive effect was mainly evident on a small spatial scale close to the turbines, where species diversity was significantly higher. Their research indicated that the artificial reef structures were large enough to attract fish species that prefer rocky habitats, but not large enough to impact on species inhabiting the original sand bottom between the turbines. None of the key fish species or functional fish groups showed signs of negative long-term effects due to the OWF.

Previous concerns relating to resident sandeel populations at Horns Rev OWF were found to be unwarranted and no adverse impacts were recorded in this regard. An increase in the abundance of sandeels was noted one year following construction.

Hvidt et al. (2006) used hydroacoustic techniques (supplemented by fishing data) to quantify fish stocks associated with the Horns Rev OWF in Denmark. They found no clear regional differences that could be linked to the presence of the wind farm; no distinct, significant, temporal or geographic patterns in densities, biomass or length distribution were identified in sampling periods, diurnal variations, or transects inside and outside of the wind farm area. Instead they suggested that abiotic factors influenced fish distribution to a much higher extent than the presence of the wind farm itself. Furthermore, there were no significant statistical differences in fish densities near the turbines compared to areas between turbines.

Studies at Egmond aan Zee OWF showed high spatial and temporal dynamics in fish communities, and only minor differences in fish assemblages near the turbine foundations although, some fish species such as cod, seem to find shelter inside the wind farm (Lindeboom et al., 2011). These data reflect the broad-scale situation, not the small-scale events at turbine level.

Winter et al. (2010) studied the behavior of sole and cod at Egmond aan Zee OWF using mark-recapture and telemetry experiments. They found no evidence to suggest that sole was attracted to monopile habitats. Telemetry data best resembled a random use of the area by sole. The majority of sole movements took place at spatial scales larger than the wind farm area. Data for cod were more variable suggesting a continuum of behaviors ranging from very mobile to very resident with monopile habitats, potentially indicating that at least part of the cod population were attracted to the monopiles. Whether the monopile foundations act as attraction devices, i.e. only temporarily changing the distribution of cod without changing the population level, or whether they provide good quality habitats providing better survival or foraging and therefore enhance overall cod population, could not be concluded. No evidence for disturbance or avoidance of cod in relation to the operation of the wind turbines was found.

Reubens et al. (2011) used acoustic telemetry to investigate spatial and temporal migration patterns of cod in a wind farm (Thorntonbank OWF) in the Belgian part of the North Sea. Their 88 days' monitoring data indicated high residency times of some cod at turbine foundations and surrounding scour protection, suggesting a degree of attraction. They also noted that fine scale data for cod distribution near these structures reflected the diurnal cycle for some individuals.

It can be expected that increased production of epifauna and aggregation of fish around wind farm structures would provide feeding opportunities for marine mammals and birds. As an analogue of the reef effect, one of the most interesting recent observations was recorded at Alpha Ventus and Sheringham Shoal OWFs. Russell et al. (2014) studied the movement of tagged harbor seals (*Phoca vitulina*) at these sites, where some individuals showed striking grid-like patterns of movements as they concentrated their activity at individual turbines. The data strongly suggested that these structures were used for foraging and the directed movements show that animals could effectively navigate to and between structures. Figure 6.7 indicates the tracks of foraging harbor seal at the turbines and meteorological mast at Alpha Ventus.

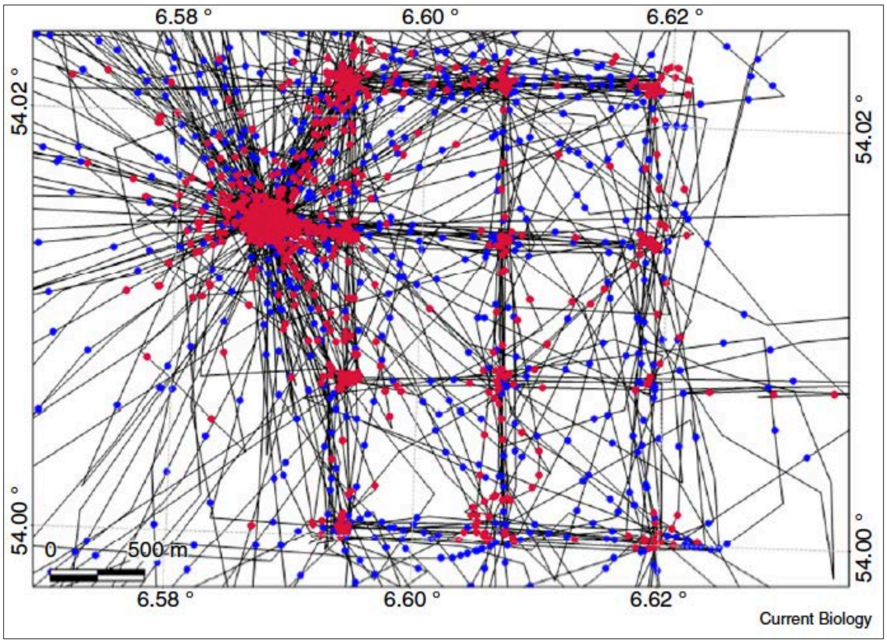

Figure 6.7: The tracks of a harbor seal around Alpha Ventus Offshore Wind Farm

source: Russell et al., 2014

Lindeboom et al. (2011) reported that more porpoise clicks were recorded using T-PODs inside the Egmond aan Zee OWF than in the reference (control) areas outside the farm during operations. Bouma and Lengkeek (2009) noted a significant increase in the abundance of Common scoter (*Melanitta nigra*) between 1999 and 2006, with common eider (*Somateria mollisima*) also being abundant. This pattern was linked to the presence of the wind farm, and the authors suggested that "*the most likely explanations are increased food availability due to the attached fauna on and in the hard substrates (reef effect) as well as the exclusion of fisheries and reduced vessel traffic in the wind farm (shelter effect)*".

Whether the reef effect at OWFs reflects increased production of fish, or simply aggregation (i.e. re-distribution) remains unclear. Ecological implications are potentially significant, for example, predators that are able to hunt more efficiently at these sites may impact prey populations more heavily, particularly if there is no increase in production to support the predation (Bohnsack et al., 1994). Further studies are required to evaluate the reef effect at OWFs where operational noise and vibration, and possibly EMF, may also influence production.

6.7 Section Conclusion

In general, the monitoring reviewed to date has not been able to detect any significant broadscale effects of wind farm construction and operation on fish and shellfish ecology, although some localized (turbine level) changes have been recorded in some instances. The natural mobility and high seasonal and inter-annual variations of fish and shellfish populations are often cited as confounding factors in the detection and assessment of the wide-scale effects of OWFs. Differences in survey techniques have also yielded different, and sometimes contrary, results. Overall, however, no significant changes in fish and shellfish ecology have been recorded.

Positive 'reef' effects have been reported in a number of OWFs and manifest themselves as increased abundance of certain fish and shellfish species, although this is not a universal observation. It is clear that once erected, turbines and associated scour protection can provide refugia for some fish and shellfish as well as suitable surfaces for attachment and growth of encrusting epifaunal populations upon which fish can feed. Removal of bottom trawling within operational wind farms may also have led to data supporting a beneficial effect, but again, this is not universal amongst all sites. While these factors would appear to be clear attractants to fish, enhanced abundances concentrated around point locations (turbines) can also attract fish predators, as noted during seal tagging studies, potentially modifying existing predator – prey relationships affecting the longer term distributions of species.

These structural aspects of colonization potential and community development at artificial reefs is likely and should be considered during the design of any new OWF in order to optimize ecological benefits and impact offset. Design considerations should also take note of ecological risks, such as potential invasions by alien/non-indigenous species (see Chapter 5: Benthic Ecology).

While it may be possible for fish and shellfish to detect EMF emissions, the significance of this in the natural environment, and within the context of their natural migration, foraging, and spawning behaviors, appears to be negligible. No significant EMF effects have so far been found from the environmental monitoring reviewed to date. Recent in situ observations from California by Love et al. (2016) would seem to add further weight to the evidence of no significant effect.

Burial of cables within the seabed would create a minimum distance separation between operational cables and fish and shellfish receptors further limiting any potential effect, although the practicability of this depends on the geology of the site. It should be noted however that the development and expansion of floating OWFs and associated dynamic cables within the water column has not been assessed to date and potential effects of EMF emissions from operational cables propagating through the water column are not known. Equally, expansion of OWFs on the US continental shelf could result in cumulative effects which are not well understood at present, particularly with regard to the potential consequences to migratory species.

7. SEABIRDS

7.1 Introduction

This chapter reviews the observed impacts of OWF construction and operation on seabirds drawn from a study of license condition monitoring reports and industry research. Appendix A describes the information used to support this chapter. Species discussed are primarily European, these being the foci of current monitoring efforts in relation of offshore wind facilities. While this chapter focuses on seabirds, it is acknowledged that terrestrial species may also be impacted particularly as a result of their attraction to illuminated offshore structures and collision during their migrations and periods of poor visibility conditions.

Figure 7.1: Cormorants (*Phalacocorax carbo*) on a turbine foundation at Rhyl Flats Offshore Wind Farm

Photographer: A. Mackay

7.2 Stakeholder Concerns

The planning process for major infrastructure projects, including OWFs, differs between European member states in some regards, although many of the stages are broadly similar. Developers are encouraged at an early stage to engage with interested parties and statutory stakeholders which can include licensing authorities, local planning authorities, statutory nature conservation bodies (SNCBs) and usually leading and influential wildlife non-governmental organizations (NGOs) such as the Royal Society for the Protection of Birds (RSPB) in the United Kingdom.

At the scoping stage of a project, detailed characterizations of seabird populations and distributions within and around the proposals are generally not available, although initial investigative surveys might have commenced. Comments and concerns received from the stakeholders at early planning and feasibility stages help develop the scope of initial surveys but tend to relate to generic topics as follows:

- Displacement;
- Barrier effect;
- Habitat loss; and
- Collision risk.

In addition, a number of offshore shallow water sites, can support significant populations of seabirds by providing preferred roosting, nesting of feeding habitat such as sand banks, and coastal areas, where wind farms with grounded foundations are mostly sited. In some cases, these preferred habitat locations are designated as seabird sites on the basis of the significant numbers of resident and migratory species that they continually support and it is in this regard that such sites can receive national and international (European) protection. Impacts which can affect the quality and extent of the habitats within these sites can affect seabirds and will also require careful consideration and assessment. Proposed OWFs may lie on principal migration routes to preferred wintering habitats, and thus may pose a barrier around which birds will have to fly. Where significant, such diversions could affect bird energetics and have effects on overall fitness. A key concern of stakeholders is therefore ensuring that there is a good understanding of the connectivity (or lack of) between the proposed wind farm site and any local designated bird areas to ensure that species for which protected sites have been designated are not significantly adversely affected. Table 7.1 presents the typical concerns that are usually identified by the agencies and stakeholders during project scoping and consultation of OWF projects together with general mitigation measures that may be applied to ameliorate potential significant adverse impacts.

Table 7.1: Typical Concerns Raised by Stakeholders During Scoping of Potential Effects of Offshore Wind Farm Construction and Operation on Seabird Ecology

<table>
<tr><th>Concern</th><th>Source</th><th>Pathway</th><th>Effect</th><th>Typical Mitigation</th></tr>
<tr><td colspan="5">Construction and Operational Phases</td></tr>
<tr><td>Displacement/ disturbance (leading to an effective loss of habitat)</td><td>Construction vessels and wind turbines during construction, wind turbines during operation</td><td rowspan="3">Physical presence, visual and noise disturbance</td><td>Reduced densities or absence of bird species within the array and potential increase in seabird densities in adjacent areas and control sites</td><td>Seasonal constraints on construction program</td></tr>
<tr><td>Barrier effects</td><td>Construction vessels and wind turbines during construction, wind turbines during operation</td><td>Avoidance and increased energetics.
Sites close to breeding colonies could result in chicks being exposed to potential predation as adult birds have to forage further afield</td><td rowspan="2">Wind farm design, i.e. larger gaps between rows of turbines to allow a corridor effect</td></tr>
<tr><td>Connectivity with</td><td>As above</td><td>Adverse impacts on</td></tr>
</table>

protected sites and important bird colonies			nature conservation objectives and site integrity	
Attraction	Turbine structures and foundations.	Physical presence	Provision of offshore roosting opportunities and foraging habitat for some species.	None
Operational Phase				
Collision risk	Turbines and swept area of the rotor blade	Birds colliding with moving turbine blades or flying into turbine structures	Mortality	Appropriate wind farm siting and design Turn off turbines during migrations

7.3 General Monitoring Rationale

Monitoring of seabirds within and around OWFs has generally been undertaken to better understand and document potential changes in the spatial and temporal distributions of seabirds, their use and passage movements around the wind farm (displacement) and behavior, such as the timings of the arrival of migratory species within the vicinity. Census data are also collected to help verify model predictions concerning the numbers of collision victims for relevant species.

Seabird monitoring techniques have evolved since the construction of the first wind farms over 20 years ago. Initial monitoring techniques involved monthly census surveys of species which were undertaken by trained observers on board survey vessels following agreed transects through wind farm sites and adjacent areas. Before, after, control, impact (BACI) survey designs were employed detect and assess significant change attributable to the presence of the wind farm and associated construction and maintenance vessel traffic. This technique provided high resolution taxonomic information which was useful in the determination and description of species specific interactions, although this technique was limited to daylight hours and periods of good weather and visibility. To overcome some of the practical constraints of vessel based visual observations, some OWFs have more recently installed radar devices. These have been able to track and record the different behaviors of seabirds at varying distances to offshore turbines and provide insights on avoidance (or otherwise) of wind farms by seabirds and potential barrier effects. Radar studies are limited in terms of the taxonomic resolution that they can provide and so are typically complemented with visual records from observers based on vessels, offshore platforms or coastal observation posts.

In the last decade, remote sensing using various tagging devices and telemetry have been increasingly used to further improve the knowledge on bird movements and behaviors. Telemetry methods have been assessed in Thaxter et al (2015b) and include:

- geolocators, that require the bird to be re-caught, give rather inaccurate positional data, but are small and inexpensive at around $60 per unit and which can be fitted to a wide range of birds including small passerines;
- archival GPS requiring data recovery of the tag and two captures of the same bird;
- GPS local remote transmission, such as through a network of relays at the breeding colony; and
- wider transmission devices such as the Argos GPS/satellite.

This type of sensing work is still in its infancy but is starting to unlock information on bird movements and behavior outside the breeding season. For instance, Thaxter et al (2015a) used a long-term GPS system that was able to recharge itself using miniature solar panels, to collect data on lesser black-backed gulls (*Larus fuscus*) over three years. These tags are limited to two dimensions, however, by adding an accelerometer (to larger species of bird such as large gulls and above) movements of birds can be tracked in three dimensions (including vertical) Thaxter et al (2015b). Using these systems, differences in flight heights have been measured for diurnal and nocturnal flights and variations in flight behaviors between land and water can now be established. These data are proving to be extremely useful when considering potential collision risks with wind turbines.

Work by Garthe et al (2016) on tagged gannets in the German sector of the North Sea, showed that gannets (*Morus bassanus*) largely avoided the wind farm areas to the north of their colony in Helgoland, and that the issues for gannet survival related mostly to exclusion from their foraging areas (habitat loss) rather than collision with the turbines. It is noted that there is some debate at present on the effects that these types of devices are having on bird behavior and long term survival. As Thaxter et al (in press) suggests, trials of GPS tags on great skua *Stercorarius skua* were not at all successful beyond the first summer season.

More recently still, advances in aerial digital photography has enabled accurate counts of individual species over large areas of sea for monitoring and assessment purposes, in particular for quantifying broadscale displacement of seabirds and for establishing the effects of multiple OWFs within a region (see Hi-Def, 2016 as an example).

7.4 Description of Impacts

7.4.1 Impacts During Construction/Decommissioning

7.4.1.1 Displacement/disturbance

Some seabirds naturally avoid offshore structures and may also be disturbed from areas of vessel traffic. The physical presence of turbines and the movements of construction and maintenance vessels could lead to seabirds being displaced from areas previously used for foraging resulting in an effective loss of habitat. Displacement may also result in increases in competition for food resource at adjacent areas where similar suitable foraging may be found. Birds which rely on shallow and/or coastal areas are considered most at risk from displacement and loss of habitat as these locations are also favored for OWF development. In contrast, some species, notably some gulls, appear to be attracted to OWFs possibly as a result of the greater feeding and/or roosting opportunities offered by the new, albeit artificial, habitats.

Wind farm developers have attempted to quantify seabird displacement by designing a suitable survey strategy that encompasses the wind farm array site and a buffer zone, typically up to 4 km in all directions around the wind farm. In addition to this there has been attempts to create reference areas that should ideally be similar to the array site in terms of seabed depth and distance from the coast and support similar species and densities of the populations of seabirds found within the study area, but be sufficiently far away not to be impacted by the wind farm construction or operation.

Dierschke et al (2016) categorizes seabirds according to five behaviors to wind farms from strong avoidance, weak avoidance, no wind farm effect through to weak attraction and strong attraction. It was noted that individual birds may react differently to the wind farm than others of the same species. Avoidance is usually further categorized into displacement and barrier effect, while disturbance is normally a condition during construction rather than the operation of the wind farm. In general, monitoring studies have demonstrated displacement effects in seabirds, and particularly in divers and common scoter which appear to be particularly sensitive compared to other species. Dierschke et al (2016) concluded that the two species showing consistent displacement from the wind farms studied were red throated diver (*Gravia stellata*) and gannet.

Although a limited number of longer-term studies have suggested some habituation and recovery, many of the UK licensing conditions only allowed for 3 years of post-construction monitoring. This may not be a sufficiently long enough time to detect and characterize seabird recovery or other longer term trends. In addition, initial monitoring of commercial scale offshore wind facilities in the UK routinely employed control sites that were too small (often smaller than the wind farm array sites themselves) and too close to the wind farm development, so if birds were displaced from the wind farm they could also be partially displaced from the control sites as well. This highlights potential problems of some previous monitoring studies which have employed a traditional BACI design for monitoring birds. For scarcer species or for species displaying a clustered distribution or high inter annual variation, the survey areas may have been simply too small to allow robust statistical comparison (MMO, 2014). Advances in aerial survey techniques, as mentioned above, may allow for much larger areas to be surveyed to alleviate these issues.

Elsewhere in Europe, such as Germany, the Netherlands and Denmark, site seabird characterizations of wind farms are undertaken on behalf of governmental bodies rather than individual developers. The advantage of this system is that the developer may not experience the same financial constraints while research opportunities and monitoring designs are maximized to account for much larger control and buffer areas resulting in statistically more robust data. The Alpha Ventus OWF is a good example and uses a control site that is many times larger than that of the wind farm itself and is at least 20 km from the wind farm at its nearest point.

7.4.1.2 Habitat Loss

Habitat loss is usually dealt with in impacts assessment as a sub-component of displacement and disturbance. Where species are scared off from entering or using a wind farm site, then that habitat is no longer available and is effectively lost to that individual or population.

The amount of seabed typically lost by the construction of a wind farm is typically <1% of the total wind farm development area, even allowing for the worse case of using gravity base foundations. While it is true that some seabed will be lost during the life time of the wind farm new habitat will inevitably be created, which may equal or exceed the quality of the seabed lost. It has been demonstrated that seabed habitat will typically reappear in wind farms during the post-construction period. This can be partially explained by less human disturbance in terms of construction vessels but also by the restoration or the creation of new foraging habitats from activities such as scour or cable protection.

7.4.2 Impacts During Operation

The impacts of displacement, disturbance and habitat loss equally apply during the operational phase. In addition to these the main impacts are barrier effects and increased collision risk arising from the physical presence of the infrastructure.

7.4.2.1 Barrier Effect

Wind farms can act as barriers to migration or to feeding movements between colonies and marine feeding grounds resulting in longer flight times and great expenditure of energy. The extent to which this occurs is poorly understood at present

Barrier effects are distinct from displacement as they relate to birds that do not necessarily associate with the area but might be flying through an area due to migration or en-route to a major foraging area. For example, the wind farm might be located between a seabird's breeding colony and the main feeding grounds. By actively avoiding the wind farm and flying around it, birds might be expending more energy than they otherwise would in the absence of the wind farm, and in the worst-case, might mean that they are absent from the breeding colony for longer than they otherwise would which might increase potential chick predation.

The effects of wind farms as barriers on different types of birds may be tested using numerical simulations. Masden et al (2010) used an energetic modelling approach to suggest that wind farms acting as a barrier could have a greater effect in terms of energetic cost on seabirds which make frequent but short duration flights for foraging, such as terns, auks, and cormorants, compared to species that make few foraging trips but of a longer duration, such as gannet, and Northern fulmar (*Fulmarus glacialis*). Masden's paper does not take into account any strong avoidance or attraction to the wind farm from that particular group of species however.

Radar has been used to good effect to establish the behavior of migratory birds on approach to OWFs including any change on flight trajectories or flight heights. However, it is better for larger species with obvious flight patterns i.e. 'v' formation of geese as opposed to low flying birds like ducks or shearwaters where the 'signal noise' from waves can mask birds. Radar studies on geese have demonstrated that birds often fly at higher altitudes over the wind farm rather than avoiding the whole area.

7.4.2.2 Collision Risk

The collision between a bird and wind turbine is a relatively rare event, but is difficult to verify and quantify in the field. Collisions with man-made structures are not new, for example, there are well documented cases of birds being attracted to lighthouses on moonless nights during migration periods, resulting in hundreds or even thousands of deaths from one lighthouse.

In the absence of any direct observations, assumptions are made on the likelihood of certain bird species colliding with offshore wind turbines. Despite the lack of sufficient empirical data to prove it either way, statutory nature conservation bodies in the UK have in the past acknowledged that they do not know what collision rates are likely and have asked developers for a range of collision rates to be considered during impact assessment. It is noted that at the lower end of this range (95% avoidance) a lot of the present day wind farms in development would not have gained consent, and avoidance rates of 98% or above are commonly applied in EIA. The assumption that birds flying within the rotor swept area before construction will not take evasive action or alter their flight patterns once the wind farms are constructed is also very precautionary. Monitoring as part of licence conditions are helping to further nuance current assumptions, develop the necessary empirical data to inform future consenting decisions and further refine numerical models. In light of the current data gaps in these regards, a dedicated collaborative research project at the Thanet OWF in the UK is currently ongoing to help provide further insight into these interactions as explained in the following case study.

Case Study 14: Offshore Renewables Joint Industry Programme Research on Bird Collision and Avoidance Rates

Background

All EIAs for UK OWFs require a bird collision risk assessment which is typically based on a numerical model (normally the Band model) to estimate the numbers of birds expected to be killed by collisions with turbine blades. The model takes into account a number of parameters including turbine size, bird flight heights and speed but is extremely sensitive to changes in the parameter relating to seabird avoidance rate for which there is currently little accurate information. The absence of reliable data in this regard is an increasing concern to developers as OWFs, and their component turbines, become larger and the perceived risk of bird collisions grows. Therefore, in order to collect appropriate field data to help refine future model predictions, the Offshore Renewables Joint Industry Programme (ORJIP) is currently funding new research to study species specific interactions with wind farms and individual turbines. Outputs from this work will be applied to future OWFs and will support more confident decision making with regards potential collision risk. The following presents brief description of the research efforts undertaken to date.

Methods

The ORJIP work is a collaboration of several OWF developers, statutory bodies, wildlife charities and environmental consultancies and is supported by an advisory expert panel comprising the UK nature conservation agencies. Work commenced in March 2014 and is planned to be completed and reported in 2017.

The research aims to establish detailed behaviors of seabirds on approach to OWFs and in the proximity of turbines. This includes measures of the avoidance rate parameter including long distance (macro) avoidance, indicating avoidance of the wind farm, medium distance (meso) avoidance, indicating avoidance of rotor swept zones, and near field (micro) avoidance, indicating responses to single blades within a few meters of the rotor swept zone.

The Thanet OWF was chosen for the project as it was considered to be likely to host a number of seabird species for which there is currently great uncertainty. Several different types of seabird monitoring equipment have been installed onto the turbines of the OWF. This includes long range (12 km) and medium range (8 km) radar, thermal animal detection system (TADS) digital thermal cameras and visual observers equipped with laser range finders to record distance and altitude. The radar and camera systems are attached to several turbines within the wind farm array.

Tracks of all birds passing close to and through the OWF are recorded with a focus on five key bird species were including gannet, herring gull, lesser black-backed gull and black-legged kittiwake. The research is currently ongoing and is due for completion and reporting in early 2017.

Results

Interim results have been produced and made available to the project sponsors, but have not been made available in the public domain. The full results are expected to be published during the second quarter of 2017.

One of the other obvious parameters to measure and consider during assessment of bird collision risk are the heights that different species fly at as well as the proportion of the population flying at heights corresponding to rotor swept areas. These data are routinely being collected at OWFs during licence compliance monitoring campaigns and will be used to populate and verify predictive collision risk models in support of improved accuracy of assumptions.

Different species and species groups fly at different heights. Auks, such as guillemot (*Uria aalge*), and razorbill *Alca torda* typically fly low across the sea and below the usual rotor swept area. As such, they are not generally regarded as being at risk of collision with operational turbines (MacArthur Green, 2016). Gulls, on the other hand, more commonly fly at heights corresponding to the turbine blades and are thus at comparatively greater risk in this regard. Also, gulls tend to demonstrate attraction towards wind farm structures which would seem to increase the risk of interaction and collision greater still.

Wind turbines typically have at least a 22 m clearance to sea level at high water, from the lowest tip of a turbine blade. Therefore, any bird flying below 22 m is considered not to be at risk. However, birds fly at different heights during migration than they do during foraging, and they may also fly at different heights during periods of bad visibility or at night. Birds might also be observed flying at elevated heights to take evasive action from a passing ship.

Observations at Teeside OWF (EDF Energy Renewables, 2016) recorded the proportion of birds flying at the rotor swept height, taken to be between 15 m and 150 m above the sea surface. Records were collected during the initial EIA investigation, during the pre-construction period (2008 – 2010), and during the first year of operation (2014 – 2015) as presented in Table 7.2.

Table 7.2. Proportion of Birds Flying at Rotor Swept Height at Teeside OWF (source: EDF Energy Renewables, 2016).

Species	Proportion of birds flying at rotor swept height (15 – 150m above sea level)		
	Baseline EIA	Pre-construction 2008 - 2010	Post-construction 2014 - 2015
Eurasian Wigeon (*Anas penelope*)	6%	30%	14%
Eurasian Teal (*Anas crecca*)	1%	23%	-
Common Eider (*Somateria mollissima*)	0%	0%	13%
Common Scoter (*Melanitta nigra*)	4%	0%	3%
Red-throated Diver (*Gavia stellata*)	10%	11%	9%
Northern Fulmar (*Fulmarus glacialis*)	0%	2%	2%
Manx Shearwater (*Puffinus puffinus*)	0%	0%	0%
Northern Gannet (*Morus bassanus*)	13%	20%	21%
Greater Cormorant (*Phalacrocorax carbo*)	7%	3%	3%
Eurasian Shag (*Phalacrocorax aristotelis*)	-	0%	0%
Eurasian Oystercatcher (*Haematopus ostralegus*)	3%	7%	5%
Dunlin (*Calidris alpina*)	1%	14%	0%
Arctic Skua (*Stercorarius parasiticus*)	5%	0%	7%
European Herring Gull (*Larus argentatus*)	10%	35%	33%
Great Black-backed Gull (*Larus marinus*)	32%	56%	44%
Little Gull (*Hydrocoloeus minutus*)	0%	0%	4%
Black-headed Gull (*Chroicocephalus ridibundus*)	0%	5%	9%
Black-legged Kittiwake (*Rissa tridactyla*)	4%	33%	21%

Little Tern (*Sternula albifrons*)	0%	0%	0%
Sandwich Tern (*Thalasseus sandvicensis*)	2%	13%	10%
Common Tern (*Sterna hirundo*)	1%	3%	3%
Arctic Tern (*Sterna paradisaea*)	0%	0%	9%
Common Guillemot (*Uria aalge*)	0%	1%	0%
Razorbill (*Alca torda*)	0%	0%	0%
Atlantic Puffin (*Fratercula arctica*)	0%	0%	0%

During monitoring surveys, attempts have been made to measure flight heights using a variety of aids. These have proven not to be wholly accurate, and indeed for the earlier projects bird flights were assigned to certain height bands rather than to the nearest meter. However, new technological and methodological advancements involving aerial digital photography appear to be promising with regards to the collection and analysis of seabird flight height data (Normandeau Associates Inc., 2012).

Johnston and Cook (2015) reviewed all the current techniques for recorded flight heights and ranked them according to their accuracy. They concluded that there was not one preferred method although data derived from digital aerial techniques were more accurate than those obtained from visual observation. With digital aerial data the flight heights can be measured to the nearest meter rather than relying on fairly broad distant bands e.g. 0 m to 20 m, 20 m to 50 m and 50 m to 150 m as per traditional observational recordings. Table 7.3 compares the proportions of selected birds observed at flight heights corresponding to swept rotor areas from vessel and digital aerial surveys.

Table 7.3: Flight Height Estimates and 95% Credible Intervals taken from Conventional Visual Observation on Boats and Digital Aerial Photography (source: Johnston and Cook 2016)

	Proportion of Birds Flying Between 20 m to 120 m					
	Boat		Digital Aerial			
	Percentage	95% Credible Intervals	Percentage	95% Credible Intervals	Sample Size	Number of Sites
Black-legged kittiwake	15	12-17	13	9-16	1429	7
Lesser black-backed gull	28	20-43	42	33-52	306	7
Great black-backed gull	33	29-43	26	16-46	281	6
Manx shearwater	0	0-0	0	0-2	240	4
Northern gannet	13	6-20	50	43-57	223	5
European herring gull	32	25-41	36	28-46	222	7
Sandwich tern	7	6-15	57	45-68	205	3

Based on the percentage of different populations found at collision risk height, Furness et al (2013) found that great-blacked gull was most at risk followed by herring gull, lesser black-backed gull *Larus fuscus*, black-legged kittiwake and gannet. The percentage of populations of other species recorded at collision risk height, such as Sandwich tern red throated diver, razorbill and guillemot, was comparatively less suggesting a reduced risk of collision with turbines at sea (Johnston et al., 2014). It is interesting to note that the species most inclined to fly at the rotor swept heights, namely the large gulls, are also those identified as being attracted to wind farms.

Bird flight heights measured before a wind farm is constructed of course do not take into account any modified behavior displayed by birds post-construction and there may be behavioral differences within the same species at different sites. Table 7.4 demonstrates the variability that can occur in recorded flight heights for a single species, in this instance kittiwake, between different sites, and highlights the need for site specific information to be gathered as behaviors within a species may differ geographically. The data do not specify if the sites are baseline, in construction or post construction.

Table 7.4: Estimated Proportion of Kittiwakes Flying at Potential Collision Height (20 m to 120 m) and 95% Credible Intervals (Johnston and Cook 2016)

Site	Sample Size	Percentage at Potential Collision Height (20 m to 120 m)	
		Percentage	95% Credible Intervals
1	131	4	1-9
2	603	16	9-26
3	462	31	19-44

Flight heights of seabirds recorded by conventional methods (rangefinders, pixel size etc.) from boats and aircraft have one major disadvantage. They tend to be measured during daylight and in good weather. This immediately poses the question at what height do birds fly at during night time. The recent proliferation of remote sensing projects using global positioning system (GPS) satellite tagging is starting to provide some answers. However, it should be stressed that this work is still in its infancy and the sample size of birds remains small.

There is also the question of how a tag and harness actually effects the individual bird. Research carried out by the British Trust for Ornithology (BTO) on great skua (Niall Burton personal communication) has suggested that this species is not suitable for this type of study as only one of the 24 individuals tagged reappeared at its breeding colony the following season, and that particular individual had managed to lose its harness. Data gathered by the BTO on lesser black-backed gulls has been much more successful.

Ross-Smith et al (2016) took raw data gathered from GPS tagging studies on a colony of lesser blacked gulls from Orfordness in Suffolk southern England, and a population of great skuas from two colonies in the Orkneys and Shetlands (northern Scotland). They applied a Bayesian model to the data and were able to establish flight height distributions for these two species at different times of the day and over land, coastal areas and open sea Tables 7.5 and Table 7.6 present the modelled flight heights for lesser black backed gull and great skua, respectively.

Table 7.5: Modelled Height at which 50% of Lesser Black-backed Gulls Fly from Data Gathered During the Breeding Season from GPS Tagging Studies (Ross-Smith et al 2016)

	Terrestrial	Coastal	Marine
Daylight	22.9 m	8.7 m	12.8 m
Twilight	12.0 m	2.5 m	10.4 m
Dark	14.0 m	5.4 m	5.6 m

Table 7.6: Modelled Height at which 50% of Great Skuas Fly from Data Gathered During the Breeding Season from GPS Tagging Studies (Ross-Smith et al 2016)

	Terrestrial	Coastal/Marine
Daylight	2.2 m	0.2 m
Twilight	0.6 m	0.4 m
Dark	1.1 m	0.6 m

From an OWF perspective, it is encouraging that the lesser black-backed gull flies highest over land and during the day. Flight movements at night are less frequent and are generally at a lower altitude. If this pattern is replicated in other gull species this could reduce the precautionary stance by SNCBs particularly in the application of the collision risk model. Results of the ORJIP study (case study 14 above) would help elucidate actual collision risk in this regard. Great skuas were noted to fly well below the rotor swept height during the day and night.

7.5 Typical Mitigation Measures

Specific mitigation measures imposed on wind farms to reduced potential impacts on seabirds are presented in Table 7.7. Mitigation has been largely applied to reduce potential impacts on bird populations during the construction phase through temporal program restrictions. By and large these are aimed at reducing the impacts of construction vessels and associated disturbance effects at certain times of year, when specific bird populations are likely to be at their peak abundance. The Grampian type condition imposed at London Array OWF (Table 7.7.) was different in that the wind farm was due to be built in two phases, phase two to be dependent on the results of the seabird monitoring from phase one (see also case study 15 below).

Table 7.7: Summary of the Measures Agreed to Mitigate the Potential Impacts of Offshore Wind Farm Construction and Operation on Seabirds Ecology

Offshore Wind Farm	Mitigation Type(s)	Duration	Receptor of Concern
Burbo Bank	Construction period restricted to March to October	5 months	Wintering birds
Rhyl Flats	Seasonal exclusion period 16 December to March inclusive for construction activities	3.5 months	Common Scoter
Gwynt y Môr	Construction traffic limited to existing navigation lanes to reduce vessel disturbance to red throated diver and common scoter.	Permanent	Red-throated Diver and Common Scoter
Scroby Sands	Sequence of piling south to north aimed to minimize effect on little tern colony *Sterna albifrons*. Turbine erection is from north to south	Breeding Season	Little Tern
Thanet	Cable laying seasonal restriction within the intertidal zone 1 October to 15 April	6.5 months	Shorebirds
London Array	Grampian type conditions – limiting construction to phase 1, phase 2 can only commence once licensing authority satisfied no significant impact		Red-throated Diver

7.6 Observed Environmental Effects from Monitoring and Research

7.6.1 Displacement

The ES for the Kentish Flats OWF predicted foraging by red-throated diver could be impacted during construction as a result of displacement from the OWF site. Extensive monitoring during the operation of the Kentish Flat OWF demonstrated that red-throated divers were permanently displaced from the wind farm area for 7 years following its construction. The following case study presents a review of red throated diver monitoring reports compiled by the Kentish Flats OWF operator before construction started and up to 7 years during its operational phase.

Case Study 15: Monitoring of Red Throated Diver (*Gravia stellata*) Displacement
Kentish Flats Offshore Wind Farm

Background

Kentish Flats OWF is a wind farm located approximately 10 km off the coast of Kent, UK, on a large, flat and shallow plateau just outside the main Thames shipping lanes. Water depth on site is approximately 5 m.

Construction was completed in August 2005, with commissioning and testing of all turbines completed by September 2005. The wind farm consists of 30 Vestas V90-3MW wind turbines with a total capacity of 90 MW.

Methods

As part of the application process for permission to develop the Kentish Flats site, a full EIA was required. A vessel based census survey was undertaken on nine occasions between October 2001 and April 2002 and prior to the construction of the OWF. These data served as the basis for comparison with subsequent data acquired during licence condition monitoring.

The pre-application baseline seabird surveys were repeated to collect similar census information before, during and at least 3years following construction. In the event the developer agreed to an extended post construction survey period of up to 7 years finally reporting their conclusions in 2014. During that time the survey methods were modified, to reflect the experiences gathered at this and other sites, and the improvements in technology particularly from digital aerial photography.

Results

Initial attempts to use comparisons between the control and wind farm area were made on completion of the 3 years post-construction monitoring, however as the control site was surveyed on 38 occasions as opposed to the wind farm itself on 108 occasions the data were statistically weakened. No firm conclusions regarding displacement attributable to the wind farm could be made for any species at this time.

The developer maintained their monitoring program beyond the usual 3 years post-construction period and supplemented their vessel based observations with aerial digital photography. From these extended data they were able to conclude in 2013 that displacement of red throated diver had indeed taken place from the wind farm area, by as much as 94% and that birds were displaced by as far as 3 km away. They report no sign of habituation reported from other sites, and suggest that red-throated divers might display more tolerance of disturbance in other locations of greater importance to them in terms of foraging habitat than that found around Kentish Flats OWF.

Conclusions

Aerial surveys covering the whole of the Thames Estuary Special Protection Area (SPA) have established a winter population of around 8,000 individual red-throated divers, this number is highly variable both in temporal and spatial extent. These population estimates were completely unknown at the outset of the monitoring program at Kentish Flats and the other OWFs located within the wider Thames Estuary and demonstrate some of the hurdles facing developers in selecting a site without that prior knowledge.

Red throated divers were also raised as a potential environmental concern during the application for the development and operation of the London Array OWF. The concern related to potential effects of the development on the outer Thames Special Protection Area (SPA) and which was, at that time, being considered for classification on the basis of its important wintering red throated diver population (NIRAS, 2011). On award of the licence allowing construction and operation of the OWF, a program of licence condition monitoring was required to validate ES predictions of no significant effect and to inform the licensing authority whether subsequent phases of the development may proceed (Grampian Condition). Specifically, the intention of the Grampian Condition in this instance was to ensure that no further development beyond the initial proposed development would take place until such time that sufficient evidence had been acquired to demonstrate that subsequent development of the OWF would have no adverse impact on red throated diver populations and the integrity of the potential SPA. To our knowledge, the London Array OWF is the only example of an offshore wind development where such a [Grampian] condition has been imposed. The following case study reviews the results of 6 years of red throated diver monitoring at London Array (APEM, 2017) and outlines the final developer decision in response to the Grampian Condition.

Case Study 16 Measuring Displacement of Red Throated Diver (*Gavia stellata*) Using Aerial Video Surveillance and Use of a Grampian Condition in the Permitting Decisions
London Array Offshore Wind Farm

Background

The London Array OWF is located within the outer Thames Estuary, and comprises 175 turbines. The total capacity of the project is 630 MW. Construction began in March 2011 and was mainly completed in December 2012. Full operation commenced in spring 2013.

The wind farm now sits within the recently created Outer Thames Estuary Special Protection Area (SPA) which is afforded European protection on the basis of its wintering red-throated diver population[10] and which was being proposed at the time of the London Array application. The local population of red throated diver is recognized as the largest in the UK and is estimated at 6,466 birds (38% of Great Britain’s wintering population)[11]. This case study reviews the monitoring of the distributions of the Outer Thames Estuary red throated diver population over 6 years in relation to pre, during and post construction phases of the London Array OWF (APEM, 2017) and describes the use of a Grampian Condition within the permitting process.

The Grampian Condition

The London Array OWF project originally comprised two sites, known as ‘Phase 1’ and ‘Phase 2’. Due to the importance of the area for red-throated diver, and associated proposals for the SPA, development consent was only granted for Phase 1 of the project as concerns still existed that significant impacts may occur on the Outer Thames Estuary red-throated diver population if both phases were to go ahead. Phase 2 was the subject of a ‘Grampian Condition’ whereby the area could not be developed unless the developer could demonstrate that any change caused by the construction of the Phase 1 turbines to the red-throated diver habitat, would not compromise the conservation objectives of the SPA. Consequently, the ornithological monitoring program at London Array OWF placed a significant emphasis on detecting changes and impacts to the wintering red-throated diver populations.

Despite the original intentions to develop the wind farm in full, in February 2014 an announcement was made by the developer (London Array Limited) that they would not be proceeding with the development of Phase 2 of the project[12]. The reasons cited included the environmental uncertainties associated with the area and the technical challenges of the site. The environmental uncertainty related to the way in which the developers would have to wait for a minimum of three years until the ornithological monitoring at Phase 1 was complete, in order to satisfy the regulatory authorities that there would not be an unacceptable impact on red-throated diver as a result of Phase 2 (depending on positive findings of the monitoring). London Array Limited therefore terminated the agreement for lease with The Crown Estate with regards to Phase 2.

10 http://publications.naturalengland.org.uk/publication/3233957
11 http://jncc.defra.gov.uk/page-7249
12 http://www.londonarray.com/project/london-array-to-stay-at-630mw/?_sm_au_=isVVJ3qVnFMqvSZQ

As per the original licence condition, the ornithological monitoring surveys relating to Phase 1 were continued as planned. Post-construction surveys for red throated divers were carried out during the winters of 2013/14, 2014/15, and 2015/16. These data enabled comparisons with the data from pre-construction aerial surveys which were carried out in the winters of 2009 / 10 and 2010 / 11. Construction surveys were also undertaken during the winters of 2011/12 and 2012/13.

Methods

Ornithological surveys were undertaken over six years (pre, during and post-construction) using a high resolution digital aerial survey methodology. Each survey was flown using twin-engine aircraft on a 500 m grid at a 3 cm ground sampling distance (GSD) resolution.

The area surveyed was divided into two zones including Zone 1 (the development area, the London Array OWF, and a 1 km buffer area), and Zone 2 (control zone south west of the OWF). Originally, further control zones (Zones 3, 4, 5, 6, and 7) had been established to facilitate additional monitoring to inform the Phase 2 development (based on the Grampian condition), however monitoring of these areas was discontinued prior to post-construction monitoring once Phase 2 was cancelled. Figure 7.2 shows the locations of the original Zones used during the monitoring campaign.

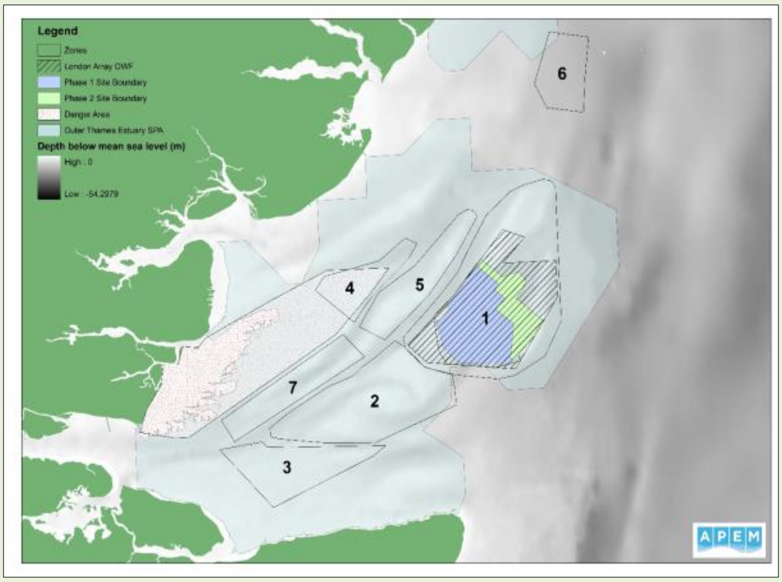

Figure 7.2 Layout of the red-throated diver monitoring zones at London Array Offshore Wind Farm.
(source: APEM, 2017)

Zone 1 included the OWF, the Phase 2 OWF footprint (now redundant) and buffer areas. The Zone 2 control zone was designed to enable detection of displacement of birds from the OWF area, due to the way in which Zone 2 is characterized by potentially favorable habitat for red-throated divers (i.e. water depths of less than 20 m and limited shipping traffic). Zone 2 was also extended with a 1 km buffer to capture bird densities in adjacent shipping lanes.

Results

Figure 7.3 compares the peak population estimates in the OWF area (Zone 1) and the control area (Zone 2). Figure 7.4 shows the cumulative distributions of red throated divers during each winter monitoring period. Detailed analysis of the data has not yet been undertaken (APEM, 2017). It is therefore inappropriate to attribute factors to observed changes in red throated diver distributions at this time although some speculative interpretations are summarized below.

Numbers of divers in Zone 1 decreased during the winter period of 2011/12 and after construction had started suggesting potential construction disturbance effects, possibly related to the associated movement of vessel traffic to which red throated divers are considered to be sensitive (APEM, 2017). A corresponding, albeit slight, increase in the numbers of birds in Zone 2 suggested that some birds may have been displaced from the OWF to areas of suitable habitat to the south and east although other birds from the OWF area may have been displaced elsewhere.

Numbers of divers started to increase in 2012/13 and after the main construction works had been completed in December 2012. This suggested that some of the initially displaced birds had moved back into the area once the main construction disturbance effects had abated. However, the natural influx of red throated divers to the wider Thames Estuary in January and February was also noted as a possible factor influencing abundance and distribution at this time. APEM (2017) highlight that "*major annual and monthly fluctuations in diver numbers on the Thames make it difficult to interpret with certainty the drivers of local changes in diver numbers and distribution.*"

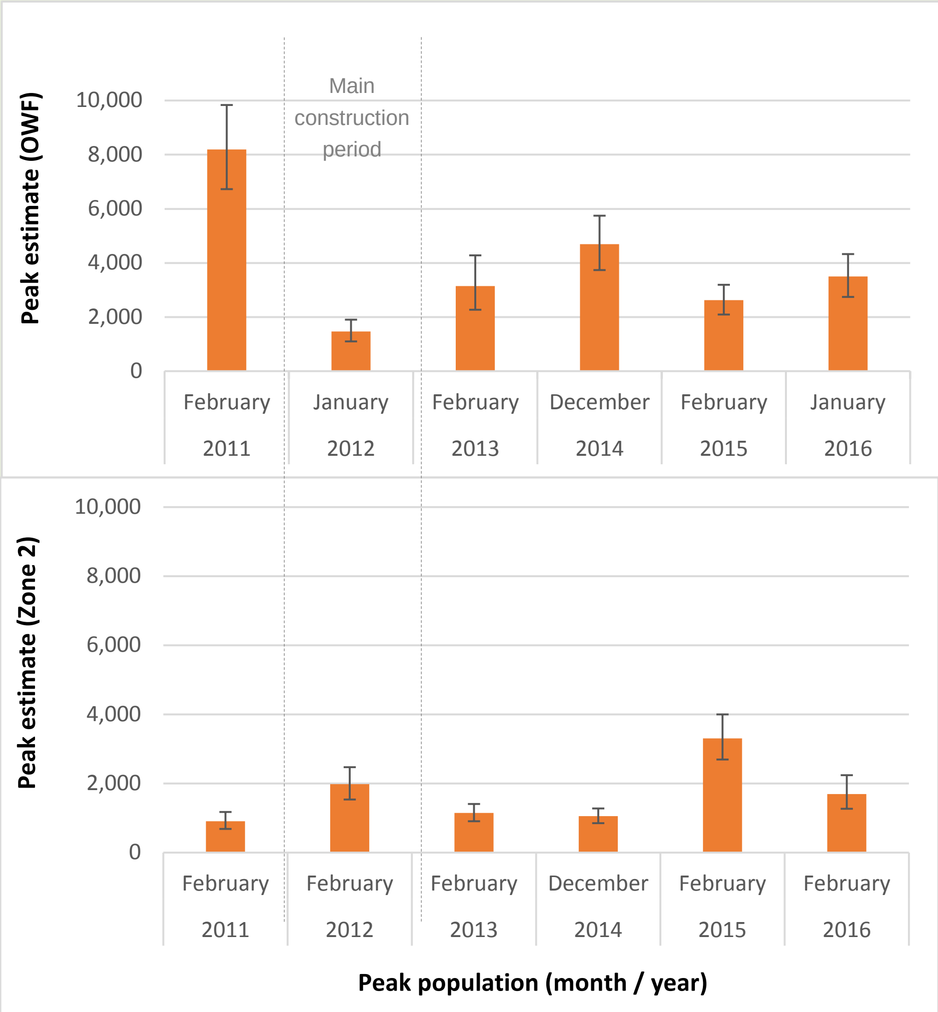

Figure 7.3 Peak estimate counts of red throated divers per year at London Array Offshore Wind Farm
(source: APEM, 2017)

During the post-construction monitoring period, divers appeared to continue to move back into Zone 1 although abundance fluctuated over this time possibly as a result of natural variations in the annual influx of red throated divers to the wider Thames area during winter. Despite generally increasing in abundance, numbers of red throated divers within Zone 1 remained below baseline values during the most recent survey in 2015/16. In particular, red throated divers seemingly continued to avoid the OWF during the first three years of operation. It is noted that although the bulk of the construction work had been completed by December 2012, other residual activities, such as cable laying and placement of scour protection material, continued to take place throughout the autumn of 2013 and 2014. In addition, maintenance activities will have been constantly undertaken throughout the operational monitoring program. These activities may have had ongoing disturbance effects on red throated diver during the operational phase monitoring.

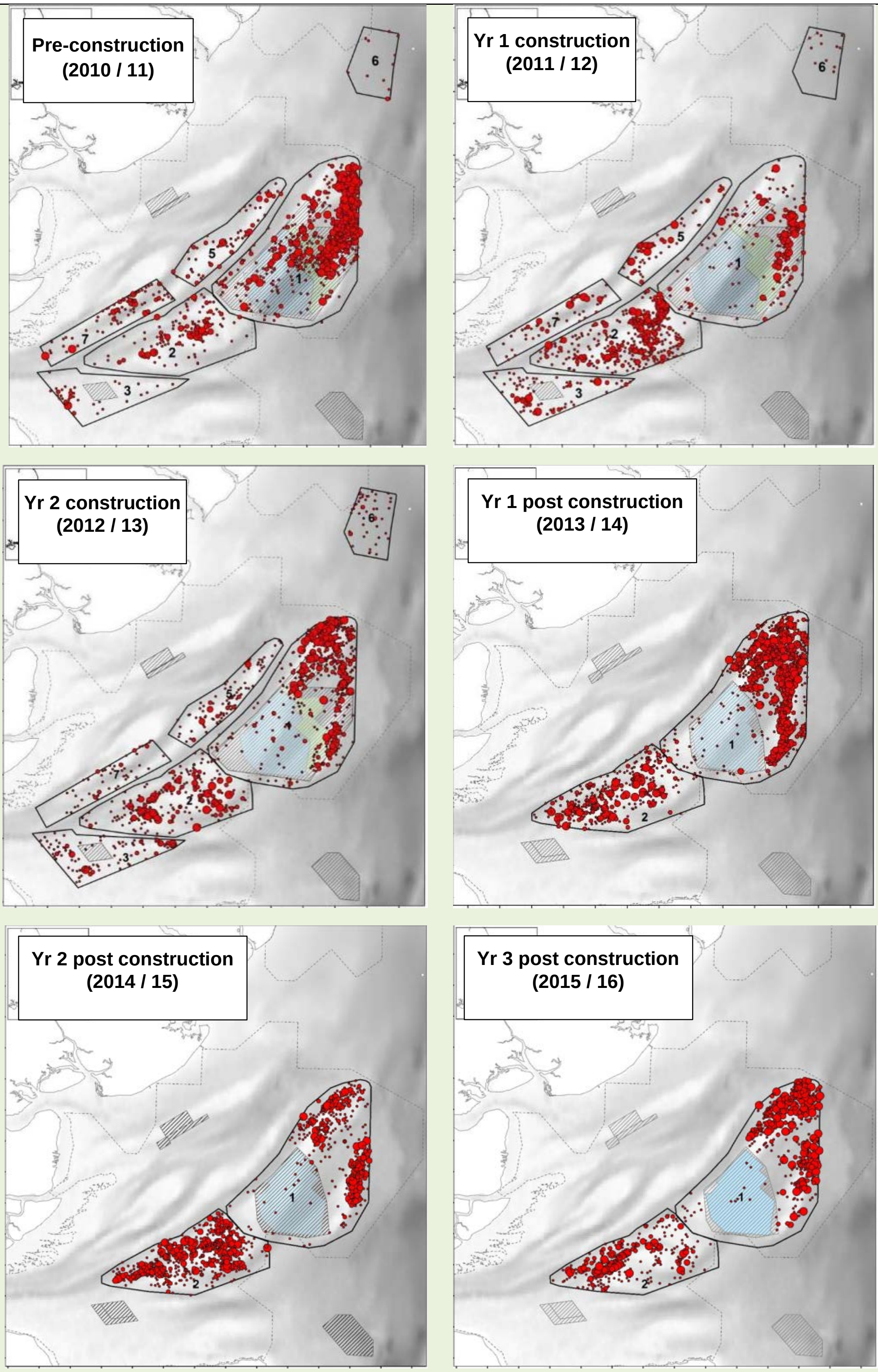

Figure 7.4. Annual cumulative winter distributions of red throated divers at London Array Offshore Wind Farm

(source: APEM, 2017)

Blue shading = London Array OWF Phase 1 Green shading = London Array OWF Phase 2

It is not known if further field monitoring of red throated diver numbers and distribution are planned in connection with the London Array OWF. The 3-year post construction monitoring fulfils the existing permit obligations in this regard, and so further data acquisition seems unlikely. However, the data collected to date will be pooled with other similar data collected for the area and analyzed to assess the degree to which the OWF has influenced the distribution of divers in the Outer Thames Estuary and will be reported in due course (APEM, 2017).

Conclusions

APEM (2017) noted that it should not necessarily be assumed that disturbance effects resulting from the construction and operation of the OWF are the only potential cause of the changes in diver abundance and distribution across years. Environmental factors, such as an exceptionally cold winter in 2010/11 may have resulted in a particularly high influx of red-throated divers into the region during that time, while the winters of 2011/12, 2012/13, 2013/14 and 2014/15 were considered to be more mild, potentially resulting in a wider dispersion. Methodological considerations such as diurnal variation of the surveys, in addition to other factors such as varying hydrodynamics and the presence of other developments across the wider region also have the potential to have contributed to temporal variations in distribution and abundance. APEM (2017) concluded that all of the aforementioned variables are likely to have had some influence on the study findings, combined with potential displacement effects of construction.

The data collected from this monitoring campaign will now be interpreted within a spatial statistical model which will be able to account for a number of different factors, such as bathymetry, habitat, and anthropogenic pressures in explaining observed distribution patterns. The authors indicated that this work will be published in due course in collaboration with the statutory conservation agencies in the UK and that it will assist in the further development and evaluation of modelling approaches to inform decision making.

Seabird monitoring at Lynn and Inner Dowsing OWFs suggested displacement in some species post construction but increased densities in others, although results were inconclusive (RPS, 2012b). Other environmental factors including the variable distributions in offshore food resources were highlighted as potential confounding factors caveating conclusions in this regard. The short term nature of the data collection period was also noted to potentially limit the statistical significance of the results. Methodological variability between survey occasions was also reported, and which may have further limited comparisons of spatial and temporal distribution data as explored. The following case study explains the 3 years of post-construction seabird monitoring at the Lynn and Inner Dowsing OWFs (RPS, 2012b).

Case Study 17: Monitoring of Seabird Displacement
Lynn and Inner Dowsing Offshore Wind Farm

Background

The Lynn and Inner Dowsing OWFs are two adjacent offshore wind facilities located approximately 6 km to 7 km offshore in the southern North Sea. Together they comprise 54 turbines installed on monopile foundations. Construction of both OWFs was undertaken in 2007 and 2008 and was substantially completed by December 2008.

In compliance with licence requirements, a series of vessel based surveys were required to be undertaken during pre and during construction stages and for up to 3 years post construction to address the following aims.

- Assess changes in the usage of the sea area by feeding and passage birds;
- Assess collision risk prior to construction and any actual collisions post construction; and
- Survey the benthos to inform reasons for possible changes in bird distribution and density on site.

This case study reviews the vessel based seabird monitoring that has been undertaken during each of the phases the construction and operation of the OWFs.

Methods

A total of 22 vessel based surveys were undertaken during the 2007/2008 construction period and 36 surveys were conducted during the 3-year post construction period between 2008/9 and 2011/12. These consisted of a series of line transect surveys with all birds recorded within a 300 m of the vessel recorded. Flying birds were also recorded and classified according to their respective flight height bands including < 20 m (below potential strike height of the turbine), 20 m to 120 m (within potential strike height of the turbine and > 120 m (above potential strike height).

Baseline surveys were conducted during 2001 to 2005 and focused on the presence of red throated diver and common scoter given the apparent concern relating to these species at the time. The baseline surveys were able to establish that prior to OWF construction, the most numerous groups of birds using the site were gulls and terns together with migrating pink footed geese. Species for which local protected sites have been designated were present in low numbers prior to OWF construction or were observed flying over the planned OWF sites in significant numbers but would experience negligible rates of collision.

Results

During construction, seven species of seabird were recorded at slightly lower densities compared to pre-construction periods. These included gannet, kittiwake, common gull, great-backed gull, herring gull, and northern fulmar. Nevertheless, gulls were noted to remain abundant and were frequently recorded during the construction monitoring. Sandwich and common tern abundance actually increased in the Lynn OWF and were observed using the turbine platforms in 2007, although less consistently in 2008.

Higher numbers of auks (razorbill and guillemot) were recorded within the Lynn OWF site during construction compared to baselines, particularly during their post-breeding period. They were noted to be swimming and feeding amongst the turbines in 2007. However, there appeared to be a shift away from the turbines in the Lynn site in 2008. Some evidence of a distribution shift in guillemots from the center to the outer turbines within both OWF was recorded and was tentatively suggested as a displacement effect. Densities of red-throated diver were lower in the wind farms compared to control areas suggesting possible displacement of this species although the generally low numbers recorded caveated conclusions.

During the first 3 years of operation, red throated diver was more abundant in the control area compared to the OWF sites and associated buffer areas suggesting a potential displacement effect. However, the lack of any control data prior to the construction of the OWF limits conclusions in this regard (RPS, 2014). Skua, kittiwake Sandwich tern and guillemot appeared to favor particular parts of the study irrespective of the presence of operational OWFs and their distributions may have been more influenced by bathymetric features and associated feeding opportunities (RPS, 2014). Kittiwake, skua, and guillemot numbers increased in the third year of operation possibly suggesting a degree of habituation whilst growing numbers of Sandwich tern may have been in response to increases in small shoaling fish around the turbine foundations (reef effect).

Conclusion

Results of potential displacement effects of seabirds were inconsistent and no pattern could be determined. Some species appeared to have increased in abundance while others appeared to have declined. Evidence of a distribution shift of guillemot away from the center of the wind farms and towards the outer turbines and preferential use of the control site by red throated diver was noted and may be representative of a displacement effect. Fluctuations in the distribution of food prey availability was noted as a factor potentially influencing seabird distributions over time.

Monitoring at Barrow OWF identified declines in the numbers of auks, great black-backed gull, herring gull, kittiwake, and lesser black-backed gull during construction but once operational, numbers of these species increased although observed differences were not significant (BOWind, undated). With regards to the gull species observed, BOWind (undated) suggested that the difference in numbers between observation periods may be due to natural variations in populations, metocean conditions or foraging conditions rather than to wind farm effects. Similarly, the monitoring at Burbo Bank OWF revealed declines in the abundance of auks, common scoter, and red-throated diver. However due to low numbers generally recorded and the statistical weakness of this data, no firm conclusions were made. Burbo Bank is adjacent to a busy shipping lane, and numbers of birds may be suppressed due the proximity of local vessel activity.

Use of the wider area by seabirds was described from the construction monitoring report for Gwynt y Môr OWF which states that red-throated diver was not entirely displaced. Furthermore, no discernible effects on gulls, auks, fulmar, Manx shearwater, and gannet were apparent from the survey data.

The monitoring at Ormonde OWF noted auks and gannets to be significantly more abundant in the reference area than in the operational wind farm. Guillemot appeared to be significantly more abundant within the wind farm during the construction than during the pre-construction period. Manx shearwater were significantly more abundant in the wind farm than the reference area. Kittiwakes appeared to be attracted to the construction site making use of the towers to perch on.

The Robin Rigg OWF monitoring campaign showed a decline in the numbers of guillemots and razorbills during construction and a partial recovery during the early operational phase. No significant effect on red-throated diver abundance was noted.

The Walney OWF post construction monitoring campaign indicated that common scoter and red-throated diver were mainly found outside the wind farm area, suggesting avoidance of the operational turbine array. The Rhyl Flats OWF monitoring report for post construction (year 2) described auks as being displaced from the wind farm, however there was no mention of this in the following years report.

Little terns showed no sign of displacement from the Scroby Sands OWF. The population viability of the nearby colonies appears to be more effected by fish prey availability, and predation of the chicks by kestrels (*Falco tinnunculus*). Only 2 years post-construction monitoring was carried out, and no predictions were made regarding collision risk.

Reduced numbers of red-throated diver and auks were recorded from Gunfleet OWF during the construction period however some return of red-throated divers was recorded in the second post-construction year suggesting that in this instance they were displaying a low level of habituation. Auk numbers however had not recovered 2 years post-construction.

Monitoring at the Thanet OWF calculated that red-throated diver within the OWF were at population densities of only 18% of the pre-construction levels during construction and were only at 27% of baseline values during the first 3 years post-construction. The same study also demonstrated that gannets had also been displaced, with densities recorded at 43% of those found in the buffer zone 1 km from the development. Auks also appeared to have been displaced, however razorbill numbers had recovered to pre-construction levels after the second year of post-construction surveys. Guillemot numbers remained depressed.

One year of post construction monitoring at Teeside OWF concluded that there were no major changes in the abundance of bird species attributable to the presence of the wind farm. However, some smaller changes are noted within the data (EDF Energy Renewables, 2016). For example, vessel based peak counts of common scoter within and around the OWF were lower after construction compared to the pre-construction surveys. Peak counts of lesser black-backed gull, black headed gull, Manx shearwater, gannet, and fulmar were also reduced post construction, compared to pre-construction survey occasions. Red throated diver numbers, on the other hand, remained largely consistent between monitoring periods although numbers of individuals of these species were comparatively low in comparison to the abundance of other species present. The peak abundance of cormorant and terns also showed little variation between pre and post monitoring occasions and numbers of razorbill, puffin, and guillemot had increased over the pre-construction condition.

Densities of fulmar, razorbill, and kittiwake were reduced in the Westermost OWF, and within the surrounding areas up to 2 km distance, during construction compared to baseline conditions (Percival & Ford, 2015) suggesting potential displacement during this time. With regards to razorbill, densities were also lower in reference areas located over 4 km distance from the OWF suggesting other factors other than the OWF may have influenced broadscale distributions at this time (Percival & Ford, 2015). Gannet, guillemot, and little gull densities were also depressed within the OWF during construction but were similar to pre-construction values just outside of the wind farm boundaries suggesting potential displacement from the OWF only. In contrast, densities of herring gull and great black-backed gull remained similar or increased during construction suggesting potential attraction effects. Despite the observed trends, the variability in these data meant that any significant differences could not be detected (Percival & Ford, 2015). The exception to this was the observed decline in puffin (*Fraterula arctica*) densities within the OWF during the construction period and the concomitant significant increases in densities in areas outside the OWF boundaries. The authors concluded that this indicated a significant displacement effect for puffin. During the first year of operation, densities of gannet, kittiwake, guillemot, and puffin decreased within and outside of the Westermost Rough OWF boundaries, but the declines within the OWF were found to be disproportionately greater (Percival & Ford, 2016). While suggestive of displacement of these species, further monitoring from subsequent survey is required to attribute effects (Percival & Ford, 2016).

Displacement of some bird species has been recorded from Belgian wind farms. Monitoring at Thorntonbank OWF, for example, reported displacement by common gull and Belwind OWF reported displacement of gannet, common guillemot and razorbill.

Monitoring at Alpha Ventus OWF in Germany reported a decline in lesser black backed-gull, guillemot kittiwake, and gannet post construction. Diver numbers were recorded as not showing much change, but were fairly uncommon in the baseline studies. Interestingly although numbers of lesser black-backed gull numbers were lower post construction, those that were recorded were reported to be feeding in and amongst the turbines and were foraging more actively when very close to the wind farm than when they were further away within the study area.

In Denmark ornithological surveys undertaken between 1999 and 2005 at Horns Rev OWF suggested that common scoter was displaced from the wind farm (Danish Energy Agency, 2013). Observations made by maintenance crews and helicopter pilots (i.e. not part of any scientific survey) between 2006 and 2007 reported increasing numbers of birds within the wind farm. On the back of this, four further surveys were commissioned. In three out of four of these surveys more common scoter was recorded than from any previous survey including pre-construction surveys. The fact that birds were recorded in greater numbers than before suggests factors other than habituation are at play. It was concluded that common scoter may occur at high densities between wind turbines at sea, but that this is only likely to occur a number of years after construction. A habitat suitability model was developed for common scoter prey items which provided a link between benthos availability and distribution of common scoter. The same study found no return to the wind farm sites by red-throated divers. The belief is that this species is genuinely displaced from these sites and that it displays a stronger adverse response than any other seabird.

7.6.2 Barrier Effect

Barrier effects were demonstrated in post-construction surveys at North Hoyle where gannets were observed with 'scalloped' flight around the outlying turbines. It should be noted that gannets have amongst the longest foraging ranges of all UK breeding seabirds (Thaxter et al 2012) and a relatively small OWF, such as North Hoyle, would not present a significant barrier to it. However, the potential cumulative effects of the planned very large OWFs in the North Sea may warrant further review once operational in a few years' time.

Radar studies at Walney OWF demonstrated that pink-footed goose were unaffected by the wind farm and adjusted their flight heights to fly over the wind farm. Analysis of whooper swan and pink footed goose counts at a regular local wintering wetland habitat showed that the construction and first year of operation of the West of Duddon Sands OWF did not influence the migration arrival of these species.

7.6.3 Attraction During Construction

Cormorant (*Phalacrocorax carbo*) appear to be positively attracted to the construction site, utilizing the half` completed turbines (foundation and transition pieces) as perches and roosts. Cormorants, herring gull, and kittiwakes were all observed to be positively attracted to Robin Rigg post-construction utilizing the turbine structures. Lesser black-backed gulls appeared to be attracted to Walney OWF. Gull numbers were recorded as abundant at Gunfleet Sands particularly post-construction. Common gulls displayed an element of attraction during the construction of Kentish Flats possibly due to increased feeding opportunities.

Belgian monitoring studies have similarly recorded apparent attraction of OWF to gulls and terns including common and Sandwich terns, lesser black-backed gull, and herring gull. Little gulls were also attracted to the Alpha Ventus OWF.

Dierschke et al (2016) describes the cormorant as strongly attracted to wind farms, utilizing the wind farm structures as outposts to expand their foraging ranges. The wind farms described are generally located closer to shore and Dierschke (2016) poses the question as to whether cormorants will be able to expand their range once the larger and more distant wind farms principally in the North Sea are constructed. It should be noted that cormorants are rarely encountered in a truly pelagic environment. For example, there were only 12 individual sightings of cormorant made in the entire two-year boat survey on the Dogger Bank OWF zone (125-290 km offshore), when other seabird species like black-legged kittiwake, and common guillemot were counted in their hundreds of thousands (*personal observations*.).

7.6.4 Other Behaviors

Night time surveys at Teesside OWF from shore based surveys using image intensifiers demonstrated that gulls and terns were inactive during periods of darkness. Conversely, wading birds were equally as active at night as they were during the day. This difference in activity is significant if applied to the collision risk model. For example, if birds can be demonstrated not to be active at night, then some of the precaution can be removed.

7.6.5 Collision Risk

Radar studies together with complementary visual observations were conducted at the Egmond aan Zee OWF to establish the potential collision risk to resident and migratory birds. Studies were conducted over a 3-year period during the operation of the wind farm (Krijgsveld et al., 2011) as described in the following case study.

Case Study 18: Collision Risk Assessment
Egmond aan Zee Offshore Wind Farm

Background

Egmond aan Zee OWF is located in Dutch territorial waters 10 km to 18 km off the coast at Egmond aan Zee. It comprises 36 × 3MW Vestas turbines installed using monopile foundations The turbines have a blade tip height of 115 m. The OWF was constructed in 2006 and became operational in 2007.

Post construction surveys were undertaken within and around the OWF as part of a 3-year research program to establish the extent of collision risk and barrier effect to local seabird populations and migratory birds (Krijgsveld et al., 2011). This case study summarizes the findings of the monitoring program.

Methods

Data were collected using both radar and visual observations. Horizontal S-band radar was employed to measure flight paths, speed and direction of birds. Vertical X-band Radar was used to measure the bird fluxes (i.e. the numbers of birds in a unit area in a unit time) and bird flight heights.

The radars were attached to the OWF met mast which was located at the edge of the wind farm and operated continuously for the duration of the study (April 2007 to June 2010). Visual observers were also deployed on the met mast for one day every month.

The visual surveys included a 360° panorama scan at sea-level height and one at a higher (not specified height). Only birds recorded within 3 km of the OWF were included.

Some observations were made at night time during spring and autumn migrations utilizing moon watching reinforced with flight call registrations (both observed in the field and recorded).

Results

The overall abundance of birds recorded within and around the OWF during the daytime was low and was attributed to the natural characteristics of the site, rather than the presence of the wind farm. Numbers were lowest in summer and winter. A total of 103 species were recorded from the visual observations within the wind farm. Variation in species composition and abundance occurred within and between years. The researchers noted that naturally, bird numbers vary largely between years due to various factors, such as weather conditions and variation in distribution at sea.

The most common species recorded were gulls particularly lesser black-backed and herring gulls in summer, and common gull and kittiwake during winter. Cormorants were present all year round with the wind farm structures apparently providing suitable perching opportunities allowing them to extend their range further offshore. Conspicuous pelagic seabirds noted during the surveys included common gannet especially in March. Divers, common scoters, and auk species were also present in lower numbers. Nocturnal species identified included thrushes (blackbirds, redwing, and song thrush) and some waders and gulls. During migration periods in spring and autumn land birds were most numerous particularly starlings (*Sturnus vulgaris*) and blackbird (*Turdus merula*).

Avoidance of the wind farm occurred on average at a rate of 28% (i.e. there was an average of 28% less birds flying inside the wind farm compared to outside). Avoidance was lowest in winter (18%) and highest in autumn (34%) and was higher at night than during the day.

The presence of the wind farm did affect flight directions; birds were recorded adjusting their flight paths to avoid the wind farm especially at close range. Bird flight through the wind farm was greatest where only a single line of turbine protruded and where the spacing between the turbines was at its greatest. Operational turbines were avoided more than stationary ones.

Of the migratory species recorded, it was found that geese (mainly Brent geese) were the wariest of the wind farm. Gannets were also noted to show high levels of avoidance with only 3% recorded flying within the turbines and 14% observed at the edge of the wind farm. Sea ducks, divers and auks also displayed avoidance behavior. Gulls did not avoid the wind farm and cormorants were attracted to it. Terns, especially Sandwich terns were actively foraging at the edge of the wind farm (believed to be exploiting greater fish prey abundance) while generally not flying through it. Table 7.8 shows the rate of macro-avoidance observed at Egmond aan Zee OWF.

Table 7.8: Macro Avoidance of Bird Species Groups Observed at Egmond aan Zee Offshore Wind Farm.

Groups Observed	Avoidance Rate (%)
Sea ducks (common scoter)	71
Divers	68
Geese and Swans (Brent geese)	68
Gannets	64
Grebes	28
Tubenoses (fulmar and shearwaters)	28
Other ducks	28
Waders	28
Skuas	28
Cormorant	18

The numbers of birds passing through the wind farm varied enormously, peak periods occurred in spring and autumn during species seasonal migrations. Birds recorded at being at collision risk were those flying between 25 m and 115 m. This was subsequently revised upwards to 139 m to account for wake effects of the rotors.

In total, over 1.8 million birds were estimated to have flown through the wind farm each year at rotor height, the majority of which were passerines (60%) followed by gulls (33 %) and cormorants (4 %). Visual observations showed that those birds that did enter the wind farm avoided the turbines and exhibited higher avoidance at night. Of the birds entering the wind farm, at least 97.6% avoided flying in the rotor swept area. Based on bird fluxes in the area and their flight behavior, the authors suggested that actual collision rate will be low.

In order to estimate the number of collision victims, the flux through the wind farm for each species group was related to the collisions risk measured on land. Flux was determined as the flux through the wind farm at rotor height using avoidance and flight height behaviors. In addition, the authors used the Band numerical model to calculate collision risk. Assuming a collision risk that is similar to that on land it was found that an order of magnitude of some hundreds of gulls would collide with the wind farm per year. Calculations based on the Band model, however, suggested half this number would collide with the turbines. Since the Band model uses the avoidance rates observed on site, it was considered the more accurate of the two methods. The very high numbers of migrating songbirds that passed through the wind farm at collision risk height (estimated 1 million) were of note. It was highlighted that the highest rates of collisions at Egmond aan Zee OWF would involve migrating passerines and that there may be in the order of some hundreds of individual collision victims of all passerines passing the OWF per year.

Conclusions

Disturbance to local seabirds was noted. Pelagic seabirds in particular displayed the highest avoidance rates. Some 18% to 34% birds avoided the entire wind farm sometimes out to 5 km or more. Many birds chose to fly around the entire wind farm rather than entering it. Sensitive species included divers, gannet, sea ducks and migrating waterfowl. Gulls and cormorants were comparatively less sensitive. Of the birds entering the wind farm at least 97.6% avoided flying in the rotor swept area.

Of the birds flying through and over the wind farm area (c. 5.2 million birds per year) approximately 35% flew at an altitude where they were at risk of collision, approximating to around 1.8 million birds. The highest number of collisions was expected to be among the migrating passerines, as they were the most numerous group in absolute numbers and were proportionately the most likely to fly within the risk zone.

Investigations into bird collisions were made at the FINO 1 research platform located approximately 45 km north of the island of Borkum (German sector). Bird carcasses (mostly terrestrial birds) were collected during a total of 44 visits to the platform during October 2003 and December 2004. A total of 442 birds comprising 21 species were found dead on the platform over the 14-month period. Injuries recorded appeared to be consistent with impact strikes with the platform and included bleeding at the bill, contusions to the skull and broken legs. It was noted that over 50% of the bird strikes had occurred in just two nights involving a total of 86 and 196 birds respectively. Both of these nights coincided with poor visibility conditions including mist or drizzle. It was assumed that there was an increased attraction to the illuminated platform on these occasions. The following case study describes observations of bird strikes at the FINO 1 research platform and discusses potential mitigation measures that could be put into place to minimize risks (Hüppop et al, 2006).

Case Study 19: Real-time Observations of Bird Strikes with Offshore Structures
FINO platforms 1, 2 and 3 Monitoring Study

Background

The German Government, through the Federal Maritime and Hydrographic Agency, has plans for the licensing of up to 20 OWFs in German territorial waters in the North and Baltic Seas. There are concerns relating to the impacts of these structures on the nocturnal migration of millions of passerines and shorebirds. Three permanent monitoring stations have been erected and funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety next to OWFs to record weather and oceanographic measurements and which have also provided opportunity to record ecological effects including effects on bird migration. The following describes observations of bird strikes at the one of the offshore research platforms (Hüppop et al, 2006) and provides some insight into the potential risk of passerine species with offshore structures.

FINO 1 Research platform

Methods

Two Platforms FINO 1 and 3 are located in the southern North Sea, FINO 1 is next to Alpha Ventus OWF, FINO 3 is in the location of a planned but not yet built OWF 80 km offshore from Sylt, FINO 2 is in the Baltic Sea adjacent to enBW Baltic 2 OWF. Bird migration has been recorded since 2003 using a combination of remote sensing devices including radar, thermal imaging, video, and audio systems.

Findings

Bird migration through the Baltic Sea as measured at FINO 2 is several times higher than that recorded in the North Sea as measured at FINO 1, which is not surprising if birds are assumed to migrate along a north south axis. Birds can be tracked up to a height of 3,400 m, but were most numerous at 200 m or lower, i.e. within the rotor swept zone of a wind turbine. There was not sufficient resolution to measure birds at more narrow bands, so it is not known the proportion of birds flying below 20 m. Very low altitude flights are often masked by wave clutter.

The visual automated recording system (VARS) camera system deployed on FINO 2 recorded nocturnal light attraction of birds to the platform. Nights of high numbers of attracted birds were relatively rare events and were characterized by low visibility, the onset of precipitation, adverse winds (a change from tailwind to headwind) and/or decreasing cloud cover.

At the FINO 1 research platform located approximately 45 km north of the island of Borkum bird carcasses (mostly terrestrial birds) were collected during a total of 44 visits to the platform during October 2003 and

December 2004. A total of 442 birds comprising 21 species were found dead on the platform over the 14-month period. Injuries recorded appeared to be consistent with impact strikes with the platform and included bleeding at the bill, contusions to the skull and broken legs. It was noted that over 50% of the bird strikes had occurred in just 2 nights involving a total of 86 and 196 birds respectively. Both of these nights coincided with poor visibility conditions including mist or drizzle. It was assumed that there was an increased attraction to the illuminated platform on these occasions. During the second night, thermal imaging revealed that birds circled the illuminated platform, apparently disorientated. It was concluded that since some of the dead birds may have fallen into the sea or taken by gulls, then the total number of collision victims was probably considerably higher than that recorded.

Corpses of migrating birds have been recorded from all three platforms. Video streams together with pathological examinations confirm that these birds died as a result of colliding with the structure. At FINO 1 the corpses were dominated by thrushes (*Turdus* spp.), which are short distance winter migrants to western and southern Europe. At FINO 2, the corpses principally comprised willow warbler (*Phylloscopus trochilus*) which is a long distance migrant to sub-Saharan Africa and a summer visitor to most of Europe.

Conclusions

There is a balance to be made between adequate navigational light and too much light leading to 'attractions' of migratory birds. Lighting levels in the UK are determined by bodies such as Trinity House and the Maritime and Coastguard Agency. Although the study of birds attracted to illumination on turbines is fairly limited there are many examples of large numbers of passerines and seabirds being attracted to lighthouses. Bardsey Island (North Wales) as a leading bird observatory, has over 60 years of data on attractions to its lighthouse and makes for very somber reading. Many decoy lights have been set up at ground level to divert the birds from colliding with the main lighthouse structure. In 2014 Trinity House replaced the old white optical light with a red light emitting diode (LED).

Damian & Merck (2013) note that to protect migrating birds, it is recommended to use light only in line with demand. The authors go on to highlight that during periods of night time mass migrations in bad weather or poor visibility conditions, the German approval authority (BSH) reserves the right to require the turbines to be fitted with deterrent devices or to temporarily shut down turbines following assessment of the avian collision risk.

As well as the smaller passerine species, larger migratory waterfowl species are also at potential risk of collision where OWFs are located along migratory routes. Pre-application surveys for the Lynn and Inner Dowsing and Humber Gateway OWFs identified significant migration movements of pink footed geese (*Anser brachyrhynchus*) approximately 10 km offshore and potentially coincident with the proposed site of the wind farms. In response to stakeholder concerns of potential collision risk, a program of monitoring of migratory pink footed geese was required to be undertaken both during and after the respective construction period. The following two case studies present reviews of migratory pink footed goose monitoring work that was undertaken one year after the construction of the Lynn and Inner Dowsing OWF (RPS, 2009) and at the Humber Gateway OWF (APHA, 2015) using bird detection radar.

Case Study 20: Monitoring of Collision Risk
Lynn and Inner Dowsing Offshore Wind Farms

Background

The Lynn and Inner Dowsing OWFs are two adjacent wind farms located approximately 6 km to 7 km offshore. Together they comprise 54 turbines installed on monopile foundations. Erection of the turbines was achieved in 2007. The nacelles and rotor blades were installed during 2008.

Following observations of seasonal movements of pink footed geese (*Anser brachyrhynchus*) within the vicinity of the planned OWF, the regulators called monitoring of potential collision to be undertaken. A dedicated survey was conducted over two 6 week periods (1 October to 14 November 2007 and 29 September to 9 November), coinciding with the timing of the migration of pink footed geese in this area.

Method

The study used bespoke land based Bird Detection Radar (BDR), comprising two radars, including a S band antenna, to detect birds in the horizontal plane, and a X band antenna to detect birds in the vertical plane. The antenna heads were positioned approximately 4 m above ground. The S band radar covered an area with a radius of 11.1 km. The altitudinal X band radar scanned above the unit through a narrow beam in an arc of 1.4 km. Radar observations were coupled with visual observations where possible to record the flight characteristics of the geese during their autumn migration including flight path, height, timing, weather conditions, numbers of flocks and numbers of individuals.

Results

In 2007, approximately half of the flocks of geese recorded were noted to be flying through the turbine areas and of these, around one third were flying below 125 m and therefore at a height that put them at risk of colliding with the turbine and rotor swept area. In 2008, the numbers of flocks of geese flying through the turbine areas reduced and all but two flocks were recorded to be flying at heights that were above the rotor swept zone. In addition, a large proportion of the geese (43.2%) which did not fly over the wind farms flew at heights that were lower than 125 m. Figure 7.5 A and B show the trajectories of those geese flying at collision height in autumn 2007 and autumn 2008 respectively.

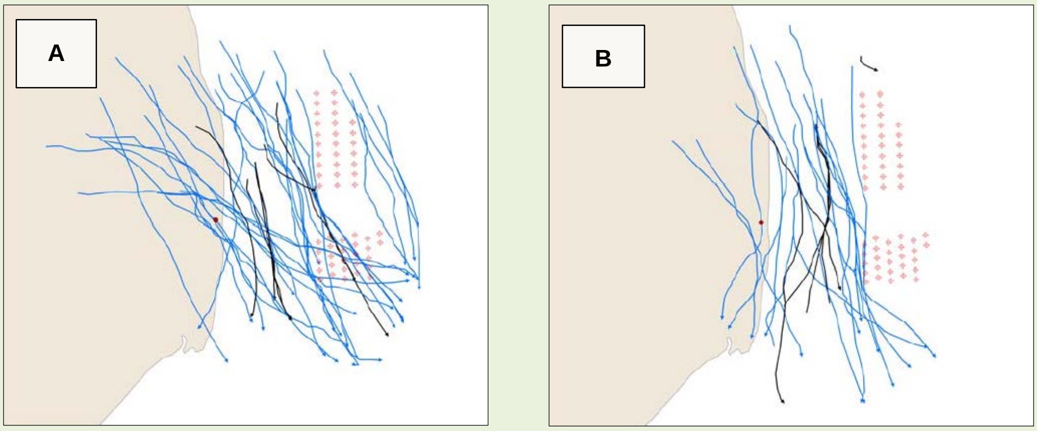

Figure 7.5: Trajectories of geese flying at collision height in 2007 (A) and 2008 (B) at Lynn and Inner Dowsinig Offshore Wind farm

The data show that in both years the geese flying at collision height initially followed the same route through the site. However, in 2008 it appeared that as geese approached the western edges of the arrays, the average flight direction was shifted to a more southerly course before returning to the original heading once clear of the turbines. Closer inspection of the new flight paths in 2008 revealed that on average they were 3.5 % longer (an additional flight distance of 486 m) than in 2007.

Conclusions

During 2007, only the turbine foundation and transition pieces were installed which appeared to be tolerated by the migrating pink footed geese allowing them to fly through the wind farms. However, the fitting of the towers, nacelles and rotor blades in 2008 appeared to elicit an avoidance behavior which affected their flight path. Geese flew around the turbines and then continued on their original route once clear. Geese flying through the wind farms flew at a height above the rotor swept area.

Importantly, predictions made from the 2007 data suggested that 21 to 27 flights would be at potential collision height. The observations from monitoring showed that actually, only 2 flights were at this height during the monitoring period suggesting that the predictions were over precautionary.

In conclusion the data collected indicated that pink footed geese can detect ad avoid wind turbines.

Case Study 21: Bird Detection Radar of Migrating Pink-footed Goose (*Anser brachyrhynchus)*
Humber Gateway Offshore Wind Farm

Background

The Humber Gateway OWF is located approximately 8 km off the Holderness coastline, UK, just north of the outer Humber estuary in the North Sea. Water depth across the OWF is approximately 10-18 m. The wind farm consists of 73 x 3MW Vestas turbines with a total capacity of 219 MW. Construction of the OWF was completed in 2015.

The OWF lies just over 40 km north of the Lynn & Inner Dowsing OWFs and is similarly recognized as being located along the migration route for the pink-footed goose. To validate numerical simulations and confirm ES predictions of no significant collision risk, a radar monitoring study was included as a condition of the construction and operation Licence to detect the movements, spatial distribution, and flight heights of the pink-footed goose. This case study reviews the results of the first year of post construction radar monitoring of pink footed geese (Animal and Plant Health Agency (APHA) (2015).

Methods

In compliance with licence conditions, a radar study was undertaken in 2012 prior to the construction of the wind farm to collect baseline data on the migration characteristics of pink footed geese within and around the footprint of the Humber Gateway OWF. This exercise was repeated post construction from 14th Sept to 20th Nov 2015 (a total of 68 days) to cover the autumn migration period. The surveys were combined with visual observations during daylight hours to ground truth the results from the radar and covered a total of 476 hours of observation. An offsetting technique is used to extend the range of the radar to 14.8 km to adequately track the geese across the entire wind farm. Two radar units were deployed one in the S-Band measuring birds in the horizontal plane and the other the X-Band measuring in the vertical plane.

Results

Table 8.1 summarizes the results of the pre and year 1 post construction pink footed goose radar monitoring.

Table 8.1. Summary comparison of pre and post radar monitoring of pink footed geese at OWF (source: APHA, 2015)

Parameter	No of tracks (% of total no of tracks)	
	2012	2015
Total no of tracks	205	312
Total groundtruthed	110 (53.7%)	117 (37.5%)
Groundtruthed at time of observation	-	84 (26.9%)
Observed but groundtruthed retrospectively	-	33 (10.6%)
Identified through radar video analysis	95 (46.3%)	195 (62.5%)
With altitude data	95 (46.3%)	105 (33.6%)
In daylight	187 (91.2%)	175 (56.1%)
At night	18 (8.8%)	137 (43.9%)
Within the wind farm footprint	23 (11.2%)	8 (2.6%)
Within rotor-swept zone	24 (11.7%, 25.3% of tracks with altitude data)	51 (16.3%, 48.6% of tracks with altitude data)
Within footprint and rotor-swept zone	2 (1%, 2.1% of tracks with altitude data)	1 (0.3%, 0.9% of tracks with altitude data)

More goose tracks were recorded in 2015 compared to 2012 and more night time observations were made. Two main pulses of geese movements were recorded during the post construction monitoring, including the 25th – 27th September (63 tracks) and 31st October – 21st November (230 tracks), highlighting the irregular temporal distribution of this species over the observation period.

In comparison with baseline data collected on 2012, there was a significant decline in the use of the OWF. Only 2.6% of the goose tracks passed through the OWF following construction compared to 11.2% during the pre-construction period. Figure 7.6 shows the locations of the radar tracks of geese in relation to the Humber OWF recorded in 2012 and 2015.

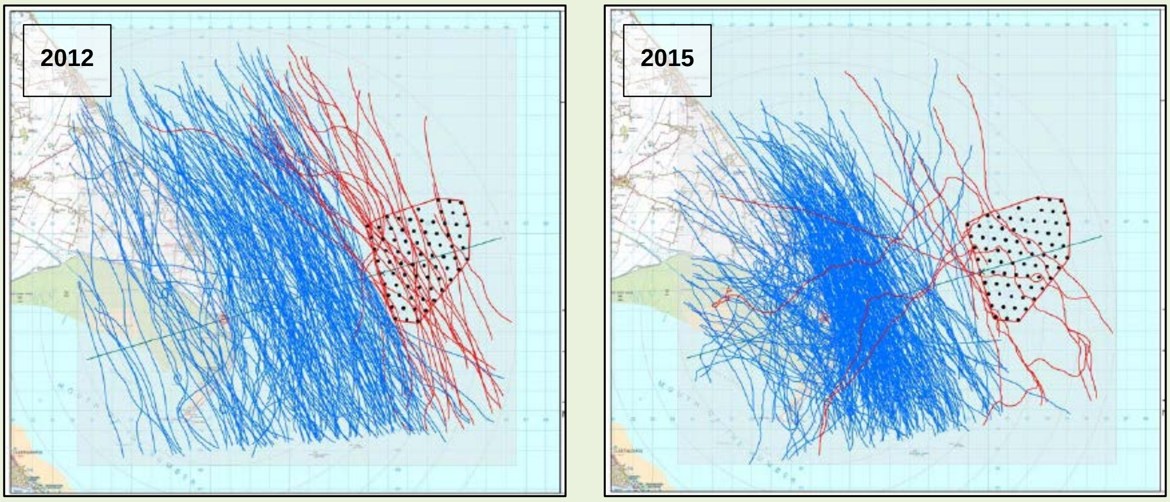

Figure 7.6. Radar tracks of pink footed geese recorded in 2012 and 2015 at Humber Gateway Offshore Wind Farm.

Red lines indicate geese flying through the OWF
Blue lines indicate geese not flying through the OWF
(source APHA, 2015)

The geese were also noted to fly closer to the coast in 2015 than in 2012. Significance testing showed that geese flew significantly further away from the wind farm footprint and closer to the coast in 2015 than in 2012. However, flight lines were practically identical between the two monitoring occasions in terms of direction (predominately south-easterly), although mean distance flown through the study area was increased by 1 nautical mile in 2015. A number of the tracks recorded in 2015 also suggested macro avoidance with birds apparently turning towards the coast on approach to the OWF. This change in direction was not recorded in 2012.

Most geese avoided the OWF in 2015. Only eight tracks (out of a total of 312) occurred within the operational wind farm. Of these, two flocks were observed to gain altitude on approach and to fly over the OWF at above the rotor swept height. Five of the tracks occurred at night or during periods of low visibility so that any vertical avoidance was not visually verified. The remaining flock through the turbines at rotor-swept height (24-136m) with some evidence of micro-avoidance of individual turbines occurring. It was unclear as to why these geese flew through the turbines without taking any evasive action although wind conditions at this time were thought to be a potential contributing factor (APHA, 2015).

Further analysis of the post construction data showed that the locations of the goose tracks were closely aligned to the wind direction. When the wind direction was from the north east, the geese flew close to the coast. When the wind direction changed to south west, this appeared to force the geese further out to the sea. Furthermore, the birds were observed to increase altitude to fly over the wind farm rather than fly against the prevailing wind.

Another variable measured using the 2015 data was poor visibility. This showed that the geese apparently had difficulty maintaining their normal course during periods of bad weather. The authors noted that under these conditions, birds could be at increased risk of collision through attraction to navigation lights, although the susceptibility of waterfowl in this regard in not known (APHA, 2015).

Conclusions

The 2015 monitoring data showed that only 0.3% of all tracks recorded were within the OWF footprint and at rotor swept height. Furthermore, the geese were predominately distributed within nearshore areas with those close to or within the turbine array exhibiting macro and micro avoidance behavior. In conclusion, the year 1 radar monitoring campaign supported the ES predictions of no significant impacts on pink footed goose populations and provided evidence that the risk of collision was low. The authors noted the presence of another OWF to the north which may have influenced flight trajectories of geese before reaching the current study area.

Quantification of collision risk has been attempted at onshore wind farms. The harvesting rates were highly variable and depended on season and general abundance of birds. Lowland sites like Little Cheney Court in Kent had an estimated mortality of up to six bird deaths per turbine, based on carcass searches around turbine bases. Upland sites where the density of birds are far lower had correspondingly lower mortality rates.

Estimates for OWFs have been made based on the Band model (option not specified) at Belwind OWF which suggested an annual mortality of 2.4 gulls per turbine, the majority likely to be lesser black-backed gull (Vanermen et al., 2013). However, directly measuring any collision event is extremely rare, and as yet, there are no studies in print that have been able to measure this in the offshore environment; the ORJIP study (see Case Study 14) is due to report during the second quarter of 2017 and may throw considerable light on the issue.

Percival & Ford (2015) re-appraised the collision risk with turbines at the Westermost Rough OWF following the licence condition monitoring of seabirds during construction. They found that in most cases, the risk had increased over that which had been initially predicted in the ES. Table 7.9 compares the results of the collision risk modelling based on a 98% avoidance rate for key bird species prior to and during OWF construction. It is noted that the avoidance rate of 98 % was applied to all birds studied regardless of their actual species specific abilities to detect and avoid turbines. It is envisaged that the findings of the current ORJIP project (see case study 14) will be able to refine individual species avoidance behaviors and further improve the resolution of future collision risk modelling.

Table 7.9 Comparison of Collision Risk Modelling Results Calculated Before and During Construction at Westermost Rough Offshore Wind Farm (source: Percival & Ford, 2015).

Species	Predicted Collision Risk (no. of collisions per year)	
	Environmental Statement	During Construction
Gannet	0.53	2.9
Kittiwake	0.85	6.9
Great skua	-	0.4
Common gull	1.22	7.5
Lesser black-backed gull	1.25	0
Herring gull	0.30	9.7
Great black-backed gull	0.68	6.8
Common gull	0.53	0
Little gull	-	0.16

Potential cumulative impacts on birds are highly contentious and are difficult to assess. Decisions are confounded further where agencies and regulators interpretations differ highlighting the need for early consensus amongst all stakeholders. Applications for three adjacent OWF of the UK coast in the southern North Sea resulted in unacceptable cumulative impacts on seabird populations resulting in cancellation of one of the projects in favor of the other two as explained in the following case study.

Case Study 22: Docking Shoal Offshore Wind Farm - An Offshore Wind Farm Too Many

Background

Docking Shoal OWF (540 MW) was one of three potential OWF developments located off the east England coast located in the Greater Wash. Two other wind farms Race Bank (580 MW) and Dudgeon (560 MW) were granted consent in 2012 at the same time Docking Shoal was refused consent.

Process

The area around the Greater Wash off the North Norfolk coast is internationally important for a number of seabird, wading birds and waterfowl. The planning application of the Docking Shoal windfarm had revealed the potential development site to be used by large numbers of foraging Sandwich terns. This population of terns was directly connected to the tern colonies at Blakeney Point and Scolt Head Island full within the North Norfolk Coast Special Protection Area (SPA), a Natura 2000 site protected under the EU Birds and Habitats Directives

UK Planning legislation under Regulation 61 of the Conservation of Habitats and Species Regulations 2010 (as amended) (the Habitat Regulations) requires the Secretary of State (Government Minister) to consider whether the proposed Development and Ancillary Development would be likely to have a significant effect on a European Site, as defined in the Habitats Regulations (either alone or in combination with other plans or projects).

If an effect is deemed possible an appropriate assessment of the implications of the European Site in view of its conservation objectives, i.e. species of fauna, flora or geological feature of interest.

The appropriate assessment considered the likely effect of the development in isolation and in combination with other proposed OWFs including Race Bank and Dudgeon, together with the OWF being constructed at the time Sheringham Shoal, and Triton Knoll which was still at the planning stage.

Docking Shoal was not directly connected with or necessary to the management of a European Site, however it was considered to have the potential to affect one.

The statutory advisory nature conservation agency JNCC (Joint Nature Conservation Committee) believed that the development was likely to have a significant effect on foraging Sandwich terns from the SPA either arising from displacement or as a consequence of birds striking the turbine blades.

This comment from the JNCC is significant as it demonstrates that in the absence of clear empirical data gathered in the field, a rigid precautionary stance is taken.

The Governmental Department DECC (Department for Environment and Climate Change) in their appropriate assessment concluded that a maximum mortality threshold of 94 Sandwich terns per annum was appropriate when assessing the potential for an adverse effect of the wind farm alone and in combination with the other wind farm sites in consideration on the breeding Sandwich tern population of the North Norfolk Coast SPA. Concerns were raised on this threshold number by the JNCC and Natural England (NE) (also a statutory advisory body) together with the Royal Society for the Preservation of Birds (RSPB) a leading and highly influential wildlife NGO, on the following grounds:

i. They lacked confidence in the justification for DECC's choice of collision risk modelling (CRM) methodology;
ii. The inherent uncertainty around the avoidance rate used; and
iii. Disagree with the number of birds, suggesting a threshold of no more than 75.

DECC maintained its justification of 94 birds based on a Population Viability Analysis (PVA) of Sandwich terns as an upper limit for all wind farm developments likely to impact on the bird population at that SPA. A mortality of 94 birds per annum was estimated to result in a decline of the population over 25 years of 4.76%. The harvest rate of 75% leading to a 4% decline over the same time period. DECC took the view that this slight increase was acceptable. A PVA model undertaken for the developer, Centrica, concluded that 5 to 10% of the reference population size offered a reasonable chance of retaining population and site integrity, i.e. an annual harvest rate between 98 and 157 birds.

Decision

DECC concluded that there would be no adverse impact in the integrity of the North Norfolk Coast SPA either alone or in combination with the other wind farms, provided that the 94 bird mortality was exceeded.

The appropriate assessment concluded that there were two ways that this could be achieved:

i. Refuse consent for Docking Shoal, but grant in full the Race Bank and Dudgeon developments; or
ii. Limit the initial stage of all three developments, by consent conditions.

Either option in DECCs view would be acceptable, however they took the view that based on the predicted kill per turbine rate per annum of the three wind farm developments, Docking Shoal (0.84), Race Bank (0.45) and Dudgeon (0.31), that Docking Shoal had the potential to kill a disproportional number of birds compared to the other two sites, and that by dropping Docking Shoal the other two sites could be developed out in full. They acknowledged that in the light of further empirical data that a different conclusion could be reached, but felt with the evidence to hand that was the best decision both for the wind farm industry and the environment.

Race Bank and Dudgeon are currently in construction. Initial digital aerial bird monitoring surveys have been undertaken over the whole area including the area of the proposed Docking Shoal development. Post construction monitoring is planned in due course and will include broad scale aerial surveys and tagging of Sandwich terns at the two nearby Sandwich tern breeding colonies along the North Norfolk coast. Both of these wind farms are undertaking collaborative monitoring work and have moved away from the BACI approach.

7.7 Section Conclusion

Due to their relatively small size, the earlier commercial scale wind farms were not perceived to pose a significant risk to seabirds. However, as OWFs have expanded and wind turbines have become larger, the potential for significant interaction has increased. Additionally, the clustering of wind farms within specific regions and within ecological ranges of seabirds increases the risk of significant cumulative impacts for which assessment methods are improving.

The expansion of OWFs in Europe has been concomitant with important advancements in bird survey technologies and methodologies. The use of high definition aerial imagery and radar as well as thermal cameras is now much more commonplace in site characterization and assessment, providing data that are complementary to, or replacements for, the more traditional vessel transect observations. In addition, there has been (and continues to be) considerable improvements in the understanding of seabird ecology as a result of continued research efforts including the use of electronic tagging and tracking of seabirds, ship and static radar, thermal cameras, and site specific observations, including night recordings of vocalizations made by migrating birds. These efforts have been instrumental in attempting to achieve consensus on important behaviors, in particular flight heights, turbine detection and turbine avoidance capabilities for each species, but also in determining species foraging ranges, important foraging habitats and their connectivity with seabird colonies and coastal foci.

In addition to advancements in technology and ecological understanding, new predictive models have been developed and refined to accommodate and synthesize site data within the context of the improving ecological information. Iterative improvements in collision risk modeling has provided stakeholders and regulators with increasingly more robust assessments of potential impacts although underlying assumptions still need to be carefully considered. Changes in bird behavior, i.e. how they approach, avoid or are attracted to turbines, during periods of adverse weather or poor visibility also needs to be accounted for. Also, results from this sort of modelling have little meaning on their own and will need to be related to the wider population to assess population viability over relevant timescales.

From the monitoring reviewed, it is difficult to generalize the impacts of OWF on seabirds as this has depended on the composition of the species present and the relative value and use of the area under investigation. However, some general observations can be made.

Seabirds can be displaced from the OWF site during construction and operation with some species, such as divers (loons) being particularly affected. Divers may be displaced for many years following construction with little or no habituation recorded during the respective monitoring periods. Other species such as auks may recover more quickly but more observations are required to determine whether recovery to baseline levels occurs. Some species, notably gulls and cormorant, appear to be attracted to operational wind farms once they are operational, using the transition pieces as perches and fishing amongst the turbines. The abundance of sea duck, (common scoter), was reported to have increased over baselines in some Danish studies possibly in response to the presence of new habitat and associated feeding (mussels) opportunities. Attraction to operational OWF can increase collision risk for those species flying at heights corresponding to rotor swept areas.

Actual monitoring of bird collisions with offshore turbines has not been undertaken. Estimations of collision risk for each OWF have relied on site observational data collected during pre-application stages including species census data and site/species specific flight heights. However, radar tracking at some OWF has shown that some birds, notably waterfowl (geese) are able to detect turbines and temporarily adjust their flight paths to avoid OWF continuing on their original course once clear of the turbine array. The findings of the current research at Thanet OWF (see Case Study 14) is expected to further improve understanding in this regard to help further refine predictive models. Future monitoring of bird collision risk is likely to involve radar, coupled with observer surveys, in order to verify model predictions.

Radar surveys work well to support other forms of monitoring effort, but as a standalone technology they have two major drawbacks. Firstly, in the horizontal axis a lot of low flying birds are missed due to general clutter from waves, so if flight height data is derived from this source it could artificially increase the proportion of birds at potential collision risk for a species. Secondly, with the exception of certain large species that have a conspicuous flight pattern e.g. ‘V’ formation in geese, the identities of birds are difficult to discern from radar alone so that ground truthing from visual observers or remote camera systems would be required.

To enable expansion of offshore wind on the US OCS, agencies are now challenged with describing sufficiently robust baselines across broad regional levels within which OWF developer site specific data can be set. The broader, regional data will be required to establish i) suitable reference populations, ii) connectivity with habitats or other populations that may lie outside of the study area and iii) the relative importance of the site for each species at local, State and Federal levels. These data are particularly important to provide context for population viability assessments in the event that the OWF under investigation is considered to potentially affect species mortality rates (i.e. through displacement or collision). Baseline data collection should be undertaken at a suitable frequency over a period of at least two years to ensure the inherent spatial and temporal variability is captured. During the acquisition of baseline data agencies should also collect concomitant meteorological and ocean physical datasets for the purposes of establishing links between physical environmental variables and observed variations in seabed distributions. Recommendations, emerging from the UK

COWRIE research, highlight the potential importance of hydrodynamic covariate data in the analysis of seabird information and which may explain the variation in seabird distributions. Passerine (terrestrial) species should also be considered within regional data collection programs given their potential to interact with offshore structures, particularly during migration and during periods of adverse weather or poor visibility. The focus in the European context has been on species that have a connectivity with protected sites and this has placed particular emphasis on seabirds, and water birds, while ignoring the numerically greater populations of migrating land birds.

The ecological significance of displacement, and *de facto* habitat loss, remains unclear and has not been addressed in current European OWF programs. Agencies should consider research into the consequences of displacement on individual fitness and/or on the breeding success of the affected population at the appropriate geographical and temporal scales to ensure meaningful assessment. Regional data collection programs should also identify and map comparable habitats that exist beyond predicted influences of OWF and which may be utilized by displaced individuals to further assist assessment, recognizing the potential for increased competition where such suitable adjacent habitats exist.

8. MARINE MAMMALS

8.1 Introduction

This chapter describes the predicted and observed impacts of European OWF construction and operation on marine mammals and the mitigation measures that have typically been applied to reduce potential adverse effects. Principal data sources have included academic research and state sponsored monitoring campaigns at selected wind farm sites, the results of which may be extrapolated to other wind farm developments. Appendix A describes the information used to support this chapter.

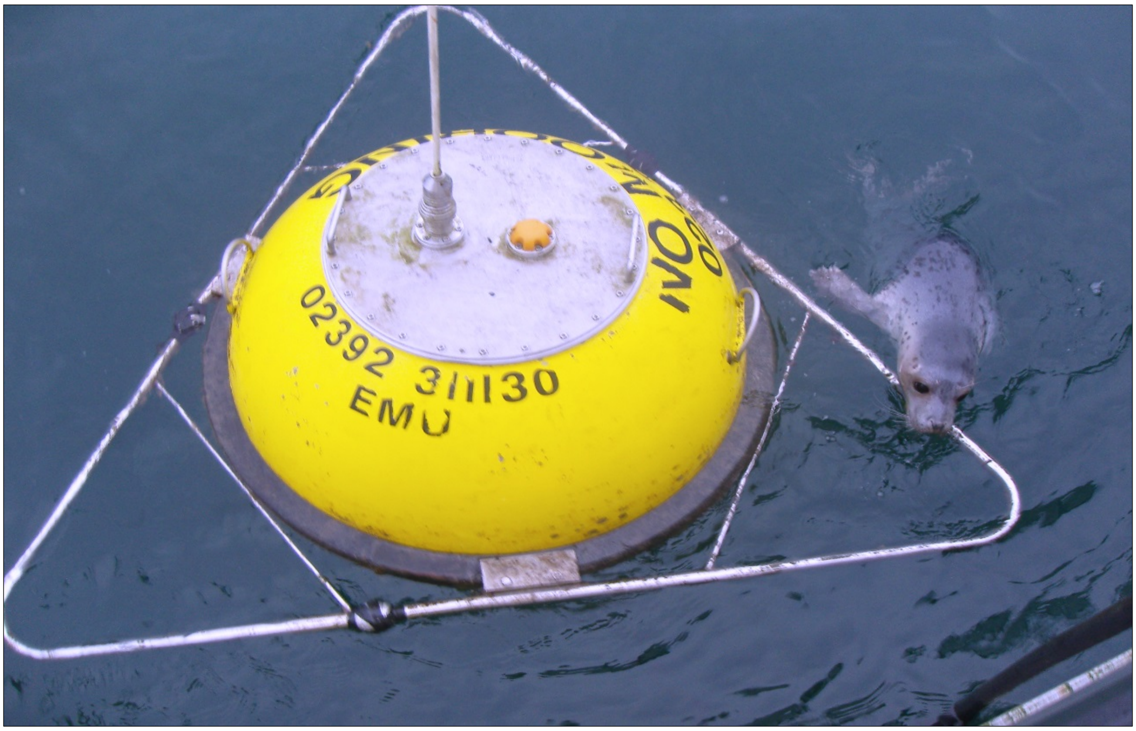

Figure 8.1: Harbor seal (*Phoca vitulina*) at Gwynt y Môr Offshore Wind Farm

Photographer: Fugro EMU

8.2 Stakeholder Concerns

Comments and concerns received from stakeholders at early planning and feasibility stages tend to relate to generic topics regarding animal welfare principally during the construction phase and the piling of monopiles and are summarized in Table 8.1.

Table 8.1. Typical Concerns Raised by Stakeholders During Scoping of Potential Effects of Offshore Wind Farm Construction and Operation on Marine Mammal Ecology

Concern	Source	Pathway	Effect	Typical Mitigation
Construction Phases				
Loud percussive noise from foundation piling works for turbines and offshore substations	Hydraulic pile hammer	Noise as sound waves propagated via the water column	Mortality, permanent and temporary auditory damage, avoidance	Choice of foundation design, marine mammal observers, acoustic deterrent devices (ADD), bubble curtains, modified construction methodologies and program restrictions, vessel speed restrictions
Increased shipping movements	Installation vessels, floatels, CTVs	Vessel traffic, vessel noise and visual disturbances	Disturbance/ displacement and increase in risk of ship strikes	
Operational Phase				
Habitat loss	Placement of foundations on the seafloor	Presence of infrastructure	Displacement	
EMF emissions	Operational cables	EMF radiation from operational cables through the. water column	Could affect cetaceans' ability to echo locate	
Increased shipping movements	Crew transfer vessels, maintenance vessel	Vessel traffic, vessel noise and visual disturbances	Disturbance/ displacement and increase in risk of ship strikes	Use of main vessel routes and vessel speed restrictions

8.3 General Monitoring Rationale

There are few examples of marine mammal monitoring at UK OWF, other than as mitigation during construction. It is often assumed that densities of marine mammals are invariably low and thus meaningful and statistically robust data could not be gathered for any before and after construction assessment for the earlier and smaller UK Round One and two wind farms. The scarcity of direct UK licence conditions requiring monitoring of marine mammals rather than reference to a general project environment management plan (PEMP) may be a result of the UK's general precautionary stance which invariably imposes strict requirements for monitoring as mitigation during construction in the PEMP to ensure that potentially noisy activities are stopped if a marine mammal is observed within the agreed mitigation zone. Impact assessment typically results in conclusions of 'negligible' or 'minor', reflecting the temporary nature of the impacts, and the highly mobile nature of the receptor, together with the standard mitigation measures offered in the construction program. Without mitigation, impacts would be classed as 'major' reflecting the internationally (European) importance and protection of marine mammals and the unlawful nature of deliberately disturbing or harming them. Monitoring during construction is integral to the overall mitigation provided in establishing when certain construction activities can safely commence.

At Scroby Sands OWF, a monitoring program for impacts on a nearby seal haul-out site was required within the licence, while Rhyl Flats OWF had an initial licence requirement to assess whether a 'sterile area' was created as a result of the wind turbines during operation. The rationale for the licence requirement at Rhyl Flats related to sightings of cetaceans around Great Ormes Head (located 11 km to the east) despite predictions in the ES that only minor impacts on marine mammals would occur. On this occasion, the requirement was reduced to mitigation monitoring during construction with the potential to stop works if cetaceans were detected in the area.

For Scroby Sands, the rationale was simply stated as "*To determine the impact of the wind farm on the seal populations*". The Scroby Sands OWF is located 2 km north of an area used by Harbor Seals (*Phoca vitulina*) and Grey seals (*Haliochoerus grypus*) as a haul out site.

Between 2007 and 2010, a number of the Round 1 and 2 OWFs were granted licenses with the same condition which left the requirement for monitoring open to discussion: "*As a number of cetaceans and pinnipeds are found in the general area of the wind farm site there is a requirement to conduct monitoring during the construction. The need for additional post-construction marine mammal monitoring, over an initial 3-year period and ongoing during the lifetime of the wind farm's operation, will be determined, in consultation with JNCC, Natural England and the Licensing Authority and reviewed at agreed periods*". Note: sites in Wales and Scotland would report to different SNCBs. Therefore, it may be that for some of these wind farms, it was agreed with the relevant authorities that post-construction monitoring was not necessary. The post-construction monitoring reports for these sites do not indicate that this monitoring was required following discussions.

The situation in other European countries contrasts somewhat with that of the UK, where a large number of impact monitoring studies have been undertaken for marine mammals. In Belgium, Denmark and Germany, impact monitoring was required as part of the construction permit. Belgian monitoring focused on a cause-effect relationship and intended to gain an understanding of the environmental impacts of OWFs to support policy, management, and design. Similarly, Denmark commissioned two environmental monitoring programs (including harbor porpoise (*Phocoena phocoena*) monitoring) at Horns Rev and Nysted, between 2000 to 2006 and 2007 and 2012 respectively, with the intention of gaining knowledge on the key issues for the planning of future OWFs. In Germany, each wind farm developer has to follow a standard investigation program 'Standards for the Environmental Impact Assessment' (abbreviated to 'StUK' in German). The StUK provides a framework that includes the current thematic and technical minimum requirements for marine environmental surveys and monitoring as well as for monitoring during the construction and operation phases (BSH, 2013).

The majority of this impact monitoring has focused on harbor porpoises and has used a before, after, control, impact (BACI) design, whereby data are collected over time prior to, and following, the impacting event. Data are collected within the wind farm area where the impact occurs, in addition to data collected at a control area. Construction monitoring was also undertaken in order to investigate the effects of piling noise and impact ranges for marine mammals.

8.4 Description of Impacts

8.4.1 Impacts During Construction/decommissioning

8.4.1.1 Underwater Noise Due to Foundation Piling

Marine mammal species are sensitive to underwater noise. During construction of OWFs, loud impact noises are often generated, typically through the piling of the foundations. Piling noise is generated through the percussion of a hydraulically powered hammer onto the end surface of a foundation pile. This creates loud pulses of noise which can propagate over large distances underwater. Noise propagates further underwater than in-air, and is influenced by complex variables, such as the bathymetric profile, water depth, substrate type and metocean conditions. The engineering parameters of the piling operations heavily govern the noise levels that will be emitted, and factors such as pile diameter, hammer energy, and sediment type are some of the principal factors that will affect this.

Cetaceans make extensive use of underwater sound and have hearing that is highly tuned for the undersea environment (Richardson et al., 1995). Their susceptibility to impacts from anthropogenic noise in the marine environment is well-documented. Seals are known to hear very well in-air as well as underwater.

Potential effects on marine mammals include ‘behavioral effects’, injury or mortality. Behavioral effects can refer to situations in which the animal is disturbed and exhibits a ‘flee’ response and/or avoidance of the area of impact but it can also refer to other behaviors such as attraction, resting, foraging, migrating, reproducing, and nursing. Permanent or temporary hearing loss may occur when animals are exposed to high sound pressure levels (SPLs), particularly over sustained periods of time. Permanent hearing loss in mammals results from the damage to the sensory hair cells of the inner ear and represents auditory injury. This gives rise to a permanent increase in threshold sensitivity over the affected frequencies and is known as ‘Permanent Threshold Shift’ (PTS). ‘Temporary Threshold Shift’ (TTS), on the other hand, is a temporary hearing impairment and is not considered an injury (Southall et al., 2007). Physical injury or mortality (i.e. physiological damage from noise and vibration propagated from a sound source with very high peak pressure or impulse levels) can also occur in extreme circumstances from piling, although the impact range for this to occur is typically very limited spatially and confined the immediate vicinity of the pile.

As discussed in Section 8.3, marine mammal monitoring in the UK has not typically been requested in licence conditions and therefore there is a distinct lack of empirical evidence on the effects of piling during and after construction. However, in the rest of Europe there have been a number of studies into the effects of construction on cetaceans and pinnipeds, although the vast majority of these have focused solely on harbor porpoises in respect of cetaceans.

8.4.1.2 Increased Vessel Movements

The potential effects of increased vessel activity are a common topic within the environmental impact assessments that have been undertaken for the UK OWFs. During construction, an increase in vessel traffic is experienced, comprising a range of vessels such as jack-up vessels, barges, and tugs. These vessels are typically slow-moving, not only due to the size of the larger vessels, but also due to the restrictions on speeds and routes that are likely to be imposed for the construction areas.

The vessel related effects that are given the most attention in the assessments vary between projects. For example, some assessments have focused on the potential for mortality or injury as a result of physical collisions between marine mammals and vessels (i.e. ship-strike), while others have dealt more with disturbance-related effects. Disturbance effects are typically categorized by those relating to noise disturbance and those involving visual disturbance (which may be at shorter range than auditory-induced response). Where applicable, it is likely that any disturbance impacts would involve elements of both types of disturbance, however it is clearly extremely complicated to disentangle the potential causes for observed behavioral responses. For the purposes of assessment, it appears that separating the effects has on occasions been preferred for some research. As Nedwell and Howell (2004) noted, there are a number of studies that show a 'flushing' of seals into the water from their haul-out sites as vessels approach, while similar behavioral responses have also been noted to kayaks; which may suggest that visual cues can dominate over acoustic disturbance in some cases.

Disturbance by vessel activity has the potential to cause marine mammals to exhibit avoidance behavior, and may interrupt foraging activity and/or migration. The underwater noise also has the potential to mask communication sounds. Historically, the EIAs undertaken in the UK have predicted effects of negligible or minor significance, due to the way in which it was anticipated that marine mammals would make short-term avoidance movements in the presence of vessels (before returning), and would be expected to have a level of 'habituation' to the traffic, due to the location of these wind farms near areas of high shipping activity.

In respect of collisions, hull impacts include blunt traumas which result from a physical collision between a marine mammal and the hull of a vessel, while propeller impacts result from collision with vessel propellers. The latter have been a focus of past EIAs for seals. Propeller impacts were identified as cause for concern by regulators following 'corkscrew injuries' being found on stranded seals that had suffered mortality, with the term 'corkscrew' originating from the physical form of the lacerations that were frequently being reported. The wounds were characterized by a smooth edged cut, extending from the head and around the body (Thompson et al., 2010; Bexton et al., 2012). More recently, these types of injuries have been attributed to cannibalism by adult seals (Brownlow et al., 2016) (see Case Study 29 below). SMRU had tagged one male grey seal that had been observed killing and eating the blubber off a seal pup. Unfortunately, this particular seal has since undergone a molt (and the tag which was attached to its fur has been lost) and SMRU are no longer able to track its movements (SMRU, personal communication). Similar to disturbance effects, impact significance relating to physical collisions were mostly deemed to be negligible to minor, due to the slow speeds at which vessels would likely be travelling, and the predictable nature of the vessel movements and routes allowing marine mammals to make avoidance responses.

8.4.2 Impacts During Operation

8.4.2.1 Underwater Operational Noise

Environmental assessments for OWFs typically consider the underwater noise effects of the operational turbines and their impacts on marine mammal species throughout the operational phase of the project. It is well established that the low intensity noise associated with the operational turbines is significantly less than the loud and high intensity sounds associated with piling during the construction phase. Operational turbine noise monitoring has been undertaken at various OWFs and the evidence suggests that it is highly unlikely that seals, harbor porpoises or dolphins would suffer permanent hearing damage, even at very short ranges (Marine Scotland, 2012), although the sounds may be audible over a number of kilometers to certain species, depending on the levels of background noise etc. Tougaard et al. (2006) noted that noise levels are weak by any standard and effects on marine mammals will only be audible within a few hundred meters of the turbines. The potential effects have been addressed in multiple ESs due to the previous lack of evidence on this topic, and due to the likely duration of the impact, i.e. for the full operational life of the wind farm, and therefore require careful consideration.

8.4.2.2 Habitat Loss

The issue of habitat loss was discussed in some ESs. The potential impact essentially relates to the loss of some areas of seabed and the water column to the presence of the physical structures of the wind farm. This is typically considered to be a minor or negligible issue as the physical structures of an OWF, and associated protection materials, will only occupy a fraction (i.e. generally less than 1%) of the developed area.

Where this potential impact was discussed in ESs, it was often anticipated that marine mammals (small cetaceans and pinnipeds) would continue to be able to use wind farm areas for foraging. Some ESs hypothesized that there may be reef effects around the wind farm structures which would be of benefit to local fish populations and might provide a food resource for marine mammal species.

8.4.2.3 Increased Vessel Movements

A number of ESs have considered the impact of increased vessel movements during the operation which are associated with the operations and maintenance of the wind farm. The vessel movements are generally seen as relatively infrequent in comparison to the increase in vessels that is experienced during construction and decommissioning of a wind farm, and therefore impacts are typically expected to be less. However, these vessels will be making transits to and from the wind farm area throughout the operational phase of the wind farm (potentially at higher speeds) and therefore might have the potential to produce effects over the long term, whereas construction impacts are limited to the construction period. It is also worth noting that if commercial, recreational or fishing vessels are excluded from a wind farm area, then there may be a net reduction in vessel activity within a wind farm area.

8.5 Typical Mitigation Measures

In the UK, only 3 of the 21 OWF licenses reviewed did not include marine mammal mitigation measures (see Table 8.2). The vast majority of OWFs have had the same type of mitigation enforced for piling activities by their respective licence conditions i.e. soft-start procedures and the use of MMOs (marine mammal observers), PAM (passive acoustic monitors) as well as the imposition of a mitigation zone. The rationale for this was typically to "*ensure that disturbance to cetaceans, seals, and basking sharks is minimized*". The UK appears to be the only country in Europe to routinely employ this type of mitigation whereby the MMOs keep watch over a mitigation zone. The MMOs are required to be trained and to hold a qualification accredited by the JNCC.

Between 2007 and 2010, a lengthy condition was included in licenses for UK OWFs for mitigating potential adverse effects on marine mammals which involved a written marine mammal mitigation scheme, use of qualified and experienced MMOs to look out for marine mammals during the construction period, a mitigation/monitoring zone (within which sightings of marine mammals would delay start-up of operations until a sufficient period time had elapsed), passive acoustic monitoring equipment, soft-start piling techniques and a reporting/communications methodology. More recent license conditions, covering the largest of the UK wind farms which have yet to be constructed, contain mitigation measures which demonstrate this increased level of complexity, as shown by Table 8.2.

Table 8.2: Summary of the Measures Agreed to Mitigate the Potential Impacts of Offshore Wind Farm Construction on Marine Mammal Ecology

Wind Farm (Start Date)	Mitigation Measures
UK	
Barrow (2005)	Temporary suspension of piling operations if cetaceans are sighted in the area.
Burbo Bank (2006)	Implementation of a soft start procedure for all drilling and/or piling operations.
Robin Rigg (2007)	Temporary suspension of piling operations if cetaceans are sighted in the area.
Lynn and Inner Dowsing (2007)	Implementation of a soft start procedure for all drilling and/or piling operations
Rhyl Flats (2008)	Temporary suspension of the commencement of individual piling operations if cetaceans are detected in the area.
Gunfleet Sands I (2008)	Implementation of a soft start procedure for all drilling and/or piling operations
Greater Gabbard (2009)	Six 'standard' conditions: ■ Issuance of an agreed written marine mammal mitigation scheme ■ Use of suitably qualified and experienced Marine Mammal Observers (MMO) ■ Delayed commencement of piling for half an hour following last detection of a marine mammals ■ Use of enhanced acoustic monitoring during periods of poor visibility and weather conditions ■ Use of an agreed soft-start procedure. ■ Issuance of and agreed communications methodology
Thanet (2009)	
Sheringham Shoal (2009)	
Gunfleet Sands II (2010)	
Ormonde (2010)	
Walney (2011)	
London Array (2011)	
Lincs (2011)	
Teesside (R2012)	
Gwynt y Môr (2012)	
West of Duddon Sands (2013)	
Westermost Rough (2014)	
Dudgeon (2017)	Use of a Seal scarer (Lofitech) acoustic deterrent device (ADD) prior to soft start.
Belgium	
Thorntonbank (2008)	Seal scarer (Lofitech) and imposition of noise threshold levels (SL = 189 dB re 1µPa, main energy at 14 kHz (Haelters et al., 2012))
Denmark	
Horns Rev I (2002)	Soft start procedure (first few piles), replaced by acoustic deterrent devices: Aquamark100 porpoise pinger and Lofitek seal scarer (Tougaard et al., 2006)
Horns Rev II (2009)	Seal scarer (Lofitech), pinger (Aquamark 100) (Brandt et al., 2009)
Nysted (2002)	Seal scarer and pinger before and during piling and vibration of steel sheet piles around one wind turbine (Carstensen et al., 2006)
Germany	
Alpha Ventus (2009)	Seal scarer, pinger (Dähne et al. (2013)) and imposition of threshold levels.
The Netherlands	
Egmond aan Zee (2006)	Soft start procedure and acoustic deterrent device, seasonal piling restrictions

Soft-start procedures to piling are universally employed as embedded mitigation. Belgian permits require this to be undertaken. However, in contrast to the UK, European OWFs tend to make greater use of acoustic deterrent devices (ADDs) and are commonly included as a requirement in many permits. For example, Danish regulators have issued permits which have conditions requiring that "*marine mammals must be scared away from the vicinity using pingers and seal repellent systems*".

German regulators have also included the use of such devices in their permits. Dutch OWF guidance makes provision for this also. The use of ADDs is currently being evaluated for wider use in the UK and is the subject of some considerable review under the UK's Offshore Renewables Joint Industry Programme (ORJIP) as explained in the following case study.

Case Study 23: Use of Acoustic Deterrent Devices as Marine Mammal Mitigation During Offshore Wind Farm Construction

ORJIP is the 'Offshore Renewables Joint Industry Programme', a UK program of environmental research which aims to reduce consenting risks for offshore wind and marine energy projects. The program is built on collaborations between industry and developers, regulators, Statutory Nature Conservation Bodies (SNCBs) and academia to work together on key environmental and consenting issues that the respective renewables sectors are facing. One of the evidence gaps facing the industry is around the impacts of underwater piling noise on marine mammals and the efficacy of the mitigation. ORJIP is looking to address strategic evidence gaps and further de-risk future projects in this respect.

In the UK, the Joint Nature Conservation Committee (JNCC) has developed a piling protocol. At the time of publication, this represented best practice mitigation for marine mammals where marine piling is taking place. The mitigation advocated in the guidance recommends that visual monitoring and/or passive acoustic monitoring is undertaken and soft-start is also employed (i.e. a gradual increase in hammer energy to warn off marine mammals in the vicinity of the activity, before adverse injury can occur). Although still considered appropriate for smaller piling operations, the adequacy of the mitigation is presently being reviewed as the technologies involved in OWF construction change. In some cases, substantially larger projects are being consented with significantly larger piles being utilized in foundation design. However, floating wind turbine projects that require no piling are also moving closer to commercial scale utilization. A comparison of the mitigation measures currently employed in the UK with those used in Europe is included in Section 8.5.

ORJIP Project 4 aims to:

- Reduce reliance on visual observations and decrease construction time by removing the need for daylight and sea state restrictions on piling and by reviewing, testing and/or developing acoustic deterrent devices (ADDs) for a range of marine mammal species;
- Conduct field tests to ensure that these ADDs will minimize risk to species sufficiently; and
- Develop protocol for the use of the ADD mitigation in consultation with the relevant authorities.

The project looked into the efficacy of current mitigation methods. A single quantitative study was available to inform an appraisal of the mitigation efficacy of the UK's MMO and PAM approach, which had been undertaken by the UK Ministry of Defense. A 'Measure of Effectiveness' rating of 15% was assigned to visual monitoring, and 5% to PAM (for all species), assuming a 2 km range. For smaller mitigation/monitoring zones (e.g. 500 m or less), the effectiveness of the mitigation would be higher than that calculated for a 2 km range. As recognized by the ORJIP report (Herschel, 2013), the findings are only of partial relevance, considering a number of the species were highly undetectable through PAM. It was acknowledged that there was some subjectivity involved in the calculation of Measure of Effectiveness, as a result of insufficient data and the averaging of the available data over seasons, times and environmental conditions.

The limiting factors for visual MMO mitigation were recognized to be that probability of detection is based on the likelihood of the surfacing part of the animal's body being sufficiently clear for an observer to detect, and the likelihood of the waves being too rough preventing detection of the individual marine mammal. A significant limiting factor for PAM was largely that it is extremely difficult to detect and classify an animal, while also determining whether the detection was within the given mitigation/monitoring zone. The measure of effectiveness rating would have been higher, had the assessment only required detection and classification of an animal. That aside, a host of limiting factors cause PAM to have a low efficacy e.g. background noise (vessel noise when towed hydrophones are used), and frequency / directionality of vocalizations. Complex arrangements of hydrophones and motion analysis are required to locate positions of detections, and even then, visual sightings are often reported to not align with acoustic detections.

There is scarce empirical evidence to suggest that soft-start is effective in mitigating impacts, and the idea that it will be is largely built on logical reasoning given what we know about underwater noise propagation and marine mammal behavior following acoustic disturbances. Data derived from seismic surveys where air-gun soft-starts were implemented does, however, show evidence of reduced sightings rates and displacement of cetaceans. There are a range of limiting factors for soft-start as an effective form of mitigation. These range from the piling parameters (e.g. pile diameter, hammer energy, seabed type etc.), engineering constraints (e.g. soft-start can sometimes only take place for shorter periods than required by the mitigation protocol) to ecological considerations. In respect of the ecology, the distance an animal can swim must be accounted for to ensure that the soft-start allows for enough time for the individual to move out of the area of injury. Soft-start aims to reduce the injury range (when compared to non-soft-start operations), however as acoustic modelling shows, some possibility of injury occurring remains where pile diameters are sufficient to cause auditory injury from the initial hammer blow.

For some species, there are technologies which show potential for the provision of reliable ADD mitigation. These are deemed to be resulting in a reduction of risk of injury, and these technologies are already being utilized during construction of wind farms throughout Europe. Harbor porpoise are considered to be receptive to the deterrence devices, and therefore this mitigation is likely to be especially effective for this species. If implemented, ADDs would be utilized prior to piling and would cease once soft-start piling begins. The zone of disturbance caused by the ADD would likely be less than the zone of disturbance related to piling and therefore the use of ADDs would not increase the spatial extent of this disturbance zone. Multiple ADDs may be required, which is typically workable when multiple vessels are on site. Further research is deemed to be required to determine the sound levels required to cause an animal to flee (which is species-specific), and to establish sounds levels that can be emitted from the ADD that are under the thresholds that constitute a 'disturbance offence' under the law, while evoking a behavioral change in the animal and a flee response. The ORJIP report (Hershel, 2013) concluded that a combination of ADD use and soft-start has the potential to become the best practice option for marine mammal mitigation in the UK, given the current state of research, with the caveat that a blanket approach would not be appropriate, and that neither is universally applicable.

The ORJIP Project 4 assessed the available ADDs on the market and attempted to narrow down the options to find the most appropriate devices for offshore deployment and a multi-species approach. Two devices (manufactured by Lofitech and Genus wave respectively) were considered the best technologies to meet this requirement. Research requirements were put forward for phase 2 of Project 4 which had the potential to help determine ADD mitigation which would constitute best practice. For harbor porpoise, this included trial-testing ADDs and either behavioral observations or arrays of PAM to measure over distances greater than those considered possible for visual observation. The report suggested that long term monitoring of effectiveness should be undertaken together with construction monitoring programs. For seal species, tagging of individuals at haul-outs and tracking them following ADD exposure was suggested in order to observe behavioral responses. For bottlenose dolphins (*Tursiops truncatus*) it was proposed that behavioral observations and 3D hydrophone arrays should be utilized, either from static arrays or from vessels. It was suggested that individual recognition from the recorded sounds might enable longer term effects with repeated exposure over time. Monitoring of minke whale (*Balaenoptera acutorostrata*) responses was deemed to be non-cost-effective and should be monitored opportunistically using visual methods when monitoring other species.

One of the concerns surrounding ADDs is the potential for species habituation. The phase 1 report also recommended that the short-term trials should be scrutinized for any signs that habituation to the ADDs might occur, with potential for an extensive industry trial if so.

The general recommendations that arose during ORJIP project 4 phase 1 were:

- A gradual approach should be taken when making revisions to the current UK piling guidance. It will require time to further develop ADD technologies and ensure their efficacy is of a required level to become a standard form of mitigation;
- Other noise reduction measures exist and are used elsewhere in Europe. This has potential to be incorporated, however this was outside the scope of the ORJIP project 4; and
- More rigorous and further assessment of the efficacy of the current MMO and PAM approach to mitigation would be highly useful, and would help inform decisions over revisions to the best practice mitigation protocol.

Essentially, the project aims to aid the development of a standardized mitigation framework, facilitating developers and regulators to find agreement on the best mitigation options for a project depending on the engineering, and environmental constraints etc. ORJIP were responsible for taking the above recommendations and to progress phase 2, with the trials and monitoring of the potential ADD technologies. The ultimate goal being the development of ADD mitigation protocols in agreement with industry, regulators and SNCBs etc. At the time of writing, progress on these latter stages of the project is not yet available.

Another form of mitigation which contrasts with the UK practices is the use of threshold values for underwater noise; Danish permits require that the "*accumulated Sound Exposure Level (SEL) from each installation sequence must not exceed a threshold value of 190 dB*", while the Belgian authorities impose a noise limitation from 750 m from the sound source of 185 dB re 1 µPa (zero to peak Sound Pressure Level (SPL)) and the German authorities require that SEL must not exceed 160 dB (re 1 µPa) outside of a circle of 750m radius and the Peak Level (Lpeak) must not exceed 190 dB.

In respect of seasonal restrictions, Belgian advice states that no piling should take place between 1 January and 30 April to protect marine mammals. The Netherlands stipulate no piling between 1 January and 1 July and does not allow more than one construction activity in which piling will be undertaken in any one piling season, although they appear to be reconsidering these restrictions. The purpose of the restrictions in the Netherlands is to protect sensitive periods for key species such as the presence of herring larvae and minimize potential food chain effects.

8.6 Observed Environmental Effects from Monitoring and Research

8.6.1 Foundation Piling

8.6.1.1 Small Cetaceans

Monitoring at Horns Rev OWF initially was intended to detect general effects on harbor porpoises due to construction and operation of the wind farm. However, it was later established that it would be possible to use the data to investigate the specific effects of piling activity during construction. The monitoring and findings from the final monitoring report (Tougaard et al., 2006) are presented in the following Case Study.

Case Study 24: Harbor Porpoise Monitoring Study Horns Rev Offshore Wind Farm
Background Horns Rev OWF (OWF) is located in the North Sea, in Danish waters to the west of Esbjerg. The wind farm was commissioned in 2002, and has a total generating capacity of 160 MW (Danish Energy Authority, 2006). The wind farm comprises 80 × 2 MW turbines, with a hub height of 70 m and a total turbine height of 110 m[13]. The wind farm area is approximately 21 km^2, and is located around 18 km from shore. The harbor porpoise monitoring program at Horns Rev was one of the first long term monitoring programs for harbor porpoise at an OWF development. The monitoring was designed to use a BACI (before-after-control-impact) analysis to look at the general effects of the wind farm on porpoises with comparisons between baseline, construction and operation, however it was found that the effects of the specific activity of pile driving was also possible, as discussed in this case study. **Methods** The methods utilized line transect surveys to provide data of a high spatial resolution, while T-PODs (acoustic data loggers) were used to provide a high temporal resolution. A BACI monitoring design was chosen in order to investigate whether changes in harbor porpoise density within the wind farm and the adjacent areas had occurred following construction of the wind farm, in relation to the reference areas. However, T-POD data allowed for the specific activity of pile driving to be investigated (rather than the general construction as a whole), due to the clear changes in acoustic detections during piling works.

[13] http://www.4coffshore.com/windfarms/windfarms.aspx?windfarmId=DK03

Results and Conclusions

T-POD data indicated that harbor porpoises vacated the area of Horns Reef in its entirety (based upon a reduction in acoustic activity) (Tougaard et al., 2006). After 6 to 8 hours, the porpoise activity had returned to the levels that were deemed to be normal for the general construction period where piling was not occurring.

The authors noted that a key conclusion was that the observed reaction of the harbor porpoises did not have a spatial gradient when considered against exposure level i.e. the behavioral response was found to be as strong at the far west of Horns Reef as it was found to be within the wind farm area of construction. As a consequence, impact ranges could not be extrapolated as some other studies have done when looking at piling effects. However, the authors did conclude that behavioral effects were experienced within at least a 25 km radius (i.e. the distance between the far west of Horns Reef and the noise source), but were likely to have been significantly further in reality (Tougaard et al., 2006).

Another key finding was that the harbor porpoises seemingly returned to normal activity levels within 6 to 8 hours following piling. When consideration is given to the fact that the behavioral effects are likely to have affected an area greater than 600 km^2, the authors deemed it “remarkable” that activity levels would return to normal in such a short time (Tougaard et al., 2006). A potential explanation given was that it may be different individuals moving into the area rather than those that were displaced. This may be a possibility given that population of harbor porpoises at Horns Reef are known to be dynamic in nature.

As noted by the authors, if individuals are displaced and do not return, this could represent a far greater impact than it would for individuals that might have been irritated temporarily by the disturbance before returning.

Effects of general construction (in between piling events) were considered to be “marginal” by Tougaard et al. (2006). However, the overall conclusion regarding piling was that wide spread displacement occurred for 640 hours within a 5-month period of construction (i.e. 17% of the construction time), and were deemed to represent a significant disturbance event.

Monitoring of piling noise and the impact upon marine mammals was undertaken at the Horns Rev II OWF, in the Danish North Sea. In 2008, 91 monopile foundations were installed during the wind farm construction. Brandt et al. (2011) undertook investigations into potential effects on harbor porpoise, using T-PODs (a form of passive acoustic monitoring) with a gradient sampling design. The spatial-temporal scale of the effects was found to be relatively large; one hour after piling, porpoise acoustic activity had reduced by 100%, and was under typical levels over a range of 2.6 km for between 24 to 72 hours. This duration reduced when considered against distance; negative effects were detectable out to an average distance of 17.8 km, ceasing at 22 km. Interestingly, harbor porpoise activity actually increased at 22 km. Within 4.7 km of the construction, recovery time exceeded most pauses between piling operations. Harbor porpoises were found to reduce in their activity and abundance during the five months of construction.

The effects of the Thorntonbank OWF has also been the subject to a harbor porpoise monitoring program, and is reported by Helters, Wan Roy and Degraer (2012). A combination of standardized aerial surveys over the Belgian part of the North Sea and PAM was undertaken, with the PAM devices located inside and outside of the project area. A reduction in the population density estimates for harbor porpoises was observed. Previously observed pre-construction estimates of the abundance of harbor porpoise of 2.5 individuals/km^2 were reduced to 1.3 individuals/km^2 during construction. Regardless of the fact that harbor porpoise numbers decline in April in Belgian waters due to seasonal movements, the changes in the spatial distribution of the species indicated that an external factor had driven the change, and this was deemed to be evidence of construction-related disturbance. PAM supported this conclusion matching piling activities with patterns in acoustic porpoise detections at a fine-scale. Porpoise detections almost immediately reduced to none within a few kilometers following onset of piling, and it took hours/days for any new porpoise detections to be made in these areas.

The aerial data led the authors to conclude that an impact occurred over 22 km, which is the same approximate spatial extent of the impact observed at Horns Rev II OWF, as previously discussed (i.e. Brandt et al., 2011). Following the cessation of piling, the harbor porpoises repopulated the area with time. The impact zone of 22 km reduced to 13 km after a complete day without piling. A return of 9 km over a single day was calculated to be significantly slower than the average directional swimming speed for a porpoise, which is reported to be 0.9 m/s. Helters et al. (2012) considered this rate of return to be expected given factors such as: a relatively random movement/dispersal in the area during that period, local foraging opportunities leading to a slower displacement, seasonal patterns of migration and mass movements of tidal water. The authors could not determine what the physiological and fitness consequences of such displacement may have been for the individual animals.

A recent report was produced by Brandt et al. (2016), which scrutinized monitoring data to determine the effects of pile driving on harbor porpoise abundance as a result of eight OWFs in the German Bight. The wind farms included within the study were constructed in the German North Sea between 2009 and 2013 and include: Alpha Ventus OWF, BARD Offshore I OWF, Borkum West II OWF, Dan Tysk OWF, Global Tech I OWF, Meerwind Süd/Ost OWF, Nordsee Ost OWF, and Riffgat OWF. The methods and findings of the study are discussed in the following case study.

Case Study 25: Piling Effects on Harbor Porpoises in the German Bight (Brandt et al., 2016)

Background

Brandt et al. (2016) collated harbor porpoise monitoring data from a number of German OWF monitoring programs. The intention was to pull together the data from the various projects to gain a synthesis of the findings and an opportunity to look at the results in the context of the German part of the North Sea rather than simply at a project-specific level.

As discussed in Section 8.5, during piling in in Germany, SEL must not exceed 160 dB (re 1 μPa) outside of a circle of 750 m radius and the Peak Level (Lpeak) must not exceed 190 dB. Therefore, the authors note that the effects observed within the study may be less than those that might be observed elsewhere in the absence of similar mitigation.

Methods

The study combines data acquired over a period of 5 years (2009 to 2013) using visual aerial survey data and also between 2010 and 2013 using PAM devices. More information on piling parameters and mitigation measures were added to the combined dataset in addition to environmental data. Noise measurements were undertaken at 7 of the wind farms included within the study, and these data were also combined. Where measurements were not available, noise levels were extrapolated.

Non-parametric analysis was used to identify relationships between noise levels and changes in harbor porpoise detections. General Additive Modelling (GAM) techniques were also utilized.

Population level effects were considered using a 'population dynamic model' known as Population Consequences of Disturbances (PCoD) model.

Results and Conclusions

In comparison to the baseline, porpoises were found to decline in abundance by 90% where noise levels exceeded 170 dB. However, the decrease was only about 25% at noise levels between 145 and 150 dB. Where noise levels were 145 dB or below, the decline was < 20% and this could not necessarily be attributed to the piling noise.

The authors used GAM and non-parametric analyses to examine detailed effect ranges (see paper for full methodology and assumptions). The GAM model with POD data (all PODs) indicated a range of effect up to 17 km (including both mitigated and non-mitigated piling), while non-parametric analyses identified significant population declines vs baseline up to 20 to 30 km for non-mitigated piling. These declines were, however, only above 20% within 10 km to 15 km. As distance from piling increased, the lower the reductions in porpoise abundance were found to be. When only mitigated piling was considered, an effect range of 14 km was identified. The noise mitigation employed on these projects were still under development, and therefore this reduction in noise effect range was deemed to be less than would be expected with current working mitigation systems.

Conclusions

Brandt et al. concluded that given the result that piling noise above 143 dB SEL led to disturbance effects in porpoises (but not all porpoises), if noise mitigation was correctly implemented and sound levels of under 160 dB are achieved at a distance of 750 m from source (as required by German regulators), this would substantially reduce the spatial extent of the effect area by approximately 90%. Effects ranges differed for individual projects when modelled. For example, Dan Tysk OWF had a range of 6 km (GAM model) or 0 to 5 km (non-parametric statistics) and porpoise detections within 5 km only reduced by 51%. Conversely, detection rates at BARD OWF exhibited the biggest reduction of 83%.

From the limited amount of aerial survey data, the authors tentatively identified that harbor porpoise densities increased following cessation of piling and up to 12 hours after at distances greater than 20 km. Within 2 km of the construction site, the duration of the displacement effect ranged between 16 and 46 hours across the different wind farms and was approximately 20 to 31 hours in general.

The authors also established that before piling and construction commenced, there were significant decreases in harbor porpoise detections up to 10 km. This was attributed to the construction shipping activity and preparatory works.

The study did not find any evidence of a long term population decline over the five years of data, with some evidence of positive trends in the harbor porpoise detection data 2012 to 2013 and no signs of negative trends. Using a PCoD model with conservative parameter inputs, it was estimated that there was to be a below 30% chance of a 1% population decline in the German Bight population.

Despite the short-term effects of piling, there was not any evidence in the data to suggest that wind farm construction had any detrimental effects at the population level (Brandt et al., 2016).

To further investigate the potential effects of piling on harbor porpoises, further monitoring under the current Disturbance Effects of Noise on harbor porpoise in the North Sea (DEPONS) project has been commenced to investigate the behavioral responses of porpoises to piling impacts. The following case study briefly introduces the DEPONS project.

Case Study 26: Disturbance Effects of Noise on Harbor Porpoise in the North Sea

Project Background

The Disturbance Effects of Noise on Harbor Porpoise in the North Sea project (DEPONS) is a developer funded research program that aims to reduce uncertainty and improve knowledge of how underwater noise impacts on harbor porpoises. The project is led by Vattenfall, together with other OWF developers including Forewind, Eneco Luchterduinen, Smart Wind, and East Anglia Offshore Wind and academia. The developers ultimately recognized the need for improved understanding on the impacts of piling noise in order to facilitate growth of the offshore wind industry and to maintain a healthy harbor porpoise population in the North Sea. Once harbor porpoise responses to piling noise and their general patterns of movement are better understood, this will enable the development of a model and an evidence-based framework for impact assessments dealing with underwater noise. In a recent study, Nabe-Nielsen et al. (2011) used an individual-based simulation model to analyze the population consequences of anthropogenic disturbances in inner Danish waters. DEPONS aims to use this model type in the North Sea, which requires data acquisition for the parametrization for the North Sea and validation of the model. Therefore, a number of sub-projects have been developed to focus efforts on simulation and validation of the effects of wind farm construction and operation in the North Sea.

Sub-projects

Sub-project #1 aims to obtain data on the behavioral responses of harbor porpoises to simulated pile-driving noise. This involves tagging of captured porpoise individuals from Danish waters and tracking their movements throughout exposure to noise. Where individuals cannot be captured in locations where wind farm piling is taking place, these individuals will be subjected to noise produced by a seismic air gun. This air gun will produce comparable frequency spectrum to piling, albeit with a slightly lower peak pressure (by 20 dB). When exposed to air gun noise at a distance of 500 m, this is equivalent to a distance of 5000 m from a piling event. The tags should enable responses to be investigated over several days following exposure, and should provide information on the porpoise's activity at the time, e.g. foraging, and will also record the noise levels experienced by the animal. Statistical analyses will be employed that use a range of environmental covariates e.g. water depth and substrate type, which will feed into a parametrized individual-based population model.

Sub-project #2 is concerned with the spatial variation of harbor porpoise prey species, within the natural range of a harbor porpoise population. It is recognized that noise is likely to have greater detrimental effects on harbor porpoises if it displaces them from key foraging areas, with potential implications for the population if it relies on few areas of sufficient prey resource. Harbor porpoise population densities are considered to be a good indicator of where prey resource may be distributed. For the North Sea population, the SCANS surveys and Seabirds at Sea database include direct observations of harbor porpoises. The sub-project will also investigate bird flocks as an indicator of foraging sites (in instances where the prey of bird species and mammals is found to be comparable), and will determine if the use of fishery survey data is useful in particular areas and seasons. These various datasets will be compiled together in the most robust manner possible in order to best establish the spatial distribution of foraging sites within the model.

Sub-project #3 is focused on obtaining data on variations in movement patterns of harbor porpoises in the North Sea. Population dynamics are deemed likely to be determined by an individual's ability to disperse between areas with high prey densities and their efficiency of foraging in such areas. Modelling of dispersal patterns based on satellite-tracking observations has previously been undertaken, however, this was based on tagging of animals in areas nearer to shore with the influence of the adjacent coastline. In order to model dispersal patterns and fine-scale movements of harbor porpoises in the North Sea area, which are likely to differ from those closer to shore, more animals are to be tagged in the Skagen area of Danish waters. These harbor porpoises are likely to disperse to Skagerrak and the North Sea, as has been shown to occur previously.

Sub-project #4 looks to obtain data on local population densities near OWFs. Using C-PODs (a form of passive acoustic monitoring that detects the echolocation clicks of odontocetes), the aim is to acquire data showing the population densities at various distances from wind farms under construction. If sub-project #1 does not provide sufficient data on harbor porpoise's responses to noise, the data acquired in sub-project #4 for population densities around wind farms will feed into the simulation model. If sub-project #1 is successful, then the findings of sub-project #4 will be used to validate the simulation model outputs. Therefore, the North Sea model will include data that will be based on the high-resolution GPS tracking, and the simulation model should be able to use this fine-scale movement data to simulate harbor porpoise densities in areas around wind farms, which should be realistic. To ensure that this is indeed realistic, sub-project #4 will aim to validate the simulation model by using passive acoustic monitoring to measure the population densities of harbor porpoises at increasing distances from a wind farm construction site (750 m, 1500 m, 3000 m and 6000 m). C-PODs and noise loggers will be placed at each station, which allows variations in harbor porpoise densities to be compared with noise levels. The monitoring was designed to take place before, during and after construction of the Dan-Tysk wind farm in the German Bight.

Sub-project #5 involves updating the simulation model and validating the results of the simulations.

Progress

A status report has been released (van Beest et al., 2015), which focused on the model parameterization and the types of processes included in the DEPONS model. Initial results from the model are presented in the report, although these are only preliminary results and indicative of what might be expected from the final model simulations at a later date. Part of the model outputs described in the status report are those based on the inner Danish waters model, and therefore until the empirical data from the North Sea is used to parameterize the DEPONS model, the results will be less accurate; the behavior of the simulated porpoises will be refined to reflect that of the North Sea porpoises at a later date and accuracy will then be improved. The modelling that informs the status report was based on deterrence behavior of harbor porpoises (in response to pile driving), which was parametrized using empirical data showing reductions in porpoise densities at varying distances from the North Sea wind farm 'Dan Tysk' construction site before and after piling.

The report authors considered five different strategies of harbor porpoise movement and dispersal, this either derived from theoretical movement models or from empirical evidence of behavior observed in the Inner Danish Waters. These movement/dispersal models were combined with three hypothetical pile driving scenarios, including a range between absences of noise to a realistic worst case scenario. Simulations of average population sizes and dynamics were compared with movement/dispersal models and piling scenarios, with the results suggesting that there were not any clear, long term effects on the average harbor porpoise population size and dynamics in the North Sea as a result of piling. This only represented preliminary results, and the model will require further refinement and the incorporation of empirical data gathered on harbor porpoise movement behavior and dispersal strategies from the North Sea. These further requirements are anticipated to be mostly fulfilled by the remainder of the DEPONS program, and the preliminary results indicate that the DEPONS model will be a highly useful tool which will assist in the planning of OWF developments.

8.6.1.2 Pinnipeds

A harbor seal (*Phoca vitulina*) haul-out and breeding site was subject to a 5-year aerial monitoring campaign during the construction of the Scroby Sands OWF located 2 km to the north (ECON, 2008). The monitoring program was specified as two aerial photographic surveys per month for 6 months (April to September) and covered pre-, during, and post-construction years. Pre-construction surveys were conducted in 2003, during construction data were gathered in 2004 and post-construction data in 2005. A further set of surveys was completed in 2006 following a significant change in seal populations (ECON, 2008). Further monitoring was also conducted to assess harbor seal pup production and use of the Scroby Sands by grey seals. It is noted that the piling of the foundations of the turbines was undertaken from October 2003 to January 2004 and occurred outside of the April-September monitoring program stipulated within the licence. The immediate responses of seals to the onset of piling at Scroby Sands OWF is therefore not available. The results of the monitoring are summarized in Figure 8.2 and show a significant decline in the numbers of Harbor seals hauled out during the construction period.

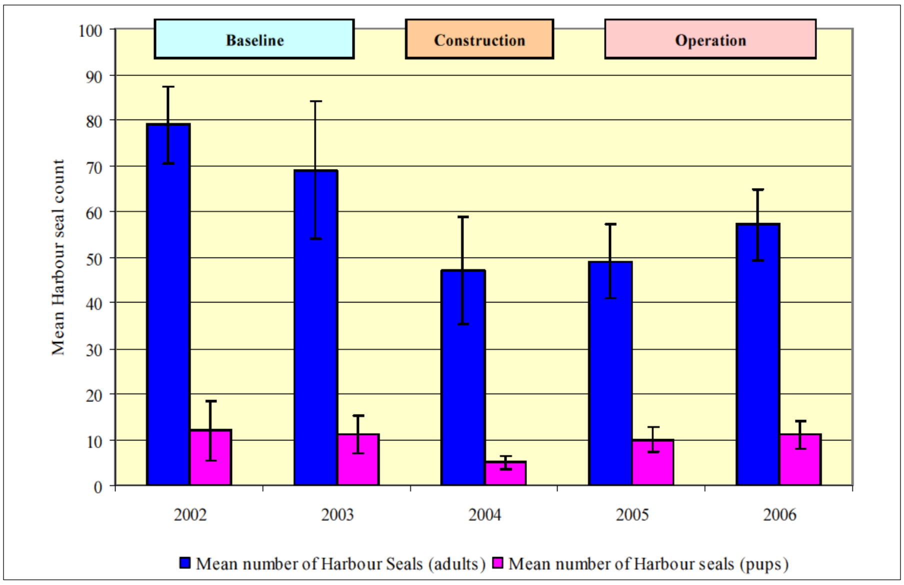

Figure 8.2. Mean abundance of Harbor seal and pups recorded from aerial surveys at Scroby Sands Offshore Wind Farm

(source ECON, 2008)

Although no monitoring was undertaken during the actual piling events, ECON (2008) refer to anecdotal evidence from local sources that the Harbor seals may had temporarily abandoned the haul out areas between a distance of 1.5 and 7.0 km. While some recovery of numbers of harbor seal is indicated during the operational phase, numbers remained depressed compared to the baseline situation. There was no evidence of any negative impacts of OWF construction and operation in breeding success at other colony sites local 20km from Scroby Sands.

Interestingly, the numbers of grey seals increased significantly during the construction period (see Figure 8.3). This was attributed to the rapid expansion of populations from nearby colonies. Reduced competition due to the decline in harbor seals was also considered a contributory factor.

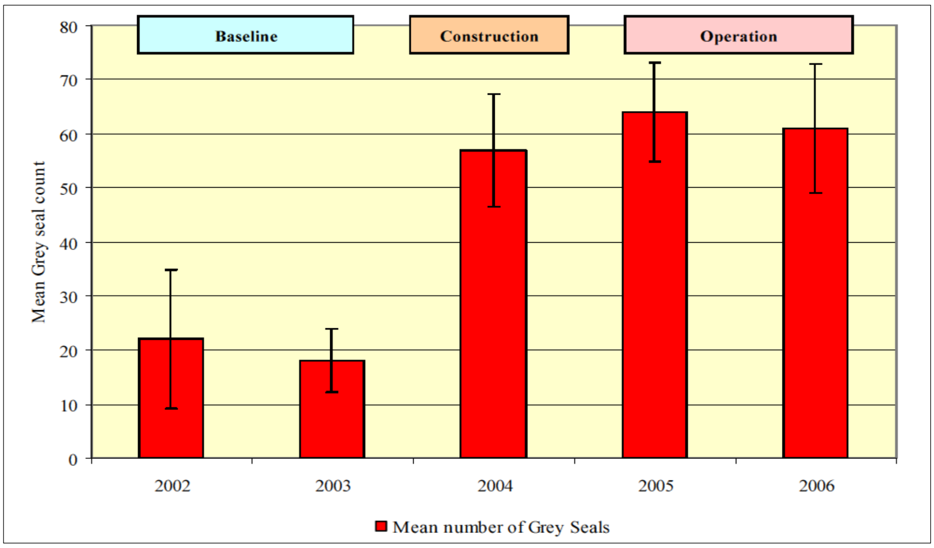

Figure 8.3. Mean abundance of Grey seals recorded during aerial surveys at Scroby Sands Offshore Wind Farm

(source ECON, 2008)

While the authors could not clearly establish whether piling activity caused the displacement of the seals, the authors believe that this was a significant factor. Rapid colonization by grey seals and/or vessel activity were considered to be factors which prevented a full recovery of the harbor seal.

Russell et al (2016) recently used historical harbor seal telemetry data from 2012 (acquired originally though GPS tagging studies) to investigate whether harbor seals exhibited avoidance behavior during piling operations and/or the general construction of other wind farms within the wider ‘greater Wash’ region. The study found that during pile driving operations at Lincs OWF, seal abundance decreased significantly within 25 km of the construction site. Within the spatial extent of this impacted area, it was found that there was a 19% to 83% (95% confidence intervals) decrease in seal abundance in comparison with the abundances during the intermissions between piling events. Based on mean harbor seal density estimates, this was calculated to represent a displacement of 440 individuals. The noise levels predicted to have been received which caused displacement were between 166 dB re 1 µPa(p-p) and 178 dB re 1 µPa(p-p).

There was found to be a strong correlation between levels of displacement and the received sound level. The animals which were displaced were found to return to the area rapidly after piling, with the distribution of seals returning to the pre-piling distribution within two hours from the cessation of piling. The authors noted how previous predictions of seal displacement durations were based on observations of harbor porpoise displacement (which can occur for greater than 24 hours following piling), due to a lack of empirical evidence on displacement of seal species, and that impact assessments should perhaps focus on short-term seal displacement, rather than displacement throughout the overall construction. As is often the case with marine mammal studies, the authors recognized that the biological implications of this displacement is poorly understood and a greater understanding of this is required. However, no population level effects were identified as a result of the wind farm construction, although the seals were predicted to have received relatively high cumulative SELs despite exhibiting avoidance and the effects of this on the seals are not known.

8.6.2 Displacement During Operation

8.6.2.1 Small Cetaceans

The Horns Rev OWF is located in an area where harbor porpoises are relatively abundant and the area provides important foraging opportunities for the species. During construction, harbor porpoises were temporarily displaced from the area during piling. However, the distribution of porpoises quickly returned to baseline levels and remained at these levels during operation (Danish Energy Authority, 2006).

At Nysted OWF, porpoises did not return to the area quickly following significant displacement during construction, contrary to the findings at Horns Rev OWF. It should be noted that pile driving was not used at Nysted (except for a single pile), and gravity foundations (which have a significantly lower noise impact) were installed instead. During the first two years of operation, levels of porpoise abundance were depressed in comparison to the baseline, which was unexpected (Danish Energy Authority, 2006). The Danish Energy Authority cited that this may have been due to the lesser importance of the Nysted area to marine mammals than the likes of Horns Rev which is of greater value to the species as a foraging ground, and that the porpoises did not return to the habitat which was deemed less important. Teilmann and Carstensen (2012) later reported on the long-term monitoring study at Nysted OWF which had taken place over 10 years as discussed in the following case study.

Case Study 27: Monitoring a Decrease in Harbor Porpoise Nysted Offshore Wind Farm
Background Nysted OWF is located within the Danish waters of the Western Baltic Sea to the south of the islands of Lolland and Falster. Nysted was commissioned in 2003 with a total generating capacity of 165 MW, comprising 72 × 2,3 MW turbines (Danish Energy Agency, 2006) with a hub height of 69 m and total turbine height of 110 m. Aside from a single monopile being installed, the turbine foundations are gravity-based. The wind farm area covers 26 km^2. Along with Horns Rev OWF, Nysted was part of the Danish offshore wind demonstration program. The program was designed to test the feasibility of large scale offshore wind development and to establish the environmental and socio-economic implications of the projects which would provide lessons for future developments. The monitoring campaign included the world's first long-term monitoring study of the effects of large-scale offshore wind energy production on harbor porpoises. The methods and findings of this study are summarized below.

Methods

The monitoring was designed to be undertaken across the different phases of the project i.e. baseline (pre-construction), during construction and operation (post-construction); the monitoring discussed here took place between 2001 and 2012.

T-PODs were placed within the wind farm area (at three stations) and at reference area 10 km to the east (also three stations), in order to monitor echolocation activity. This activity was used as a proxy for the presence of porpoises in the area. Full details of the methods are presented in Teilmann and Carstensen (2012).

Results and Conclusions

The study found that echolocation declined significantly from the baseline levels during construction as would be expected, although it was noted that porpoises almost completely left the wind farm area, while the reference area also appeared to be affected. Furthermore, the levels of echolocation had not fully recovered 10 years later during operation. However, a significant increase in porpoise detections was identified between construction and operation, with evidence of the negative effects reducing over time and an increase in porpoise numbers within the area of the wind farm. The potential reasons proposed for this by Teilmann and Carstensen (2012) were that habituation to the wind farm by the porpoises may have occurred, or that enrichment of the area might have taken place due to the reduction in fishing activity and the artificial reef effects created by the wind farm infrastructure.

To conclude on why Nysted experienced a pronounced negative effect in comparison to Horns Rev, the authors also cited that the area may not have been overly important to the porpoise population there. Horns Rev was found to have acoustic porpoise detections over ten times more frequently than Nysted, and the density estimates for the Western Baltic were around eight times lower than Horns Reef (Teilmann and Carstensen, 2012). Animals may be more likely to remain in an area that provides a valuable food resource, even if subjected to some level of disturbance, than to move into an area which is undisturbed but with lesser resources. Another potential explanation was posed to be that Nysted is relatively sheltered, and therefore may experience lower background noise levels. In respect of relative noise levels between the turbine noise and the ambient background noise, there may have been a more noticeable increase at Nysted which has been detectable over further distances (Teilmann and Carstensen, 2012).

The Rødsand 2 OWF was constructed after Nysted, and is located nearby to the west. Monitoring was undertaken at Rødsand 2 OWF again using 10 monitoring stations using T-PODs and noise loggers, with the stations position within Rødsand 2 wind farm area, at areas to the east, inside the operational Nysted OWF, and at three reference areas (Teilmann, Tougaard and Carstensen, 2012). The monitoring simply compared the baseline against operation, and did not include construction. As per the Nysted monitoring, echolocation was used as a proxy for porpoise presence. The monitoring found that levels of echolocation showed no overall change between the baseline and operation, and any changes were similar in the impact and reference areas (Teilmann et al., 2012). The authors noted that the Rødsand 2 wind farm area was especially noisy during the baseline monitoring period, possibly due to vessel activity, and therefore it cannot be ruled out that porpoises were not already affected during the baseline monitoring. During operation, the authors noted that there were no significant changes in noise levels which would be considered audible to porpoises. This could be due to generally high background noise levels masking the turbine noise, or because the noise loggers were placed relatively distant from the turbines themselves (around 350 m to 450 m from the turbines).

Case Study 28: Monitoring an Increase in Harbor Porpoises
Egmond aan Zee Offshore Wind Farm

Background

The Egmond aan Zee OWF is a Dutch demonstration offshore wind project, which was constructed in 2006 and operational since 2007. The wind farm lies to the west of North Holland (the Netherlands) in the North Sea, and is located approximately 8 km offshore, covering an area of around 40 km^2. The wind farm comprises 36 × 3 MW turbines of 70 m heights (Scheidat et al., 2012). The wind farm is the first Dutch OWF and demonstration project, the development of which enabled assessment of the technological and environmental challenges associated with the construction and operation OFWs. The knowledge gained from this project will be used to inform future large scale wind farm development in Dutch waters (Lindeboom et al., 2011).

The environmental monitoring program included a study into the impacts on harbor porpoise, which aimed to compare the baseline against the post-construction/operational phase of the wind farm in order to detect changes in the distribution, abundance and activity of harbor porpoises in the vicinity of the wind farm. The construction phase was not monitored. Harbor porpoise were previously common in Dutch waters prior to the 1950s, before a decline began, with the species being considered rare in the 1970s and 1980s. However, since the early 1990s, the decline has reversed and porpoise recordings are increasing again (Scheidat et al., 2012).

Methods

The monitoring study by Scheidat et al. (2012) compared the baseline period (T_0) with the operation period (T_1) using a BACI monitoring design.

T-PODs were utilized for the monitoring, which are stationary acoustic porpoise detectors used to monitor porpoise presence continuously within the wind farm area and at two control areas. This method of monitoring was found to be very powerful statistically in comparison to other methods such as towed hydrophones and visual observer surveys, and was therefore chosen for the monitoring campaign (Scheidat et al., 2012).

The T-POD positions were as follows:

- Within the wind farm area 2 T-PODs were deployed, which were separated by 1 nm or more in order to prevent detection of a single porpoise by two T-PODs simultaneously. Detection range of each T-POD was 500 m; and
- In the reference areas 3 T-PODs were included within 2 reference areas (i.e. 6 in total) to the north and south of the wind farm. These were also placed a minimum of 1 nm apart to avoid duplicated detections, and the reference areas were 5 nm to 6 nm from the wind farm area in order to ensure that the stations were outside of the zone of potential disturbance, but within a distance where the biotic and abiotic factors would be the same as in the wind farm area.

The statistical analysis methods used to investigate the T-POD data are described in full by Scheidat et al., (2012).

Results and Conclusions

The results showed that across all areas, there was an increase in porpoise abundance between baseline and operation. This was confirmed by visual observations increasing inside the Dutch coastal waters, indicating a wide-spread increase in porpoise numbers.

Interestingly, the results of the BACI monitoring showed significant changes in porpoise distribution between the wind farm area and the reference areas. During operation, higher porpoise activity was recorded within the wind farm area in comparison to the reference areas outside of the wind farm. This could not be explained by a north-south distributional change or local seasonality changes as no significant changes were identified between reference areas or in seasonality patterns between the areas.

While the causal factor for this increase in porpoises within the wind farm could not be established, Scheidat et al., (2012) hypothesized that the increase may have been due to elevated levels of food availability as a result of a reef effect and/or the exclusion of fishing. An alternative, but perhaps less likely, explanation discussed was that porpoises may have moved into the wind farm to avoid the heavy shipping traffic that operates in Dutch waters and may cause disturbance to the mammals.

The wind farms discussed above, all used a BACI monitoring design, which aims to determine whether or not the marine mammals avoided the wind farm areas during the construction and/or operational phases. Teilmann and Carstensen (2012) noted that this is likely to be the best testing analysis to use, but recognized that the data produced cannot determine the causal factors that underpin the observed results (operational noise, vessel disturbance, prey displacement etc.), with the exception of piling noise. Porpoises appear to react differently to similar disturbances such as OWFs, and therefore greater understanding is necessary of the causal mechanisms which act to drive these changes. This is clearly demonstrated by the way in which Nysted suffered from a long-term reduction in porpoise numbers following construction, while Horns Rev experienced a rapid recovery to around baseline levels and Egmond aan Zee found numbers to increase.

8.6.2.2 Pinnipeds

As discussed previously in Section 8.6.1.2, Russell et al (2016) used historical harbor seal telemetry data from 2012 to investigate whether harbor seals (*Phoca vitulina*) exhibited avoidance behavior during construction and operation periods at wind farms within The Wash, east England. The results present the first at-sea distribution of seals in comparison with OWF construction and operation. The authors found that there was no evidence to suggest that the seals had been displaced from the operational wind farm, while they reported an increase in seal usage of the area which includes Sheringham Shoal when compared against the baseline scenario before construction. However, the increase was only considered to be near-significant statistically and was more likely a result of the fact that the wind farm lies at the edge of an area of increased usage and this increase is not related to the wind farm.

As discussed in Section 8.6.3 below within the context of habitat loss, seals have been tracked within wind farms and found to be partaking in foraging activity around the wind farm structures. This equally demonstrates how seals have not been found to suffer displacement from wind farms during operation.

8.6.3 Habitat Loss

Russell et al. (2014) studied the effects of the Alpha Ventus OWF and Sheringham Shoal OWF structures on harbor and grey seals. Using GPS/GSM tagging, the authors monitored their movements. Individuals were shown to forage over a few days up to a month, returning to land to haul-out. Four individual seals tagged in the Netherlands entered the Alpha Ventus OWF during the tagging period. Remarkably, from the data it was apparent that two of the four seals were moving in a gridded pattern (see Figure 8.4). The seals were clearly spending time at each turbine and moving between them. The authors also noted similar gridded patterns of movement of seals at Sheringham Shoal OWF.

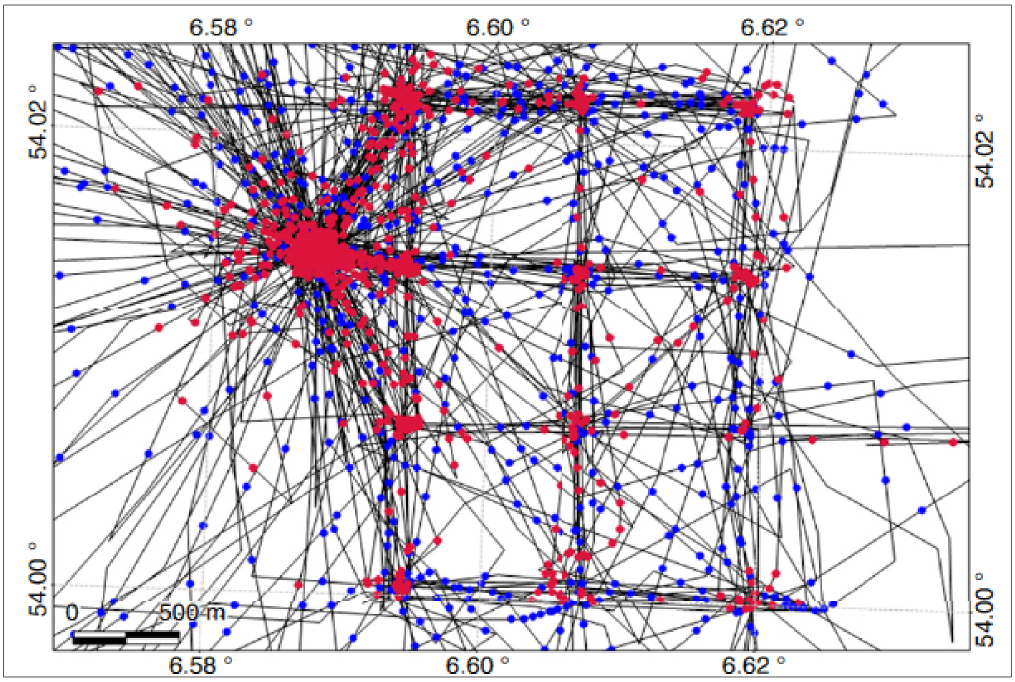

Figure 8.4: Tracks of a tagged harbor seal around Alpha Ventus Offshore Wind Farm

Points show locations at 30 minute intervals; red indicates higher chances of foraging (p(foraging) > 0.5) as predicted by state-space model and blue indicates higher chances of travelling. The individual appears to forage at all 12 turbines and the meteorological mast (constructed in 2003) to the west of the wind farm
Source: Russell et al., 2014

Russell et al. (2014) also noted how seals have been found to trace pipeline structures from other industries, and apparently increased foraging activity around these structures. The capture of seal individuals did not yield any evidence that these individuals had differing ecological characteristics or levels of fitness in comparison to seal species which were not known to forage around these anthropogenic structures.

While it appears clear that marine mammal prey species are aggregating around these structures, the ecological consequences of this behavior are not yet clear. This may suggest that the introduction of these physical structures has created a valuable reef effect habitat which are readily exploited by marine mammal prey items such as shellfish and fish. As Russell et al. note, whether this effect represents a positive effect may depend on whether or not reef effects represent an increase in prey (i.e. higher biological production) or simply a concentration of prey species (i.e. an attraction effect).

8.6.4 Increase in Vessel Movements

8.6.4.1 <u>Disturbance</u>

It is possible that underwater noise emitted by operational wind farm vessel traffic has a detrimental effect on marine mammals. However, the Swedish Environmental Protection Agency (2012) noted that there was scant evidence for this. Some studies on the impact of general shipping traffic (i.e. not wind farm related) on cetaceans have found negative effects on the marine mammals to exist (Herr et al. 2005), however wind farm maintenance vessels are likely to cause a negligible increase in baseline vessel traffic where shipping and fishing activity is already high within the area. Where empirical studies do exist for effects relating to wind farm vessel activity, those identified are discussed below.

Small Cetaceans

During the early operational phase of the OWF in 2003, there were unforeseen technical problems with the turbines that required a significant amount of repair work. This meant that an unusual large number of vessels were deployed to the wind farm area in comparison to what would usually be expected for the operational phase for any wind farm. This provided a unique opportunity for investigation into the effects of vessel traffic, as the level of traffic was comparable to that associated with construction, yet this was occurring without the actual noise-producing construction activities such as pile driving. The authors of the monitoring report for 2003 (Tougaard et al., 2003) commented on how the clear difference in abundance and echolocation activity levels between 2002 and 2003 was “remarkable”, with abundance and activity returning to near baseline levels in 2003. This suggests that the reduction in porpoise presence during construction was likely due to the underwater construction activities, rather than the vessels associated with construction. The high vessel activity during the repair activities in 2003 was found to have little effect on abundance and activity of harbor porpoises. It should be noted however, that the area of Horns Reef was already characterized by significant shipping and fishing activities along the Jutland coast and from the Port of Esbjerg, before the OWF was installed. Other locations in Danish waters with high levels of shipping traffic are also known to support high porpoise densities. As hypothesized by Tougaard et al., vessel activity impacts may be more pronounced at wind farms where baseline shipping levels are low.

As discussed previously, the increase in porpoise abundance above baseline levels within the operational phase at Egmond aan Zee OWF is an interesting case study and an explanation of the driving mechanisms for this change is yet to be established. However, Scheidat et al. (2011) have hypothesized that the wind farm may have actually resulted in a ‘sheltering’ impact for the harbor porpoise population, whereby the porpoises found the wind farm more attractive than the conditions outside of the wind farm area which are characterized by some of the highest shipping traffic levels globally. While the wind farm may offer a refuge to the porpoises, Scheidat et al. also presented the hypothesis that the reef effects and fish aggregations within the wind farm area provided a favorable prey resource for the porpoises, although this remains to be proven. Such potential explanations should be treated with caution until evidence for these effects is available, but the concept of the wind farm providing a sheltering effect was deemed to warrant discussion here.

Pinnipeds

Sundberg and Söderman (1999) found that maintenance vessels associated with Bockstigen OWF had an effect on the grey seal haul-out sites at Killingholm and Näsrevet, Sweden (near Gotland). The grey seals left their haul-out for short periods while the boats were transiting past the site, before quickly returning. When the vessels were stationary and working on the wind farm, the seals appeared to tolerate the boats and returned to land, without showing any obvious signs of stress. As suggested by Sundberg and Söderman, this may suggest that the more frequent the disturbance, the more risk of permanent abandonment of a site. Recommendations included restricting vessel traffic during molting periods or the use of a different port in order to re-route to areas at greater distances from the haul-outs.

Unlike Bockstigen OWF, a vessel restriction was imposed during construction at the Nysted OWF which made it mandatory for vessels to pass the seal sanctuary at Rødsand at an adequate distance (Edrén et al., 2004). However, the report does not state how far the restricted area extended from the sanctuary. The wind farm lies approximately 4 km to the south-west. Monitoring was undertaken at the haul-out using stationary video camera stations which provided high-resolution data throughout the construction of the Nysted wind farm (Edrén et al., 2004). The authors of the monitoring report, Edrén et al. (2004), noted that there was no change in the disturbance rates of the seals (where they flee into the water) during the construction phase and attributed this to the implementation of the vessel restriction area.

8.6.5 Collision and Propeller Impacts

Evidence of collision impacts and lacerations from propellers as a result of OWF vessel activity is scarce, largely due to the inherent difficulties of detecting such impacts occurring. However, recent evidence has come to light in the UK which has contributed to gaining a better understanding of how ‘corkscrew’ injuries (associated with propeller impacts) are likely to be derived. This is discussed in the following case study.

Case Study 29: Corkscrew Injuries: Propeller Impacts or Seal Predation?

Background

Propeller impacts upon marine mammals, predominantly seal species, have often been a concern of regulators during the development of the UK’s OWFs. The propeller impacts in question include lacerations to the body of a marine mammal, resulting in either mortality or injury. The regulatory bodies would typically require that wind farm construction would limit the use of ‘ducted propellers’ on vessels where possible in order to mitigate against the risk of injury to marine mammals. The term ‘corkscrew injury’ has been used when referring to this impact. The word “corkscrew” originates from the physical form of the lacerations that were frequently discovered on deceased stranded seals; the wounds typically represented a smooth-edged cut, extending from the head and around the body (Thompson et al., 2010; Bexton et al., 2012).

Despite there being an absence of direct evidence to prove that the injuries were a result of propeller impacts, a lack of credible alternative causes resulted in this being deemed the likely cause of the injuries. The main alternative theory considered was predation from another animal. In order to investigate this, studies were undertaken using clamp devices that mimicked a potential predator’s jaw to investigate the effects of tension forces upon a seal’s carcass (Thompson et al., 2015). The classic corkscrew-type lacerations that were so frequently observed on stranded carcasses could not be replicated using the clamping mechanisms, therefore predation was dismissed as the likely cause, while vessel propeller collisions were attributed as the most probable driving mechanism for the injuries.

Empirical Evidence for an Alternative Cause of Impact

In 2015, the Sea Mammal Research Unit (SMRU) (Thompson et al., 2015) observed and documented detailed visual observations of adult grey seal predation upon weaned grey seal pups at the Isle of May, in the Firth of Forth in Scotland. The Isle of May has had a particularly high number of corkscrew injuries in recent years and is considered a “hotspot” (Thompson et al., 2015). An adult grey seal was found to be dragging grey seal pups to a freshwater pool over multiple days, before forcing their heads beneath the water and biting into their bodies. The young seals would suffer mortality, and the adult seal would spend a significant amount of time tearing off pieces of blubber and consuming it as a food. Post-mortems examinations were undertaken for the pups’ carcasses, and 12 out of 14 of these were found to have wounds consistent with the highest category for classification of a corkscrew injury. Similar cannibalistic seal predation has been observed in places including Orkney (Scotland), Helgoland (Germany) and Skomer (Wales). Interestingly, the adult male found to be attacking seals at the Isle of May was found to transit the North Sea and move to Hegloland at a later date. However, the tag has been reported to have fallen off the seal since and SMRU are no longer able to track his progress.

These events have not just been limited to grey seals being predated upon, there have been observations of harbor seal pups suffering from these attacks too, although no confirmed records of adult harbor seals being predated upon have been logged to date. However, similar wounds have been observed in adult harbor seals and may be from the same type of predatory behavior (Thompson et al., 2015).

Conclusions and Implications for Regulation

Thompson et al. (2015) concluded that all cases on the Isle of May since 2010 can be considered likely to have been caused by these predation events. The authors deemed it premature to dismiss propeller impacts as the cause for some of these injuries, however they stated that many if not the majority of corkscrew deaths in the UK could be caused by seal predation attacks. Many of the injuries in other places within the UK are highly similar in their characteristics and therefore a proportion of these can be concluded to have been a result of grey seal predatory attacks.

The precautionary approach adopted by the Statutory Nature Conservation Bodies (SNCBs) in relation to the use of vessels with ducted propellers at OWF sites has since been reviewed. It is understood that the current stance is that while all possible care should be taken to avoid collisions with marine mammals, vessels with ducted propellers likely do not pose an increased threat above the risks associated with normal shipping activities and that mitigation and monitoring measures may not be necessary (JNCC, 2015).

8.7 Section Conclusion

The monitoring of marine mammals in Europe has largely focused on the harbor porpoise, harbor seal and grey seal. This may be expected given the abundance and widespread distributions of these species within European waters such as the North Sea and the Baltic Sea. Furthermore, the complexities of monitoring for many other species is significant. For example, certain whale species will be distributed in deep water environments and rare visitors to the waters in which OWFs are likely to be located, while some cetacean species are seasonally and/or infrequently occurring and do not necessarily warrant the level of monitoring effort that the dominant species have received.

In respect of underwater noise caused by foundation pile driving, significant empirical evidence has been gathered in the past decade to improve our understanding of the effects of this activity on marine mammals. Based on the case studies reviewed in respect of harbor porpoise, it has been demonstrated that widespread behavioral effects will always be realized during pile driving events if porpoises are frequently present in the area. The spatial scale over which displacement occurs has been shown to vary by project as would be expected based on differences in noise levels, environmental conditions and mitigation measures. However, general findings show that behavioral reactions should be expected over significant distances in effectively all such cases. For harbor porpoise, effects clearly have the potential take place over distances of 22 km to 30 km in some instances, as suggested by the findings at Horns Rev OWF (> 25 km), Horns Rev II (22 km), Thorntonbank (22 km) and from the findings of Brandt et al. (2016) which used non-parametric analyses to identify effect ranges of 20 km to 30 km for non-mitigated piling. However, Brandt et al. found that porpoise activity only reduced by more than 20% within 10 km to 15 km, therefore an effect range of 20 km to 30 km should not be considered to represent total displacement. The authors also suggested that mitigated piling resulted in an effect range of 14 km, which represents a significant reduction. For pinnipeds, statistically significant reductions in harbor seal abundance were found to occur within 25 km of the Lincs OWF construction site, again suggesting a large spatial scale of effect might be expected for pinnipeds. However, less studies on pinnipeds were identified than for harbor porpoise and future studies may find different scales of effect.

Empirical evidence of behavioral reactions in marine mammals to a known noise level is evidently of great use for modelling and for informing environmental assessments during the pre-application phase of a project. Brandt et al. (2016) found that 90% decrease in porpoise detections occurred where noise levels exceeded 170 dB, whereas at noise levels between 145 Db and 150 dB the decrease was reduced to approximately 25%. The decrease was less than 20% where noise levels were 145 dB or below, although this noise cannot necessarily be attributed exclusively to the piling noise. For harbor seals at Lincs OWF, the noise levels predicted to have been received which caused displacement were between 166 dB re 1 µPa(p-p) and 178 dB re 1 µPa(p-p). This highlights the benefit that mitigation may have for marine mammal species. The German regulators require noise levels less than 160 dB re 1 μPa^2s (SEL) and 190 dB re 1 µPa2 (peak to peak sound pressure level) to be adhered to at a distance of 750 m from the source, which is an approach that is likely to result in significantly reduced levels of displacement in harbor porpoises and harbor seals based on the noise thresholds identified above.

Based upon the varying rates of recovery from the piling-induced displacement reported within the case studies, it appears critical that the temporal aspect of displacement effects is understood. Effects within 2 km of the wind farm were found to last around 20 to 30 hours in general (tentatively) by Brandt et al. (2016), whereas porpoises returned within 6 to 8 hours at Horns Rev. At Horns Rev II, recovery time exceeded the time between piling events within 4.5 km, therefore this habitat would likely remain devoid of marine mammals if they cannot use the area during breaks in piling. Russell et al. (2016) highlighted the importance of understanding the temporal scale of effects on harbor seals, as they were found to return within 2 hours of piling ceasing. Therefore, it may be that impact assessments should perhaps focus on short-term effects of piling for harbor seals, with the consideration of the implications of piling-break durations, if indeed rapid recovery is found to be a common finding in future monitoring. The variations in recovery time may relate to environmental conditions, the value of the habitat to the species of interest, the levels of habituation by the animals amongst other variables. Therefore, it may not be possible to make generalized assumptions for species when considering these matters within future impact assessments, although this will become clearer with future wind farm development and monitoring.

General operational post-construction effects (e.g. displacement due to underwater noise, visual disturbance, loss of habitat etc.) on marine mammals generally show little or no detrimental effect on porpoise populations in comparison to the baseline levels. Evidence collected at the Nysted OWF demonstrates an exception to this, and a long-term reduction in porpoise numbers is significant. The minimal relative effect that the presence of a wind farm has had elsewhere (e.g. Horns Rev, Rødsand 2) suggests that impacts during operation would not typically be a concern. The Egmond aan Zee monitoring (which found increased porpoise activity within the wind farm during operation) is of interest, and poses questions as to whether increased prey availability or a reduction in vessel activity might have been drivers for this change. Future BACI monitoring is necessary in order to build on these studies as wind farms grow in size, while causal mechanisms warrant investigation in order to understand what is driving such changes.

Empirical evidence that provides confirmation of marine mammals entering OWFs is generally in agreement with the predictions made in ESs. Marine mammals appear to remain able to move into and forage within the wind farm areas. It is not known whether the increase in species associated with ‘reef effect’ represents an increase in biological production, or indeed an ‘ecological trap’ whereby a concentration of species selects poor-quality habitat over higher quality habitat. While the marine mammals foraging upon these species may benefit, it is not known what the potential implications are for the populations of these prey species and thus possible long-term impacts on the predatory species populations particularly after decommissioning.

In respect of increased vessel movements during construction and operation, there is a general lack of empirical evidence on how marine mammals respond to vessel movements and the noise that they produce. Some evidence exists to suggest that pinnipeds are susceptible to disturbance from vessel movements at haul-out sites, as described at Scroby Sands, where the authors considered this to have played a part in the population decline there (although not as significantly as piling). Seals also clearly responded to vessel movements at Bockstigen where they moved into the water during vessel transits. The limited evidence reviewed here suggests that vessel routing with exclusion zones around key haul-outs (such as the approach taken at Nysted OWF) is warranted where there is uncertainty over potential impacts of vessels passing close to haul-out sites at shore.

9. CUMULATIVE IMPACT ASSESMENT

The European Commission defines 'cumulative impacts' as "impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project" (EC, 1999). Other organizations/frameworks provide similar definitions (e.g. US NEPA, 1969 as amended[14]; IFC, 2012).

Assessment of cumulative impacts is required under EIA processes regulated by law in a number of countries, including the US, EU countries, and others. In the EU, a cumulative impact assessment is a requirement of the Birds, Habitats, and EIA Directives. It is also a requirement in performance standards and guidelines of lenders, such as the International Finance Institution (IFC).

Cumulative impact assessment (CIA) implemented at the project-level has been criticized by some as inefficient and/or deficient. This may be so in a number of cases, as in practice there does to be a great variety of approaches in use (e.g. methodology, extent, intensity, etc.). The US Environmental Protection Agency (EPA) noted that "*cumulative impacts … are not often fully addressed in NEPA documents due to the difficulty in understanding the complexities of these impacts, a lack of available information on their consequences, and the desire to limit the scope of environmental analysis*" (EPA, 1999). CIA has become an issue of increasing concern for offshore wind developers in the UK. In a study by RenewableUK and NERC, CIA was identified as an area of concern that contributed to substantial delays of up to 42 months in planning consents for OWF (Renewable UK, 2013).

CIA in ESs for UK Round 1 and Round 2 OWF were highly variable. Some ESs hardly discussed it, while others used different approaches and presented findings in different formats, much of which was subjective. Almost all ESs acknowledged limitations in the availability and quality of input data. Difficulties in quantifying cumulative impacts have also been part of the challenge.

King et al. (2009) noted that "*current practice illustrates the wide range of approaches used by developers in which assessment has often been qualitative rather than quantitative leading to uncertain conclusions and often major delays in project determination. Key issues have included: inadequate scoping, lack of understanding of the species involved, difficulties in assigning the range of projects which should be included within the assessment and the methods by which CIA should be undertaken*".

The European Commission's GP WIND project[15] addressed barriers to the development of onshore and OWFs in a *Good Practice Guide and Toolkit* that aims to facilitate deployment of renewable energy in support of the EU 2020 targets. Only one of 16 thematic case studies specifically addresses cumulative impacts. They observe that the main barrier to CIA is the difficulty in understanding the complex interactions of stressors (direct and indirect) from multiple (past, present, and reasonably foreseeable) sources, and their impacts on receptors (biophysical, social and economic). The scale of cumulative impacts depends on the sensitivity of receptors, biophysical location, intensity, and nature of developments – e.g. clustered or dispersed, technology type, and size.

[14] https://ceq.doe.gov/nepa/regs/ceq/1508.htm#1508.7, accessed on 3 November 2016.
[15] https://ec.europa.eu/energy/intelligent/projects/en/projects/gpwind, accessed on 3 November 2016.

Key issues were identified as:

- A lack of clear definitions and guidance on how to perform CIA;
- Fragmentation of different consenting regimes. They provide onshore examples for forestry, agriculture, and development. Offshore, fragmentation between e.g. fisheries and coastal development might complicate CIA even further;
- The spatial extent of cumulative impacts can be far-reaching. Migratory species raise transboundary issues that can be difficult to address if regulatory decisions are taken at a local level;
- Permitting/consenting procedures are generally set up to consider an individual development, which often means that cumulative impacts are insufficiently considered, especially if there is a lack of strategic planning;
- Many small-scale developments do not require EIA, and many fall outside spatial planning frameworks, consequently that information is lacking;
- Understanding of cumulative impacts in the marine environment is less developed than that onshore. Not only must offshore CIA consider marine based stressors, it must also consider onshore-based stressors that might affect the offshore environment; and
- Global dynamics such as climate change influence the predictability of effects, introducing uncertainty.

GP WiND and the UK Committee on Climate Change noted that approval rates for onshore wind farm projects were higher in Scotland than in England and suggested that good practices in Scotland might include:

- Clear guidance and scoping procedures to assist developers when making applications, including good online resources. For offshore wind, this includes a Sectoral Plan informed by Regional Locational Guidance;
- Statutory consultees, such as SNH (Scottish National Heritage) and RSPB (Royal Society for the Protection of Birds) Scotland, are very engaged and effective, providing advice and guidance on site availability and suitability early on in the planning process (Committee on Climate Change, 2011). SNH has produced guidance on the assessment of cumulative impacts (SNH, 2005) and good practice during wind farm construction (SNH, 2010). For onshore wind, a sensitivity map has been provided to identify areas where wind farms may pose a risk for important bird populations. This has been incorporated along with other natural heritage constraints into national strategic locational guidance (GP WIND, 2012);
- Collaboration with other stakeholders to overcome barriers to developments (e.g. technical solutions to air traffic control radar issues, and the creation of a Scottish Renewable Energy Ornithological Steering Group to share environmental information) has facilitated informed decision-making.; Following recognition that several large offshore wind proposals in close proximity to each other on the east coast of Scotland potentially present cumulative impacts, the Crown Estate promptly established the Forth and Tay Offshore Wind Developers Group as a joint approach to help in the assessment of potential cumulative impacts and where appropriate, to progress collaborative survey work and stakeholder consultation (GP WIND, 2012); and

- These measures have been supported by strong political will at all levels, which has translated into real action and progress – Ministers have intervened where projects were considered of 'national interest' (Committee on Climate Change, 2011).

In general, ESs for UK OWF have not reported significant cumulative impacts. Individually, a wind farm may have negligible or minor impacts on the environment, but collectively these may be more significant. Docking Shoal OWF, for example, was refused planning consent due to its unacceptable impact on birds when considered cumulatively with two adjacent wind farms. Considering the projected growth in OWF developments to help meet EU targets of sourcing 20% of energy from renewable sources by 2020, there are environmental concerns about potential cumulative impacts (Masden et al., 2010). CIA cannot be de-emphasized in future OWF assessment processes based on the conclusions of UK Round 1 and Round 2 ES to date. To the contrary, it requires an effort to improve the framework, methodology and consistency of outputs, as discussed below.

Several guidance notes on CIA have been published (Lawrence, 1994; EC, 1999; EPA, 2003; King et al., 2009; IFC, 2013; RenewableUK, 2013). Considering the diversity of stressors and receptors that converge in coastal waters, understanding the potential independent and cumulative impacts of those stressors on marine receptors can be very challenging. Quantifying the relative vulnerability of ecosystem types to cumulative stressors is difficult, and robust methods for quantifying cumulative impacts have been lacking (Kappel et al., 2012). Nevertheless, given the key importance of CIA in ecosystem based management (EBM), future assessments of OWF should aim to improve the standard of project-level CIA (Halpern et al., 2008; Levin et al., 2009; Agardy et al., 2011). For this, it might be necessary for competent authorities to provide guidance on scope and methodology, designed for regional conditions and needs, to ensure that project-level CIA integrates with EBM-level CIA, facilitating bidirectional validation and growing a scientifically sound database.

Masden et al. (2010) proposed a conceptual CIA framework that "*requires improved legislative guidance on the actions to include in assessments, and advice on the appropriate baselines against which to assess impacts. Cumulative impacts are currently considered on restricted scales (spatial and temporal) relating to individual development EIAs. [They] propose that benefits would be gained from elevating CIA to a strategic level, as a component of spatially explicit planning*". While escalation of CIA to larger, strategic/ecosystem-scale planning is expected to be advantageous, it is still possible to improve CIA at the project-level ESs as well, as this will clearly segregate responsibility between government agencies and project developers. For example, a two-level approach might help to solve the problem. Piper (2001) suggested a re-consideration of responsibility and funding.

A spatial distinction needs to be clear between CIA for EBM and CIA for wind farm projects. CIA is a key component of EBM and for this purpose its extent depends on the ecosystem characteristics (Agardy et al., 2011). A CIA for an EBMs is usually broader and bigger than a project-level CIA (Agardy et al., 2011).

The International Finance Corporation (IFC)[16] refers to a project's "area of influence", which must be defined in order to set spatial boundaries for assessment. This is not a simple process, as areas of

[16] International Finance Corporation (IFC) Environmental and Social Performance Standards (2012). www.ifc.org.

influence will vary for different stressors depending on transmission of stress and sensitivity of receptors. Furthermore, the relationships between stressors need to be considered in defining the project area of influence for CIA. Combined impacts can be either *additive* (equal to the sum of individual effects), *synergistic* (total effect is greater than the sum of the individual effects), or *antagonistic* (individual effects counteract or neutralize each other), and these will determine the project's area of influence (IFC, 2013).

IFC Performance Standard 1 states that the impact and risk identification process *"…will take into account the findings and conclusions of related and applicable plans, studies, or assessments prepared by relevant government authorities or other parties that are directly related to the project and its area of influence" including, "master economic development plans, country or regional plans, feasibility studies, alternatives analyses, and cumulative, regional, sectoral, or strategic environmental assessments where relevant".*

And that *"the [proponent] can take these into account by focusing on the project's incremental contribution to selected impacts generally recognized as important on the basis of scientific concern or concerns from the Affected Communities within the area addressed by these larger scope regional studies or cumulative assessments".*

IFC guidance uses the concept of Valued Environmental and Social Components (VECs), i.e. those being environmental and social attributes that are considered to be important in assessing risk (IFC, 2013). The guidance note provides a six-step process for assessing the potential for cumulative impacts on VECs:

- Scoping Phase I – identify VECs, spatial and temporal boundaries of the proposed project;
- Scoping Phase II – identify other activities and environmental drivers within the project's area of influence;
- Establish information on the baseline status of VECs;
- Assess cumulative impacts on VECs;
- Assess significance of predicted cumulative impacts; and
- Management of cumulative impacts – design and implementation.

It could be argued that the emphasis a finance institution might put on components (and therefore outcomes) of CIA may be different to the coastal planning focus of authorities such as BOEM, and this might need consideration. However, the IFC performance standards and guidance provide useful direction and are especially relevant to OWF projects seeking finance, since other lenders (e.g. JBIC) and risk management frameworks (e.g. Equator Principles) also refer to the IFC performance standards.

Ban et al. (2010) researched four types of CIA input data for coastal assessments:

i. Locations and intensities of activities, e.g. commercial and recreational fishing; Marine tourism; aquaculture; marine transport; marine disposal sites and land-based activities (human settlements, industrial, agriculture, mining, waste disposal);

ii. Stressors resulting from these activities;
iii. Magnitude and extent of impacts; and
iv. Vulnerability of habitats (receptors).

They identified limitations as: data availability and quality, data characteristics (e.g. data might represent an instant in time), uncertainty about the relationships (additive/interactive) of stressors on receptors, and lack of ground-truthing of CIA predictions. Improvements could be achieved by improving the coverage and quality of spatial data and by obtaining better information about potential interactions of multiple stressors (suggesting meta-analyses, expert elicitation, and Bayesian approach to integrate "prior beliefs" and update as new information becomes available).

King et al. (2009) provided guidelines on the processes, methods and techniques for assessment of cumulative impacts of OWF on birds. Their guidelines were developed by review and discussion of two commissioned position papers at an expert workshop. The process of scoping was considered by workshop participants to be essential to the provision of robust CIA and requires communication and iterative information exchange between developers, statutory bodies, and stakeholders based on standardized checklists. They also agreed that there is a need for increased guidance and more certainty in policy from regulators and statutory advisors. King et al. recommended tools and techniques for data gathering and for CIA: e.g. guidelines for selection of species, for the selection of projects, and the spatial scale of the bird reference population to be used. An overarching recommendation was for the provision of quantitative data on raw numbers, densities and population estimates for all species. They recommended that where collision mortality is likely to be significant, more detailed population modelling studies might be necessary. Disturbance and barrier-effects may accrue in a non-linear manner and, if during initial qualitative analysis they are thought likely to be significant, then a more detailed quantitative study of bird bioenergetics in relation to the effect should be carried out. They also emphasized that their guidelines are the first stage of an iterative process, and that they will need to be refined on the basis of evidence gathered from the monitoring of wind farms as understanding of the impacts of cumulative effects on birds improves.

It is tempting to attempt to simplify CIA, perhaps by considering one receptor group (e.g. birds) as indicators of overall cumulative impact significance for OWF developments within a broader coastal zone. However, the fidelity of cumulative impacts on birds and those of other ecosystem components or processes is not necessarily dependable. For example, the possible effect of OWFs as 'stepping stones' for impact of alien invasive species is a growing concern that might not be accurately reflected in a CIA of birds. Another example is how alterations to lower organism's populations in the food chain will impact higher levels. It seems likely that CIA will need to address VECs identified within appropriate spatial and temporal boundaries. A well-documented baseline is critical for CIA, and it is recommended that this be developed, if not available for all areas where OWFs are envisaged.

10. OPPORTUNITIES FOR IMPROVEMENTS IN NATIONAL ENVIRONMENTAL POLICY ACT REVIEW

10.1 Introduction

Project proponents and regulators, in the US and elsewhere, are now able to draw upon significant European experience to assist environmental assessment and permitting of OWF developments. Through repeated monitoring of the effects of OWF construction and operation, some consistent observations appear now to be emerging and with these, a growing confidence amongst stakeholders and decision makers as to the actual impacts that these developments may have on the marine environment and thus inform permit authorizations and management. For example, while categories of activities have not so far been excluded from EIA analyses in Europe, the gradual introduction of adaptive management and site specific license conditions in the UK has enabled industry to move away from generic broad-scale benthic ecology monitoring (which has so far largely failed to identify significant effects above natural variation) and to instead focus resources on managing key local sensitive features during construction. This adaptive management approach has used the learning available from historic monitoring to focus resource on the interest feature rather than on generic or insignificant issues. This chapter takes a brief look at current US impact assessment (NEPA) requirements and then consolidates the relevant European experiences to identify categories of activities which might offer opportunity for efficiencies in NEPA review.

10.2 Current United States Impact Assessment Requirements

Detailed statements of the potential significant environmental impacts of major federal actions are required to be reported under NEPA. Under BOEM's renewable energy regulations, the issuance of leases and subsequent approval of wind energy development on the Outer Continental Shelf (OCS) is a staged decision-making process. Prior to the issuance of a commercial wind energy lease, BOEM typically prepares an Environmental Assessment (EA) to consider the reasonably foreseeable impacts of lease issuance, including site characterization (i.e., surveys of the lease area and potential cable routes), and subsequent site assessment activities (i.e., construction and operation of a meteorological tower and/or buoys on the lease, if issued). If a lease is issued, the lessee may propose a commercial wind facility through the submission of a Construction and Operation Plan (COP). The COP would include information that the lessee has gathered about the lease area. BOEM will conduct a project-specific NEPA analysis, likely an Environmental Impact Statement (EIS), on the COP. The EIS is usually more detailed and most likely will be prepared for the COP.

The European experiences presented here have revealed, in some instances, consistent observations regarding the environmental impacts of OWFs, which developers and BOEM can start to utilize as a nascent evidence base. Further collation of OWF environmental monitoring studies over time, coupled with periodic 'state-of-the-art' reviews, will further add to a quality evidence base. Repeated review and audit is important in order to keep the evidence refreshed, since new OWF designs, installation methodologies, and mitigation measures could elicit different responses (positive and negative) in ecological receptors. These responses will need to be captured to further add to the evidence building. Likewise, replicated observations of the same activities within the same parameters is also important, as this will further increase confidence in the prediction and assessment of the impact of the activity under investigation. In time, and where sufficient confidence in the available evidence base allows, it may be advantageous to reduce NEPA review of specific construction and/or operation elements when a detailed EIS covering that specific COP aspect in question is demonstrated to be unwarranted.

This will allow common and familiar environmental issues to be addressed concisely at an early stage in the development life cycle within an EA rather than repeated in detail in the EIS.

10.3 Which Elements of Offshore Wind Farms Might Be Reduced in National Environmental Policy Act Review?

From the systematic review of OWF monitoring, several activities have consistently been recorded as having impacts which are temporary and/or are localized, or which appear not to have had any impacts on the environment confirmed above the natural background variation. The following introduces each of these categories of activities and discusses the merits of reducing review efforts during future NEPA analyses.

10.3.1 Operational Underwater Noise

Once operational, the wind turbines have been found to produce relatively low levels of underwater noise, which attenuate to background noise levels within a few kilometers and are below any injury or disturbance criteria, even very close to the turbine. Consistent observations have been made of fish aggregating within wind farms and around turbines, possibly in response to the refuge and feeding opportunities offered by the structures, suggesting no significant disturbance and avoidance to these fish species. Additionally, observations of the movements of tagged seals show apparent attraction to foundations of operational OWF, again possibly in response to enhanced feeding opportunities. Harbor porpoise, previously displaced by construction disturbances, have been found to return to areas within and around operational OWF, albeit not universally.

Current literature does not provide firm evidence for impacts by increased background noise on marine life. Where the background noise increases, the area over which effective use of sound by fauna will be reduced (increased masking), but dedicated studies showing population effects as a consequence of operational wind farm noise have not been undertaken. If audibility is an indicator of the potential for masking, then an area of up to 10 km surrounding a wind farm could be affected, depending on species (Tougaard et al., 2009). However, the frequency of masking sound must be equivalent to the sound of interest to the animal, and since turbine noise tends to be low frequency this is unlikely to be an issue for mammals (Au and Moore, 1990). However, there may be more of an impact on fish (Popper et al., 2014). The only conclusion appears to be that an increase in background noise as a factor of quality of habitat appears to be of less consequence to marine species compared to the positive effects of availability of food and shelter (reef effects) offered by wind farms.

Long term underwater noise data around operational turbines are limited from both noise levels under different wind states (especially high winds) and from a potential degradation of mechanical systems (i.e. wear-and-tear) perspective. Lasting effects on fish and marine mammal populations near turbines require more study to acquire greater confidence in the long-term impacts of operational noise on the subsea environment.

Underwater noise pollution is a growing problem in aquatic environments and as such may be a major source of stress for fish (Wysocki et al., 2006). The potential for wind farms to add to other noise sources needs to be considered in cumulative effects assessments. Larger and multiple OWFs located in close proximity of each other within (coastal) environments where other sources of anthropogenic noise also occur could be potentially significant. The potential health effects (e.g.

physiological stress) of long-term exposure to underwater noise are unclear. Further research into cumulative and long-term health effects is needed.

10.3.2 Physical Presence of Offshore Wind Foundation Infrastructure

The physical presence of turbine foundations and other OWF infrastructure on the seabed and in the water column can exert environmental pressures resulting in changes to physical and benthic ecological processes compared to pre-construction conditions. These pressures exist throughout the life of the project but have, to date, been recorded as causing physical and benthic ecological changes that are localized to the turbines themselves. The following discusses the effects of the presence of OWFs on physical processes and benthic ecology within the context of reducing NEPA review effort.

10.3.2.1 Physical Processes

Changes to hydrodynamic and sedimentary processes due to the presence of OWFs are localized to individual turbine foundations. Impacts that were unexpected and which were only revealed through monitoring, such as the persistence of spoil mounds on the seabed at Lynn and Inner Dowsing OWF and the development of large secondary scour holes at Scroby Sands OWF were still found to remain localized to the OWF site.

Scour at the base of the turbine foundations may increase sediment instability or create a coarser sediment habitat resulting in a modified benthic community compared to adjacent areas, however, changes remain generally within a few tens of meters from the foundations. Wake scours are limited to shallow mobile environments subject to natural sediment disturbances to which the local benthic ecology would have naturally adapted. Identifying significant benthic ecology change above the natural variation would be difficult in these circumstances.

Post-construction monitoring of physical processes has been undertaken, largely to check infrastructure integrity, particularly with regards to export cables or inter-array exposure or free spanning and the under-mining of foundations through excessive scour, in order to inform requirements for any intervening measures. Damage to this crucial infrastructure leading to subsequent OWF down time and/or partial decommissioning of assets could be costly, especially when compared to the costs of annual monitoring surveys.

This review has noted that, where assessed in the ES, the exact magnitude of change has often been either over- or under-predicted. Over-reliance on numerical models to inform impact assessment should be avoided, as unverified outputs could result in excessive monitoring or mitigation requirements without justification. There have been instances where the model outputs have been over-precautionary, resulting in more apparent significant impacts than were observed in reality. An example is the construction monitoring of suspended sediment concentrations during the installation of the export cable at Block Island OWF, where estimates of suspended sediments were up to 100 times larger than the actual observed measurements. At Lynn and Inner Dowsing OWF, the drilling of monopile foundations through a chalk sub-geology and subsequent disposal of drill cuttings on the seafloor was forecast to significantly increase SSCs in the local water column. However, despite intensive monitoring effort, no significant increase above natural background was observed.

10.3.2.2 Benthic Ecology

This review of monitoring reports noted that changes in subtidal benthos characteristics were almost always recorded, but subsequently were not attributed to wind farm development. Essentially, the reports acknowledged insufficient evidence to conclusively link cause and effect (before-after), and pointed to variability at control sites for probable natural reasons. Nevertheless, at the scale of the wind farm and surrounding area, significant impacts on benthic ecology have not been recorded.

Evidence emerging from the Belgian monitoring programs indicates that the presence of infrastructure has the potential to modify sediment and benthos around the base of the turbines due to scour, sediment enrichment and increases in the abundance of mobile epibenthos. Where this effect remains localized, the associated significance of the impact will remain minor or negligible. However, increases in the spatial extent of modified benthos may elevate significance levels accordingly. No evidence of extended spatial effects beyond 50 m has been detected through the available monitoring reports. New research planned for 2016 through 2017 at Block Island OWF under BOEMs Real-time Opportunity for Development of Environmental Observations (RODEO) initiative may prove helpful in further understanding the local influence of offshore wind turbines in this regard and the potential scale over which this might spread over time.

Degraer et al. (2012) emphasized that major impacts on the benthos component of the marine ecosystem take time to develop and become more pronounced as the wind farms ‘grow older and bigger’. Although current data suggest that OWFs are generally benign for soft-sediment benthos, it is too early to conclude. Furthermore, the risk of OWFs promoting or enabling invasions by marine non-indigenous species is very concerning, especially considering the projected growth in OWF development.

10.3.2.3 Epifaunal Colonization

Unless specifically treated, structures placed within the marine environment will be colonized by attaching and encrusting fauna and flora (biofouling). Biofouling has been studied at some European OWFs and is reasonably well understood in terms of typical species and communities and succession of colonization. In impact assessment, it is often linked with greater species diversity and biomass and associated increases in the provision of feeding and refuge for fish and other higher trophic levels and therefore is often assessed as an overall neutral or positive impact of OWF. However, long term effects on linked ecosystem components and local soft sediment benthos remain unclear. Also, the consequences of the eventual removal of infrastructure on re-powering or decommissioning of the OWF needs careful consideration, as important feeding relationships and other ecosystem services may have developed during the operational phase. If abruptly disrupted, these could have as yet unknown cascade effects on the local ecosystem components which will have developed in association with the turbines over time.

10.3.2.4 Marine Invasive Non-Indigenous Species

Several organizations and researchers have highlighted the risk that OWFs may act as ‘stepping stones’ for marine invasive species, damaging existing habitats and impacting on biodiversity and ecosystem functioning (Bergström et al., 2014; Glasby et al., 2007; Lindeboom et al., 2015).

Researchers with support of the European Commission's ASIMUTH and HYPOX[17] initiatives developed coupled biological and hydrodynamic models to predict how OWFs proposed off the coasts of Scotland and Northern Ireland might influence the spread of marine species (Adams et al., 2014). Their study focused on species that have mobile larvae, such as barnacles, mussels and limpets, and concluded that OWF structures could potentially act as 'stepping stones. Offshore installations provided source and destination (or intermediate connection) roles, creating new dispersal pathways, allowing previously impossible northward dispersal from the Northern Irish coast to Scotland. Thus, species currently only found abundantly in Northern Ireland, such as the 'lined top shell' snail (*Phorcus lineatus*) and the purple sea urchin (*Paracentrotus lividus*), may now be able to invade and establish on the Scottish coastline[18].

Adams et al. (2014) also acknowledged the role of climate change in such dispersion and potential invasions. Several invasive species are presently restricted to southern Scotland by spawning temperature requirements. Changes in sea temperatures in concert with OWF 'stepping stones' might extend the efficiency and scale of dispersion, with implications for biodiversity and ecosystem functioning. The authors recommend that OWF projects not only monitor and assess the potential spread of invasive species, but also increase monitoring effort on species with mobile larvae. Using models similar to those used by Adams et al. could help predict the coastal sites where invading species are most likely to arrive, providing information useful to EBM.

Given the potential significant impacts of invasive species on biodiversity, on ecosystem function and services, and on commercial assets, it is recommended that:

- Strategic risk assessments, including cumulative considerations, and taking cognizance of scientific advice, be developed and maintained by competent authorities;
- Site-level risk assessment be a standard requirement of all OWF impact assessments, and feed into regional assessments;
- Where the risk of importing or enhancing invasive species is identified, a full management plan should be developed; an EIA-style mitigation statement will not be sufficient. If, on review of the plan, the assessment finds that the risk can be managed to acceptable levels, then the approved plan shall be implemented, reviewed and updated as appropriate to achieve policy and legal objectives; and
- The implementation of the invasive species risk assessment procedure and any associated plans and procedures should be discussed in annual environmental monitoring reports, to provide assurance that risks are being adequately managed.

10.3.3 Raising of Sediment Plumes

European ESs and other published literature have not identified significant impacts on ecological receptors by sediment suspended by OWF construction activities including seabed dredging and cable

[17] ASIMUTH (Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms) and HYPOX (In Situ Monitoring of Oxygen Depletion Associated with Hypoxic Ecosystems of Coastal and Open Seas, and Land-Locked Water Bodies) are supported by the European Commission under the Seventh Framework Programmes projects. See: www.asimuth.eu and www.hypox.net MaREE (Marine Renewable Energy and the Environment) was supported by the European Regional Development Fund.

[18] "Science for Environment Policy": European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol. *http://ec.europa.eu/environment/integration/ research/newsalert/pdf/370na3_en.pdf*

installation. Impacts of raised suspended sediments and plume settling from the activities have been typically regarded as short lived, localized and no greater than natural variation, i.e. during storm events.

Although suspended sediments generated during the construction do not appear to have caused significant impacts, it is possible to conceive of situations where they might lead to an issue. The magnitude of suspended sediment impact on water quality would depend partly on the construction methods used. Jetting, for example, can release large amounts of sediment into the water column, and if this were to occur in close proximity to valuable spawning grounds, coral reefs or seagrass communities, for example, the impact could be significant. Careful siting of OWFs in the first instance will avoid sensitive areas, where known, while appropriate timing of construction activities will avoid critical ecological periods such as spawning and migration. It would be very useful if information on the specific environmental characteristics and sensitivities of a site for a proposed OWF were delivered to BOEM at an early planning stage to help inform scoping of the range of issues that need to be addressed and to facilitate engagement with other agencies and stakeholders to agree the breadth of decision making that will be needed.

It may be particularly useful if, in the light of sufficient pre-existing information, mitigation measures and construction methodologies could be evaluated at the time of scoping. This could include the selection and use of the appropriate trenching tool, to minimize any potential impacts on a known sensitive receptor. Equally, this could include a temporal exclusion or micro-siting of infrastructure to avoid potential sediment plume impacts on a sensitive feature or during a sensitive ecological period. Where a developer commitment for a particular intervention or construction method can be secured, then the risk of impact could be reduced allowing the issue in question to be briefly addressed in the EA and EIS.

10.3.3.1 Cable Installation

The aim of cable installation is to achieve adequate burial depth so that the cable is not exposed on the seabed. It is therefore important that during cable installations, as much of the sediment taken from the trench is retained for use as backfill. Consequently, cable installation tools will not generally release significant quantities of fine sediments into the overlying water. Bespoke monitoring at Block Island OWF confirms the findings from historic monitoring campaigns that suspended sediment concentrations during the installation of export cables are generally not detectable above background conditions more than a short distance from the activity, supporting the view that cable installation does not have significant environmental impacts (Fugro, 2016). However, the sensitivity and value of biotopes, as well as the magnitude of sediment suspension can vary considerably, depending on location and method of construction, and should perhaps be assessed on a case-by-case basis. As above, the presence and consideration of pre-existing site sensitivity information, together with the construction design and any secured mitigation, would help inform better scoping and more focused environmental documentation.

10.3.4 Electromagnetic Field Emissions

It is clear that fish can be affected by anthropogenic EMF in their natural environment, however the significance of any impacts due to EMF from OWF power cables is unclear. Some evidence suggests that the migration of elasmobranchs could be affected by power cable EMFs. In other cases, fish communities above cables were strongly similar to those away from them. There is also the possibility that some electro-sensitive species might be confused by, or attracted to, anthropogenic EMFs. The most recent *in-situ* studies from California (Love et al., 2016) seem to add to the weight of evidence of 'no significant effects'.

OSPAR (2008) states, "*there is no doubt that electromagnetic fields are detected by a number of species and that many of these species respond to them. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds. The significance of the response reactions on both individual and population level is uncertain if not unknown. More field data would be needed to draw firm conclusions but data acquisition under field conditions is complicated"*.

Despite the apparent uncertainty within the literature, environmental monitoring to date has not detected any significant effects of EMF on elasmobranchs or on any other marine species. Typically, OWF power cables are buried below the seabed surface which provides shielding from predicted EMF emissions. This is generally considered adequate mitigation to render the significance of potential impacts as negligible. Sufficient burial depends on the local geological conditions.

Floating OFWs could employ floating intra-turbine cables, floating substation(s), and the first portion of the export cable exposed as it descends to the seafloor. In these circumstances, this mitigation measure would not be applicable, and could only be used for the buried portion of the export cable.

Emissions of EMF into marine ecosystems are set to increase with the planned development and expansion of offshore wind power. Consideration needs to be given to potential cumulative effects. Bigger size and increased numbers of wind farm arrays (i.e. grids of EMF sources) may cause stress in parts of the parent ecosystem.

Potential interactions with migratory species remain unclear and there are information gaps that still need to be addressed. The information reviewed in this report strongly suggests that further tagging studies are needed, especially of EMF-sensitive migratory species in comparison to non-sensitive migratory species. The sensitivity of focal species to EMF must also be better understood. For example, Drewery (2012) noted that there was no research concerning the sensitivity of basking sharks to EMF. BOEM may wish to consider other species, particularly ESA list species, which might benefit from further consideration with regard to species specific sensitivities to EMF.

It is also worth noting that in the face of uncertainty, (Claisse et al., 2015) developed a list of Hawaii Region Focal Species, which included fish species that are more likely to be sensitive to EMF. They then compiled species-specific information available in the literature on their sensitivity to EMF, as well as life history, movement and habitat use information that could inform an analysis of their likelihood of encountering EMF from subsea cables. They noted that studies have only documented EMF sensitivity in 11 of the marine fish species in that region. There was also relatively little detailed information on fish movement and habitat use patterns for most of the focal species. Nevertheless, such information will be of some value in impact assessments, and has certainly identified gaps for future studies to address. A proactive approach may be useful elsewhere.

10.3.5 Habitat Loss

The loss of original seabed habitat is an inevitable consequence of the placement of infrastructure on the seabed, although typically the area lost is very small, equating to <1% to a few percent of the development site only, subject to the number and type of foundations used and the quantities of scour material deployed. Because of this, the significance of this impact is invariably negligible to minor. Appropriately sited OWFs will avoid loss of protected or critical habitat, such as spawning and foraging habitat, as well as known marine mammal and fish migration routes and bird flight corridors.

Despite occupying relatively small areas of seabed, wind farms themselves, as defined by their outer turbines, can cover large areas of sea (OSPAR, 2008). Displacement of some birds, i.e. divers (loons), from these areas, and from adjacent areas within a 2 km to 4 km buffer, could result in a significant loss of feeding ground for these species. The ecological significance of this displacement effect will depend upon the availability of other suitable habitat to which disturbed individuals will be displaced and the level of any increased competition with other individuals and species at the new location. To date, these issues remain poorly studied.

As well as the known and perceived site sensitivities, the OWF project description provides the basis for impact assessment, and the basis against which related permits and licenses are decided. Therefore, it is important to confirm that an approved project is constructed according to the assessed specification. Based on a Project Description, habitat loss for example might be assessed as acceptable, however, changes in methodology or specification during construction could result in a different outcome. ESs and License conditions often stipulate that mitigation measures are developed and contractually formalized in a construction environmental management plan (CEMP), and such plans often refer to management of change (MoC). However, there is often no procedure for monitoring conformance. A monitoring and non-conformance system should be specifically linked to the CEMP and the data reported, either as part of an Annual Monitoring Report or as a standalone Construction Conformance Report. Such a system promotes transparency, demonstrates accountability and enables stakeholders to gain confidence that the constructed project conforms to the approved design. The report should highlight any deviations and assess its consequences.

It is recommended that minimum reporting requirements be specified in the lease application process, and that construction phase monitoring reports should discuss conformance to an adequate level of adequate. Such detail should not be limited to direct impacts and should consider all wind farm elements. Systematic and easily traceable records will enhance project management to the benefit of all stakeholders.

10.4 What Potential Strategies Exist to Enable Efficiencies?

10.4.1 Improved Scoping

Scoping is a requirement of the NEPA process and is provided for by the CEQ Regulations. It provides the opportunity for project proponents to put forward their proposals to stakeholders and regulators and to receive feedback on the likely impacts that such proposals may have, the assessment methodologies and site investigations that may need to be followed to accurately assess and report those impacts and any mitigation that may be necessary to reduce perceived adverse impacts. Importantly, it provides opportunity for regulators and stakeholders to express any concerns that they may have and the detail in which identified issues need to be examined and addressed in the subsequent EA and EIS. The resulting scoping opinion should then be used by the proponents to refine their proposals, including the consideration of mitigation to reduce potential adverse environmental impacts. Because of this, scoping should be undertaken at an early stage in the project and at a time when the proponent still has a number of design and siting options available and when mitigation measures can still be incorporated. In this way, the best environmental option is identified and selected to be taken forward for focused assessment and lease application. The environmental advantages of the project should be clearly communicated and should include the participation of the public from across the entire geographical area expected to receive the scheme benefits, i.e. reduced emissions from renewable power generation, rather than limited to the areas within the potential view-shed and close to project (Bisbee, 2008).

An improved scoping exercise, undertaken as an iterative and participatory process distils those issues which would be meaningful in the decision making process and highlights those that can be dealt with in less detail. Reducing the effort needed to review issues that do not give rise to significant impacts, either through prior knowledge of the site sensitivities or through mitigation, would lead to a more well-defined scope and a more focused EA and EIS which is contextualized within the wider environmental benefits of the scheme.

The past experiences from environmental monitoring, as consolidated in this review, could play an important role in informing a well-defined scope, particularly in identifying issues that have been shown to be not significant. However, this would likely only be part of a broader solution to achieving improvements in NEPA review. Prior knowledge of the temporal and spatial sensitivities of the proposed OWF site and the ecology of local species and communities would also be required, at sufficient site level resolution to inform a sympathetic OWF design and construction methodology with appropriate mitigation applied, as necessary. Also, good knowledge of the geological conditions on site and along the export cable corridors is vital to help inform foundation type, construction methodology, and tool selection. Along with case study reviews and past experience, these additional datasets establish the environmental context within which the proponent's application is to be judged. Significant gaps in the datasets can give rise to uncertainties in the judgements being made, resulting in additional site investigation and extra layers of precaution which could increase the timeframe for the application and increase developer cost.

In its canvassing for opinion amongst wind farm developers on project siting and permitting challenges in the US, the Department of Energy (DoE) identified baseline knowledge gaps in environmental data as an important potential barrier to successful and timely development and highlighted that the availability of pre-existing data serves as a significant incentive to developers during site selection (van Cleve and Copping, 2010). In light of this, it may be advantageous for BOEM to be able to offer a range of environmental baseline datasets which could increase the interest in, and value of, future lease sales of wind energy areas (WEAs) as well as improve project scoping. The message emerging from the US DoE review appears to be that the greater the availability of baseline data, the greater the developer confidence such that developments are more likely to successfully proceed in data rich environments. Likewise, the availability of pre-existing data is expected to stimulate greater stakeholder confidence in the prediction and assessment of the specific environmental consequences that a development may have and this confidence may be achieved at an earlier stage in the process.

Both factors should lead to more competitive leasing and development, while still providing suitable and robust mitigation.

Considerable liaison with other agencies and stakeholders is typically required to acquire the appropriate levels of information and expertise, where available. However, academia may also prove a useful source of baseline data for site characterization purposes and for ecological information on local populations. It is acknowledged that BOEM's Environmental Studies Program (ESP) and RODEO initiative is already significantly contributing to this knowledge base and will be important in achieving any additional site or regional level characterizations for areas of OWF interest.

10.4.2 Regional Environmental Characterizations

The Regional Environmental Characterizations (REC) program was initiated in the UK with the aim of collecting broadscale physical, biological and cultural heritage datasets across several distinct geographical areas corresponding to groups of marine aggregate extraction licenses. The following briefly describes the aims and outcomes of the REC program as a possible vehicle for the collation and dissemination of environmental data at lease sites or WEA in the US and to assist in effective OWF scoping and assessment.

The aim of Regional Environmental Characterizations (REC) for the marine aggregates extraction industry in the UK was to provide an environmental reference statement defining marine and seabed conditions within the study area. Prior to these studies, environmental assessment of UK marine aggregate sites was based upon dispersed data acquired over several decades. The REC program, funded by the Marine Aggregate Levy Sustainability Fund (MALSF), provided the opportunity to acquire and interpret an integrated physical and biological dataset for each development region. Uniquely, geophysical, habitat, species, and cultural heritage data were all collected at the same time providing a truly integrated interpretation of the biological, physical, and heritage resources at regional levels.

The RECs therefore provided a unique, robust scientific basis to define the regional marine environment, outlining the character of seabed conditions in the study area. This permitted informed, confident, and consistent decision-making and consequently the RECs will be of value to all stakeholders including government, marine industry, planners and the public. The knowledge contributed to the protection of the marine environment, promote the sustainable management of the seabed, and focus future development investment.

The RECs were compiled by reviewing existing literature but were largely based upon the interpretation of specifically acquired field data. The data were used to define the physical and biological character of the seabed in the region and produce an integrated habitat dataset, thus producing a state of the art reference source. This was combined with a broad review of heritage issues and archaeological potential.

The characterization process commenced by reviewing the physical conditions in the area, for example tides, currents, seabed geology, and seabed sediment transport. The heritage assessment was then combined with the interpretation of the Quaternary geology to produce an integrated assessment, while ship and aircraft wrecks and other modern archaeology were treated separately.

Analysis of the benthic infauna and epifauna communities was combined with an evaluation of their associated physical conditions, assessed through acoustic survey and interpretation, to produce a habitat assessment. The characterization process also highlighted regional environmental sensitivities, for example, sites of potential conservation, fisheries or heritage significance, as well as informing marine spatial planning.

Overall the RECs complimented wider UK Government initiatives involving the greater use of spatial planning in the marine environment together with the strategic management of human activities.

10.4.3 Habitat Mapping

It is noted that EBM and integrated coastal management (ICM) in coastal development planning require reliable information about the features, values, and distributions of different (benthic) habitats. However, outside of site specific impact assessment studies, the characteristics and distributions of ecologically significant submerged habitats, such as hard-bottom shellfish reefs or seagrass beds, have often been poorly documented, due mainly to the high cost and intensity of fieldwork.

Data acquisition has increased in recent years due to improvements in methodology, and the development of regional strategies and implementation of field programs. Point data of biological values (collected through environmental sampling) have been complemented by bathymetry, remote sensing (including aerial photography, satellite imagery, multibeam sonar, and airborne bathymetric light detection and ranging (LIDAR)), and underwater photography, to enhance these datasets (Kostylev et al., 2001; Kenny, 2003; Kautsky et al., 2010; Sahla et al., 2016).

The integration of tools, such as hydrodynamic and ecological modelling, environmental economics, GIS, and impact assessment has strengthened the scientific framework for utilizing habitat maps in evaluation and decision-making (Haag, 2006; Nobre and Ferreira, 2009).

Broadscale maps drawn from multi-agency data are already in development and in use across Europe. Environmental agencies from various member state have collaborated on the Mapping European Seabed Habitats (MESH) project which aims to deliver seabed spatial datasets to assist a more integrated approach to spatial planning. This is being undertaken by initially collating all the mapping data undertaken and to standardize these using developed protocols to create a unified habitat classification. Standard field survey methodologies have also been developed to ensure data derived from future surveys are consistent. Data gaps in the map record are filled using predictive techniques drawing upon the known physical characteristics of the area in question.

Several government agencies with responsibility for near-shore marine assets in the US have programs for benthic habitat mapping. Prior to making OCS blocks available for lease, BOEM typically conducts studies needed for strategic-level assessment and management of potential environmental impacts. Benthic habitat maps and assessment are an output of that effort (e.g. Taylor et al 2016), providing "*an important baseline condition of … benthic habitats … and their value to fishes, in preparation for offshore development of wind energy facilities*". Other institutions have published similar reports (Barrett et al., 2001; Blyth-Skyrme et al., 2008; Kostylev et al., 2001; Passlow et al., 2006; Pickrill and Kostylev, 2007).

Cape Wind's proposal to build an OWF off the coast of Cape Cod, in Massachusetts, included 130 turbines with a capacity of 468 megawatts (http://www.capewind.org/). Tyrrell (2004) noted that concern among conservationists and fishermen about potential negative impacts on benthic habitats was generated at the project proposal stage, and that some of the controversy may have been diffused if habitat maps had been available at the outset. Several additional wind farm energy proposals off the coast of Massachusetts prompted the Massachusetts Office of Coastal Zone Management to prepare a strategic plan to survey and map benthic habitats. According to this plan, "*habitat maps of the wind farm area would help managers design surveys that would insure that the wind farm proponents 1) address all of the habitat types in the area, 2) use the proper methodology to characterize the resources and 3) reference baseline conditions for a monitoring program*".

Case study #7 provided a good example of a map product (in this case a map of the distribution and extent of valued reef habitat) which was used in negotiation with statutory agencies to agree final designs and plans for a number of construction activities. The mapping output was helpful in that it removed the previous regulator concern and allowed the construction plan of the OWF to be approved.

At project-level, habitat maps are required for impact assessment. Benthic habitat mapping is employed to determine the presence of any sensitive/valuable habitat types, assess potential impacts, and determine mitigation and monitoring. Agencies should decide in consultation what data are required to develop new, or to validate existing habitat maps (e.g. acoustic ground discrimination systems ground-truthing using grab and dropdown video observations), and what data are required during construction and operations to monitor potential changes in characteristics and distribution, bearing in mind that impacts might be direct, indirect or cumulative.

10.4.4 Mitigating Underwater Construction Noise

Percussive piling, together with other marine construction activities, remains one of the most significant impact producing factors of OWF. The issue routinely stimulates considerable stakeholder concern as it can potentially affect a wide range of fish, reptile and marine mammal receptors including high value, commercially important and protected species. In nearly all cases reviewed, the construction of OWF has required some form of associated intervention to separate valued receptors from significantly noisy activities, either spatially and/or temporally. This has often involved extensive consultation and agreement across a broad range of agencies and other stakeholders during the later stages of the impact assessment and at life-cycle stages in the development analogous to BOEMs' COP planning phase.

A wide variety of mitigating measures are used in Europe and which are briefly identified here. While there is no standard European approach, there is suitable precedent and experience at national levels upon which BOEM and developers can draw to help identify the most advantageous option, or combination of options. Thomsen et al. (2006) and CSA Ocean Sciences (2014) discuss several mitigation options as follows:

i. Spatial restriction of construction techniques, e.g. prohibiting pile-driving in confined areas in close proximity to migrating fish, and using lower volume methods where practicable (drilling, vibratory, gravity base, floating, suction buckets, etc.). Spatial measures might seek to 'warn' sensitive fish away from high-risk areas using acoustic deterrent devices or soft-start procedures as discussed below;

ii. Temporal restrictions might consider periods of special sensitivity, e.g. migration peaks, spawning periods, or the danger of masking during spawning of gadoid fishes. Noisy activities that could impact upon feeding or reproduction of fishes during these periods, and thereby threaten their local populations, might be temporarily restricted to less sensitive periods. This is sometimes difficult to achieve, e.g. where different species have different spawning seasons;
iii. Extending the duration of the hammer blow during pile-driving. This may result in a decrease of 10 dB to 15 dB in SL, mostly at higher frequencies > 2 kHz. Extending the duration of the hammer blow reduces source levels very efficiently but results in signals of longer duration that would mask harbor seal and possibly harbor porpoise communication to a greater extent than shorter signals. The method is also limited technically, since shorter pulses are more effective in driving the pile into the seabed.
iv. Mantling of the ramming pile with acoustically-isolated material, e.g. plastic, seems to be very promising, but at the time when Thomsen et al. completed their review had only been tested in a relatively short pile. This technique may result in a decrease of 5 dB to 25 dB in SL, mostly at higher frequencies;
v. New pile designs, such as double-walled piles or lower radial expansion piles, might lead to lower noise emissions;
vi. Air-bubble curtains around the pile are very expensive and might be only effective in relatively shallow water. This may result in a decrease of 10 dB to 20 dB at receptor, depending on frequency. Other source attenuation options include cofferdams and hydro sound dampers; and
vii. Soft-start/ramp-up procedure, i.e. slowly increasing the energy of the emitted sound, to warn off mobile animals such as marine mammals and fish, are often employed during seismic surveys, and have been prescribed for pile driving during the construction of some OWF (e.g. Rhyl Flats, UK).

Early cognizance of all design, geological and environmental issues is likely to be required to inform acceptable noise mitigation measures. Where mitigation can be developed and secured at a sufficiently early stage, the likelihood of significant underwater noise impacts occurring diminishes and the final assessment scopes are reduced accordingly. Clearly, there will be advantage in understanding and adopting the available noise mitigation options for any given project development site and assimilating this knowledge as an additional data strand within project scoping will further help frame the subsequent assessment requirements and deliver a more focused EA and EIS.

11. CONCLUSIONS

In Europe the opportunities for development of offshore wind facilities to meet international carbon commitments, diversify their energy mix and ensure future domestic energy security are now well recognized. Furthermore, offshore development avoids the potential for spatial conflicts with developments onshore and removes, in part, adverse visual and onshore noise impacts. Technological advancements, maturing supply chains and economies of scale have contributed to a reduction in the cost of OWF energy over recent years further incentivizing advancement of the industry.

Despite these benefits, construction and operation of offshore wind facilities present certain ecological risks which require being understood and managed carefully through monitoring, planning and design. In Europe, the development of offshore wind has been gradual, starting with comparatively small, inshore developments before expanding to larger facilities further offshore. This expansion has been accompanied by intensive monitoring and research to collect ecological response data to better understand the ecological risks, remove uncertainty, and inform better mitigation and design before scaling up for future developments. Alongside the specific OWF monitoring, considerable research has been undertaken (and is still ongoing) to characterize the ecology of fish, seabird, marine mammal, and benthic populations at regional scales to contextualize and better describe potential impacts.

In order to harness the potential of OWF and enable industry, it is the goal of authorizing agencies to review the environmental consequences of OWF applications in the timeliest and most efficient manner possible while still performing a quality assessment. Key to achieving this is to uncouple the significant impacts from those which are insignificant so that the scope of EA and EIS is proportional to the level of impact in line with 40 CFR 1502.2(b). The experience from European OWF monitoring campaigns reviewed here have identified several categories of OWF activities which are commonly or consistently associated with minor impacts or negligible impacts as follows;

- Operational underwater noise;
- Physical presence of infrastructure;
- Raising of sediment plumes;
- Electromagnetic field (EMF) emissions; and
- Habitat loss.

However, in the current state of knowledge, reducing the review effort of these activities from NEPA consideration for OWF developments in the USA runs the risk of an inadequate analysis of any potential site specific sensitivities, potential longer term and cumulative impacts and any particular OWF design feature, which may have an adverse interaction with the receiving environment. This is particularly true in the absence of a strong environmental baseline and robust OWF project description which would otherwise inform a well-defined scope and a focused EA and EIS. Efforts should be made to prepare comprehensive scopes and contextual site characterization data which can justify reduction or removal of categories of activities from later NEPA review in light of the project design and any mitigation to which the developer has already committed. Scoping should also communicate the overall advantages of the project as well as highlight any opportunities for biodiversity enhancement to a broad audience across a wide geographical range rather than to those within predicted impact areas close to the scheme. Finally, stakeholders may have special interests for which they may be inclined to contest the use of any generalized impact assessments or the reduction/removal of site specific evaluations and/or monitoring efforts.

In conclusion, review of existing environmental monitoring data for OWFs is useful in highlighting potential construction and operational activities that may be reduced or excluded from NEPA review. However, this is likely to be only one part of a wider strategy to improve efficiencies in NEPA documentation. Detailed and participatory scoping, supported by robust, high resolution environmental data, is also required to confidently identify relevant issues and dismiss those that can be either mitigated or are shown not to be significant.

The accounts of OWF monitoring in Europe presented here have not been exhaustive; there is considerable environmental monitoring that remains ongoing in compliance with license conditions and therefore was not available for this study. Also, there is a considerable delay between completing a monitoring survey and its reporting to the public domain so that some monitoring completed as much as a year ago has not been covered here either.

There are also a number of important collaborative research projects due to report next year (2017) (see Case Studies ♯14 and ♯26) and which are expected to significantly advance understanding of seabird and harbor porpoise behavior in response to OWF activities. Although focused on European populations, the results of these studies are expected to be broadly applicable to the US situation and could potentially support the development of general principles regarding bird and marine mammal avoidance at site specific and cumulative levels. However, specific US species may have different tolerances to OWF impacts and so application of behavioral response to the US situation should be undertaken with caution.

Periodic review of OWF monitoring and research in the future will be required to update the current knowledge base and to assist identification of further improvements in NEPA documentation. The scope of this study can be used as a template for applying future case study results to NEPA permitting.

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A. APPENDIX A. DATA REVIEW AND GAP ANALYSIS

Fugro EMU Limited

Improving Efficiencies of National Environmental Policy Act Documentation for Offshore Wind Facilities
M16PC00007

Data Review and Gap Appraisal

Fugro EMU Document No.: 160693–2
Fugro Consultants Inc. Reference.: 04.81160010
September 19th, 2016

Bureau of Ocean Energy Management

Final

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Data Review and Gap Appraisal

Fugro EMU Document No.: 160693–2
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September 19th, 2016

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EXECUTIVE SUMMARY

In response to anticipated increases in offshore wind farm lease applications on the United States (US) continental shelf, the Bureau of Ocean Energy Management (BOEM) (the regulatory authority with responsibility for leasing and permitting of offshore wind facilities) has called for options to improve efficiencies in the documentation typically produced under the National Environmental Policy Act (NEPA). Fugro's contribution to achieving this is to create a series of case studies of offshore wind farm environmental impacts drawn from existing European monitoring campaigns of operational wind farms to which regulators, developers and stakeholders can refer during NEPA review and which may allow for macro-level characterization of the level of impact with the principal goal being the identification and eventual scoping out of interactions which have been shown to have minor or negligible consequences for environmental receptors.

This initial report describes the published data that are currently available to create the case studies, identifies potential sources of other information which may be relevant to the case study building and provides an outline strategy for their acquisition. It is intended as a pre-cursor to the case studies themselves and serves as an overview of the quantity and nature of the different reports and studies that have either already been collected or will be targeted for collation by Fugro as supporting evidence of the environmental impacts of offshore wind farm construction and operation. Additionally, this report describes any inaccessible information for the purposes of a gap analysis to help appraise the possible limitations to the current study.

The case studies themselves will be presented in a subsequent report for presentation to BOEM and will be substantially supported by the information described here.

CONTENTS

TABLES IN THE MAIN TEXT

ABBREVIATIONS

ADD	Acoustic deterrent device
BACI	Before, after, control, impact
BOEM	Bureau of Ocean Energy Management
CEQ	Council on Environmental Quality
COP	Construction and Operations Plan
COWRIE	Collaborative Offshore Wind Research into the Environment
DECC	Department of Energy and Climate Change (now Department of Business Environment and Industrial Strategy, BEIS)
DEPONS	Disturbance effects on the harbor porpoise population in the North Sea
EIA	Environmental impact assessment
EIS	Environmental impact statement
EMF	Electromagnetic field
EPS	European Protected Species
ES	Environmental statement
FLOW	Far and large offshore wind
GIS	Geographic information systems
JCP	Joint cetacean protocol
JNCC	Joint Nature Conservation Committee
MMO	Marine Management Organisation
MMOs	Marine mammal observers
MS	Marine Scotland
MUMM	The Management Unit of the North Sea Mathematical Models
NE	Natural England
NEPA	National Environmental Policy Act
NSW-MEP	Monitoring and Evaluation Programme (Netherlands)
OWF	Offshore wind farm
ORJIP	Offshore Renewables Joint Industry Programme
PAM	Passive acoustic monitoring
PVA	Population viability analysis
RBINS	Royal Belgium Institute for Natural Sciences
RODEO	Real-time opportunity for development of environmental observations
RSPB	The Royal Society for the Protection of Birds
SCANS	Small cetacean abundance in the North Sea
SMRU	Sea Mammal Research Unit
SOSS	Strategic Ornithological Support Services
SpORRAn	Scottish Offshore Renewables Research Framework
TCE	The Crown Estate
UK	United Kingdom
US	United States
UXO	Unexploded ordnance

1. INTRODUCTION

The 2005 Council on Environmental Quality (CEQ) Regulations (§ 1502.5) calls for respective United States (US) agencies to prepare environmental impact statements (EIS) in a sufficiently timely fashion to enable findings to be used practically within the decision making processes and to be available prior to that portion of public hearings relevant to impact statement. The regulations also remind authors that the purpose of NEPA is not to produce paperwork but to assist regulators in good decision making based on a sound understanding of the likely environmental consequences of proposed actions and the effectiveness of various options for counter-measures to protect and restore natural heritage assets (§ 1500.1).

In light of anticipated increases in offshore wind farm applications in the near future, as well as the ambitions of the CEQ regulations above, the Bureau of Ocean Energy Management (BOEM) has recognized the need to streamline the preparation, review and analysis of associated environmental information and impacts and has initiated studies to identify research that could improve efficiencies in NEPA documentation, lessen the regulatory and stakeholder review burden and ameliorate the permitting process while still performing an informed quality study.

In order to achieve this, Fugro has recognized that it will be highly advantageous to remove some elements from repeated study, especially where perceived concerns have not been realized following post-construction monitoring campaigns. A suitably robust evidence base of environmental monitoring should be able to demonstrate consistent impacts for given receptors, conditions, geographic locations and vulnerabilities. In particular, it may be possible to reduce certain aspects of planned activities, or environmental components, from the consideration of NEPA analysis where the following conditions exist:

- Precedent;
- High confidence in the baseline environmental data;
- Receptor similarity of conditions;
- A robust design envelope; and
- Effective and agreed mitigation which may need to be conditioned within the final Construction and Operations Plan (COP) permit.

Fugro has therefore proposed to conduct a review of environmental monitoring of operational wind farms and to compile a robust evidence base comprising suitable case studies for review during the NEPA process. The case studies will focus on instances where some or all of the above conditions have been met and will draw upon nearly 20 years of European experiences of monitoring and measuring the environmental impacts of offshore wind construction and operation. It is intended that the case studies will not only serve as valuable reference material for use by authors to streamline impact analysis procedures but also as sources of empirical evidence of impacts, or lack of impacts, for presentation during stakeholder engagement and consultation.

This document is an initial report to describe the information that is currently available for use by Fugro to underpin the case studies and highlights possible data gaps that might otherwise support strong conclusions regarding the possible reduction of efforts to review certain aspects from the NEPA scope.

1.1 AIMS AND OBJECTIVES

The aim of this document is to present a concise summary of the information currently available for subsequent case study building and to highlight any important data gaps in the evidence base. This has been achieved by completing the following objectives:

- Review of information drawn from environmental monitoring studies of European offshore wind farms, principally to include field monitoring reports but also environmental impact statements, licence conditions and academic research;
- Identification of other sources of information and highlight their relevance to the current project and case study building. This may include the results of recent monitoring that completes, or significantly enhances, time-series data or which are of relevance to US conditions; and
- Identification of data gaps in the evidence base.

1.2 SCOPE OF THIS REPORT

This report reviews permitting and monitoring reports from offshore wind licence compliance monitoring campaigns within Europe where the longest history of operational wind farms, and hence environmental monitoring, exist. These reports have been commissioned and completed by developer organisations as part of their obligations under the terms of their specific licences to construct and build an offshore wind farm in European waters and in compliance with respective consent application procedures. In addition to these mandatory reports, a number of independent research projects and complementary joint industry partnerships have been completed in Europe to identify and evaluate the environmental effects of offshore wind farms and which are also introduced here. Information is therefore presented within a European context and relates to European species, habitats and value systems.

This document is organized into several key marine environmental chapters representing the key topics typically affected by offshore wind farm construction and operation and which are normally addressed during NEPA review as follows:

- Physical processes;
- Underwater noise;
- Benthic ecology;
- Fish and shellfish ecology;
- Birds; and
- Marine mammals.

Other NEPA topics such as view-sheds, commercial fisheries, marine archaeology, other users, and terrestrial ecology are outside of the scope of this current study. Only marine aspects of the topics above are covered here.

For each topic, information is presented on the basis of whether it is currently available to the study, whether it will be acquired during the course of the study and whether it is unlikely to be accessible to the study.

There are currently 3,230 wind turbines installed across 84 offshore wind farms in 11 European countries. A further 6 offshore wind farms are scheduled for constructed this year (EWEA, 2016). The review presented here is therefore unlikely to be exhaustive as new monitoring is continuously being undertaken and updated. Instead the study identifies those wind farms which have been already well studied and where a time series of monitoring information exists.

The stages of development covered in this study include construction and initial operation (in general up to 3 or 4 years post-construction). Large scale decommissioning of offshore wind has not taken place in Europe and thus observation of environmental effects of this activity have not been recorded. The closest analogue to this, is the decommissioning of five very shallow water turbines at the Yttre Stengrund wind farm in Sweden and two turbines in Liverpool Bay (UK). The Vindeby offshore wind farm in Denmark is being prepared for decommissioning in the near future. Environmental impacts of larger scale decommissioning are therefore currently not known but is currently accepted to be generally comparable to or within those associated with the construction phase in terms of spatial scale and magnitude.

Similarly, there are no operational, large scale, commercial floating wind farm array and so impacts associated with these facilities that are dissimilar to pile foundation turbines have not been observed or measured. Statoil’s Hywind project (five floating turbines off the east coast of Scotland) has recently been awarded planning consent with commissioning due in 2017. While this presents a good opportunity to monitor impacts associated with floating turbines, these data will not be available within the timeline of this study. Two further Scottish floating offshore wind farms are currently in planning.

2. METHODOLOGY AND RATIONALE

2.1 DATA COLLECTION

Although some differences in process and execution exist, all countries in Europe where offshore wind farms have been built and are operating, have commenced a program of environmental monitoring for the purposes of the following broad aims:

- Validation of predictions of environmental impacts made in EIS documents;
- Reduction of uncertainty;
- Informing policy, management and design of future offshore wind farms; and
- Assessment of the effectiveness of mitigation.

In the United Kingdom (UK), Renewable UK (industry trade body) produced a review of consenting lessons learnt (Renewable UK, 2011) which highlighted the need to understand the evidence gained from data collection associated with licence conditions, and to refine and improve data collection strategies. In response to this, and other policy reviews, the UK government agencies, headed by the Marine Management Organisation (MMO), commissioned Fugro to lead a review of the available offshore wind farm monitoring data produced to date and to provide a series of recommendations to improve future monitoring strategies. This resulted in the acquisition of reports describing the results of licence condition monitoring of the environmental impacts of offshore wind farms, primarily in the UK, with some additional information drawn from other European countries for comparison and context. Fugro completed the review in 2013 and the associated report was published within the public domain in 2014.

Much of the information used to complete this review remained in Fugro's possession and it is this material that has been re-used in the current project. On this occasion the information has been re-visited to draw out empirical evidence of environmental change as well as instances where repeated study has revealed no impact or only minor consequences on receptors. As noted at the time, much of the environmental monitoring data underpinning the previous MMO review was derived from studies at smaller offshore wind farms which are located in comparatively shallow water and close to shore. More recent data is required to supplement that already held by Fugro, complete existing time series datasets and to describe impacts associated with larger wind farm arrays located in deeper waters.

2.2 DATA SOURCES

The last few years (2013 to present) will have resulted in additional monitoring reports currently outside the public domain as each wind farm has completed its required construction and post-construction monitoring. The main government body in the UK responsible for signing off and holding required monitoring reports is the MMO. Once the reports have been signed off, they are to be accessible to the public on request. This study will include liaising directly with the MMO to obtain all of the reports which are currently available but which Fugro does not hold.

In addition to the MMO, there are a number of other information sources that will be interrogated for new monitoring reports and data as described below. A number of data sources are specific for the topic in question and have been identified in the following topic specific chapters. However, there are several resources available holding data relevant to all topics considered here as outlined below.

Marine Data Exchange (UK)

The Marine Data Exchange is a searchable web information portal hosted by The Crown Estate. It holds survey data and reports collated during the application, construction and operation of offshore wind farms in the UK (see http://www.marinedataexchange.co.uk/). All offshore wind farm developers are obligated to provide all the survey data that they have collected to the Marine Data Exchange on award of their licence. Data are available on an open source basis to facilitate knowledge sharing and reduce industry expenditure, time and duplication of effort.

Collaborative Offshore Wind Research into the Environment (COWRIE) (UK)

The Crown Estate, a collection of lands and holdings belonging to the British monarch, manages leasing of the seabed in the UK. COWRIE (Collaborative Offshore Wind Research into the Environment) was set up by The Crown Estate as an independent body to carry out research into the impact of offshore wind farm development on the marine environment and wildlife. The research initiative was established in 2001 and was initially tasked to identify and address issues for which little or no prior knowledge existed, fill these data gaps and identify potential mitigation measures to ensure offshore wind development is undertaken in a sustainable manner and to assist the preparation of impact analyses for the early Round 1 offshore wind farm developments. Priority areas for research related to impacts on birds, marine mammals and fish. Further funding and expansion of COWRIE's remit, including the establishment of a number of specialist technical working groups, was achieved following the successful leasing of larger Round 2 and 3 offshore wind farm developments. The expanded work conducted by COWRIE included development of a coherent research program, management and dissemination of environmental data and education and outreach.

Since 2001 the COWRIE initiative has resulted in a comprehensive body of peer reviewed studies on the impacts of offshore wind farm as well as guidance documents and best practice. These studies are publically available and will be used to supplement the empirical observations drawn from the reviews of the licence site specific monitoring in support of the development of the subsequent case study report (see https://www.thecrownestate.co.uk/energy-minerals-and-infrastructure/downloads/cowrie/).

The Royal Belgium Institute for Natural Sciences (RBINS)

The Management Unit of the North Sea Mathematical Models (MUMM) is part of the Operational Directorate Natural Environment of the Royal Belgium Institute for Natural Sciences (RBINS). It has responsibility for coordinating a comprehensive program of licence compliance environmental monitoring of offshore wind farms in the Belgium sector. The program commenced in 2005 and focuses on physical (hydro-geomorphology), underwater noise, benthic ecology, fish, seabird and marine mammal issues. The program aims to provide information that enhances understanding of the environmental impacts of offshore wind farms to inform policy, management and future design and to allow for the application of appropriate mitigation to even halt activities in the case of extreme damage to the ecosystem occurs.

There have been a number of outputs from the monitoring program to date comprising mostly research papers on selected scientific targets and which are integrated into annual environmental reports. The latest integrated reports available currently available to this study continue to build upon the developing understanding of the impacts of offshore wind farms including benthic relationships, interactions with harbor porpoise and development of seabird monitoring techniques (see https://www.naturalsciences.be/en/science/do/98/page/2493).

The Vindval Research Program (Sweden)

The Vindval program is a partnership between the Swedish Energy Agency (Energimyndigheten) and the Swedish Environmental Protection Agency (Naturvårdsverket) (2005 – 2018). It aims to investigate whether wind power causes any negative effects on the environment and how such effects can be counteracted and/or reduced. The program has funded about thirty projects, half of which were related to offshore wind power (see http://www.naturvardsverket.se/CWE2013/About-Vindval/).

Alpha Ventus (Germany)

Thirteen offshore wind farms are currently operational in Germany, ranging in capacity from 2.5 MW (Breitling) to 400 MW (Bard and Global Tec). Total capacity is currently 2,695 MW; 96% (or 2,574 MW) of which was commissioned after 2012. Reports of the environmental monitoring for these wind farms are not publically available however, research by the Alfred Wegener Institute in Bremerhaven has focused on the Alpha Ventus wind farm, with twelve turbines generating 60 MW near Borkum since 2010 and is published here http://www.bsh.de/de/Meeresnutzung/Wirtschaft/Windparks/Windparks/Projekte/StUK3/index.jsp. The following conference paper provides a useful overview of wind farms in Germany.

- Lüdeke (2015). A Review of 10 Years of Research of Offshore Wind Farms in Germany: The State of Knowledge of Ecological Impacts. Conference: 8th International Conference on Environmental and Geological Science and Engineering, At Salerno, Italy (June 2015). Volume: Advances in Environmental and Geological Science and Engineering.

The Monitoring and Evaluation Program (NSW-MEP) (Netherlands)

The Egmond aan Zee offshore wind farm is linked to a comprehensive Monitoring and Evaluation Program (NSW-MEP), which started during construction in 2006 and ran until 2012. It was planned that experience gained from the project would be used to develop wind energy in the Netherlands, and the Dutch Ministry of Economic Affairs therefore designated it as a Demonstration Project. Further information can be found here http://www.noordzeewind.nl/en/knowledge/reportsdata/

Scottish Offshore Renewables Research Framework (SpORRAn) (Scotland)

The Scottish Offshore Renewables Research Framework is led by Marine Scotland and draws together experts from academia, government and industry to identify research priorities to facilitate the sustainable development of offshore renewables in Scotland and to inform future plans and projects. The framework compromises seven specialist receptor groups addressing key themes including marine mammals, ornithology, benthic ecology, commercial species, diadromous fish, socio-economics and physical processes (hydrology and geomorphology). The framework and specialist groups were only initiated this year (2016) and so no research outputs are available as yet.

International or General

General research, policy and advice is also available as summarized below:

- BAILEY, H., et al., (2014). Assessing Environmental Impacts of Offshore Wind Farms - Lessons Learned and Recommendations for the Future. *Aquatic Biosystems.* 10:8

- BROUGHTON, K., (2012). *Science Review of Artificial Reefs.* US Marine Sanctuaries Conservation Series, Office of National Marine Sanctuaries.
- ELLIOTT, M., (2002). The Role of the DPSIR Approach and Conceptual Models in Marine Environmental Management - an Example for Offshore Wind Power. *Marine Pollution Bulletin.* **44**, pp. iii–vii
- HAMMAR, L., et al., (2016). Offshore Wind Power for Marine Conservation. *Open Journal of Marine Science.* **6**, pp. 66-78.
- LANGHAMER, O., (2012). Artificial Reef Effect in Relation to Offshore Renewable Energy Conversion - State of the Art. *The Scientific World Journal 2012.* pp. 1-8.
- LEFCHECK, J.S., et al., (2015). Biodiversity Enhances Ecosystem Multifunctionality Across Trophic Levels and Habitats. *Nature Communications.* DOI: 10.1038/ncomms7936.
- LINDEBOOM, H.J., et al., (2014). Offshore Wind Park Monitoring Programmes, Lessons Learned and Recommendations for the Future. *Hydrobiologia.* **756**, pp. 169.
- OSPAR Commission, (2008). *Assessment of the Environmental Impact of Offshore Wind-Farms.* London. ISBN 978-1-906840-07-5.
- OSPAR Commission, (2008). *OSPAR Guidance on Environmental Consideration for Offshore Wind Farm Development.* London. Reference number: 2008-3.
- OSPAR Commission, (2010). *Other Human Uses and Impacts. In: Quality Status Report.*
- ROTH, E.M., et al., (2004). *Overview of Environmental Impacts of Offshore Wind Energy. Concerted Action for Offshore Wind Energy Deployment (COD).* EC Contract NNE5-2001-00633.
- WILHELMSSON, D., et al., (eds.) (2010). *Greening Blue Energy: Identifying and Managing the Biodiversity Risks and Opportunities of Offshore Renewable Energy.* Gland, Switzerland: IUCN. pp. 102.

2.3 APPRAISAL OF DATA GAPS

An understanding of the limitations of the data acquired is important to ensure that any conclusions drawn are not based on weak or missing evidence. Gaps in knowledge and limitations to the information collected to date have been described under each topic chapter.

In addition to topic specific limitations, it is important to note that most (80%) of the turbine foundations installed across Europe are monopiles while approximately 9% of the installed foundations are gravity bases. Jacket foundations account for around 5%. Tripods and tripiles make up the remaining 6%. As such, the majority of environmental impact data currently available relates to monopile foundations. So far in the US, only jacket foundations have been installed at Block Island wind farm and as such some caution may need to be exercised when comparing European and US experiences where the installation and operational (and removal) design and execution may have differing impacts.

3. PHYSICAL PROCESSES

3.1 INTRODUCTION

This section provides an overview of currently available data and reports regarding potential impacts of offshore wind on coastal and marine physical processes. It will also highlight where there are current data gaps, how additional studies and monitoring reports will prove valuable in reducing uncertainty and examples of joint industry partnerships where research is being conducted on physical processes and offshore wind. This review and gap analysis is primarily derived from existing UK based monitoring studies, with some additional reports from elsewhere in Europe.

In general, physical processes monitoring requirements (which often include pre-construction, during construction and post-construction phases) for offshore wind fall into four main categories. These are:

- Seabed scour (associated with turbine foundations, integrity of export and inter-array cables and, to a lesser extent, monitoring of post-storm changes);
- Suspended sediment concentrations (mostly attributed to construction-phase cable burial and turbine foundation activities, with potential impacts on shellfish, spawning grounds and other sensitive seabed receptors);
- Changes to tidal currents and the formation of wakes (associated with offshore wind structures); and
- Coastal monitoring (with emphasis on shoreline stability for nearshore wind farms; assessment of potential impacts on protected coastal sites and sandbanks; and ensuring proper export cable burial at landfall locations).

Marine geophysical techniques are commonly adopted for physical processes monitoring. These have included single and multibeam bathymetry for scour measurements, optical backscatter to measure suspended sediments and a range of fixed and towed current profilers to measure currents and wake. Traditional beach profiling, aerial photography and geographic information systems (GIS) is employed for coastal monitoring. These methods were often coupled with numerical modelling predictions within environmental statements (ES) to assess potential change.

It should be noted that not every consented wind farm in the UK required monitoring for all of the aspects listed above. For example, scour monitoring and changes to suspended sediment concentrations was required for almost all of the studied sites, whereas coastal monitoring, currents and wake monitoring was only required in a few cases (refer to Table 3.1).

3.2 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Offshore wind permitting and monitoring reports summarizing physical processes which are currently held by Fugro are summarized in Table 3.1. The table provides an overview of approximately 20 fully operational Round 1 and Round 2 offshore wind farm sites from the UK, up until 2013. Available reports include ES, License Conditions and Monitoring Reports for various phases of each development. Additionally, the last column in Table 3.1 provides information on what type of physical process monitoring was required (e.g. scour and suspended sediment concentrations) according to each wind farm's license conditions.

ES and Licence Conditions are available for all of the listed wind farms, as are the monitoring reports for many of the earlier developments. However, many of the monitoring reports from 2009 onwards are currently not held by Fugro, but it is likely that many of these will be available on request, assuming monitoring requirements have been completed. As part of this study, Fugro will be requesting these reports.

Table 12.1: Summary of Information Available for the Characterization and Monitoring of Physical Processes at UK Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Type of Monitoring
North Hoyle	30	60	5-12	7	2003	1	Y	Y	P	P	P	P	Y	Scour, SSC
Scroby Sands	30	60	0-8	2.5	2004	1	N	Y	N/A		P	Y		Scour, SSC
Kentish Flats	30	90	3-15	10	2005	1	Y	Y	Y	Y	Y	Y	Y	Scour, SSC
Barrow	30	90	15-20	7	2006	1	Y	Y	Y	N/A	Y	Y		Scour, SSC, C&W
Burbo Bank	25	90	0-6	7	2007	1	Y	Y	Y	Y	Y	Pl	Y	Scour, SSC, C&W
Lynn & Inner Dowsing	54	194	6-11	5	2008	1	Y	Y	Y	Y	Y	Y	Y	Scour, SSC, C&W
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y	Y	Y	Y	Y	Y	Scour, SSC
Gunfleet Sands II						2	Y	Y	Y	Y	Y	Y		Scour, SSC
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y	Y	Y	P	Y		Scour, SSC, C&W
Robin Rigg	60	180	0-12	?	2009	1	Y	P			Y			Scour
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y	P					Scour, SSC
Thanet	30	150	20-25	11	2010	2	P	Y	Y					Scour, SSC
Ormonde	30	150	17-22	9.5	2011	1	Y	Y	Y					Scour, SSC
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y						Scour, SSC, Coastal
Walney 1 & 2	51	367	21-50	14	2011	1	Y	Y	P		P			Scour, SSC
London Array	175	630	0-25	20	2012	2	Y	Y						Scour, SSC
Teesside	27	62	7-15	1.5	2012	1	Y	Y						Scour, SSC, Coastal
Gwynt y Môr	160	576		13	2013	2	Y	Y						Scour, SSC
Lincs	75	270	10-15	8	2013	2	Y	Y						Scour, SSC
West of Duddon	108	389	17-24	15	2013	2	Y	Y						Scour, SSC

Notes

Y= report available; P = partial report available; Scour = Seabed scour; SSC = Suspended sediment concentrations; C&W = Changes to tidal currents and the formation of wakes

Other European countries which currently have fully operational offshore wind developments include Denmark, Sweden, Germany and Belgium. Fugro holds a number of non UK monitoring reports (or summaries thereof) which will be used as part of the overall review. These are briefly summarized in Table 3.2 below.

Table 12.2: Summary of Non UK Offshore Wind Monitoring Studies Held by Fugro

Country	Offshore Wind Farm	Source	Summary of Physical Processes Monitoring
Denmark	Anholt	Energinet (2009). Anholt Offshore Wind Farm – Hydrography, sediment spill, water quality, geomorphology and coastal morphology.	Currents and waves, sedimentation, coastal stability, seabed morphology and scour.
Denmark	Nysted	Energi E2. Annual Status Report Nysted Offshore Wind Farm Environmental Monitoring Program (2001, 2002, 2003,2004).	Construction phase sedimentation, operational effects on coastal morphology.
Sweden	Lilligrund	Vattenfall (2009). Environmental Monitoring – Lillgrund Offshore Wind Farm.	Construction phase monitoring of dredging and spillage, suspended sediments, sediment deposition, coastal stability.
Belgium	Various	Degraer et al, (2012). Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea.	Hydro-geomorphology.

3.3 POTENTIAL DATA TARGETS

Fugro will endeavor to obtain new additional monitoring reports from the UK and other countries such as Denmark, the Netherlands and Belgium to update current knowledge and provide further evidence of effects of offshore wind farms on physical processes to underpin the subsequent case studies. Some of the offshore wind farms from countries outside of the UK have used different foundation types compared to traditional monopile types that have been installed in the UK, so construction and operational impacts of these wind farms may yield additional insight into physical impacts on the marine environment. It should be noted that to date it has been particularly difficult to obtain ESs or monitoring reports from Germany.

We expect to be able to obtain or locate new reports from a variety of sources, including:

- The MMO;
- The Crown Estate (UK);
- Marine Scotland Licensing Operations Team;
- The Danish Energy Agency;
- Tethys (DOE);
- C4 Offshore (global offshore wind database); and
- Directly from developers or via their websites.

The additional UK reports will enhance our existing knowledge of potential effects on physical processes, since many of the reports will include Round 2 sites, which are typically larger and located in deeper water than those developed during Round 1. Furthermore, these newer monitoring reports may provide insight into consistency of offshore wind effects (e.g. scour); the effects of larger foundations on physical processes and new efficient, and accepted, monitoring methods. Some of these more recent monitoring reports may also provide additional insight distinct hydrodynamic (e.g. strong currents) and geological environments (e.g. sandbanks) which haven't been available to review.

In addition to the monitoring reports which individual developers are obliged to undertake as part of the licence commitments, there are also several joint industry partnerships which have been formed to assess the effects of offshore wind farms on the physical environment. Some of these initiatives are briefly summarized below.

Far and Large Offshore Wind (FLOW)

FLOW is a Dutch research program and joint industry partnership with the ultimate aim of reducing the cost of offshore wind energy. One of the initiatives is a scour protection study to develop scour prediction models and optimization of scour protection design, coupled with development and application of continuous scour monitoring and measurement systems. The partners involved in the scour protection study include Deltares, Eneco, TU Delft and Van Oord. More information can be found at: http://flow-offshore.nl/page/home-en

EXPOSURES

EXPOSURES is an EU-funded partnership between the University of Southampton IT Innovation and Marine South East. Some of the project aims are to focus on rapid and cost effective seabed monitoring systems and technology to measure scour, erosion and suspended sediments. For more information, refer to: http://www.it-innovation.soton.ac.uk/projects/exposures

Sandia National Laboratories

Sandia is a US federally funded research and development center owned by the Lockheed Martin Corporation. As part of their Energy and Climate group, they are currently undertaking research on offshore wind and sediment transport. They have three technical areas of interest which include:

- Structural design and regional sediment stability risk maps;
- Ecological risk associated with changes to wave propagation, flow and sediment circulation patterns; and
- Infrastructure risk and maintenance costs attributed to local scour.

Research partners include Fugro, Global Marine, Tetra Tech, Mott McDonald and Fishermen's Energy. More information can be found at: http://energy.sandia.gov/energy/renewable-energy/wind-power/offshore-wind/offshore-wind-rdd-sediment-transport/

COWRIE (Collaborative Offshore Wind Research into the Environment)

COWRIE is an independent body which was set up by The Crown Estate (UK) to research and evaluate potential impacts of offshore wind farm on wildlife and the environment. COWRIE produced a large number of research reports, covering a range of different receptors and effects. Some of these studies include sediment mobility and coastal processes modelling. These are freely available at: https://www.thecrownestate.co.uk/energy-minerals-and-infrastructure/downloads/cowrie/

3.4 APPRAISAL OF DATA GAPS

As more offshore wind farms are constructed around Europe, and monitoring is undertaken, it is expected that uncertainty in physical processes impacts should reduce considerably, allowing the regulators and developers to focus their monitoring on those areas where high uncertainty remains. For example, previous studies in the UK have shown that scour extent around foundations and construction related suspended sediment concentrations are often localized, short term, predictable and relatively easily calculated based on engineering design, hydrodynamics and geological substrate type.

In contrast, there is still some uncertainty about longer term impacts, for example on highly mobile substrates such as large sandbanks, especially as wind farms continue to grow in size and are developed on these dynamic environments. It will be particularly important to evaluate predictions and monitoring results from future Round 3 offshore wind farms in the UK which are much larger and located much further offshore than anything that is currently in operation. Cumulative effects monitoring also continues to be an active area of research due to the lack of any real-time empirical data from multiple neighboring wind farms.

To date it has also been difficult to confirm the validity of numerical modelling predictions/results with empirical data. It is postulated that once these comparisons have been undertaken and validated, the scientific community's confidence in these models will increase; this could potentially result in a decrease in expensive ship-based surveys. As developers explore new ways to monitor their windfarms and predict the impacts presented in their EIS, their methods may be adopted successfully elsewhere for future wind farm monitoring, emphasizing the importance of adaptive management. High resolution satellite imagery and unmanned aerial surveys (a.k.a. drones) may also reveal new novel, and less expensive, techniques to obtain and monitor physical marine data. The role of high magnitude storms and sea level rise on coastal processes with regard export cable integrity at landfall sites should also be assessed carefully to inform future developments.

4. UNDERWATER NOISE

4.1 INTRODUCTION

This section describes the data which have been acquired at this stage for review of the measurements of underwater noise arising from offshore wind farm construction and operation. For the purposes of this study, only data relevant to the assessment and measurement of underwater noise as it relates to offshore wind developments has been reviewed. Airborne noise, i.e. noise produced offshore and transmitted above water, is not considered.

Over the last 10 years, through advances in research, there has been significant development in modelling performance, techniques and thresholds related to marine species used to assess the impact of the introduction of the wind farm, with stakeholders and their advisors becoming better informed of the issues.

In general, the basic processes leading to a consent decision, and the requirements of a licence issued, in relation to underwater noise and offshore wind farms are replicated across countries in Europe. The predicted impact of noise during offshore wind farm construction, its operational phase and sometimes decommissioning is calculated using modelling software, of which a variety of modelling software and techniques are used by the assessing organization. Consent decisions are based on the extent of the predicted impact, which is related to the level of noise at its source position and how rapidly this noise is attenuated over range. This attenuation is dependent on environmental conditions in the water, for example water depth.

During construction and operation of the OWF, the underwater noise levels are monitored to verify that the predictions made in the assessment are reasonable, and any conditions applied to the development in the licence are not breached. The specifics and strictness of the requirements and the extent to which they have been monitored vary from country to country.

The requirement to monitor underwater noise during construction of the wind turbines tends to focus on the installation of the foundations; as a rule, this is the greatest single source of noise for the entire project. Conditions attached to licences allowing for wind farm construction and operation usually require monitoring of some or all of the foundations installed. The requirement is often vague and how the monitoring is conducted varies from site to site and country to country, and thus many datasets are not readily comparable. Monitoring underwater noise during the wind farm's operational phase is sometimes required.

Reports detailing the requirements that have been placed on developers, the ways impacts have been mitigated and results of monitoring undertaken have been collected and are described below.

4.2 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Table 4.1 summarizes the data currently available for review.

Table 12.3: Summary of Information Available for the Characterization and Monitoring of Underwater Noise at UK Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round (UK)	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
North Hoyle (UK)	30	60	5-12	7	2003	1	Y	Y					Y	
Scroby Sands	30	60	0-8	2.5	2004	1	N	Y						
Kentish Flats	30	90	3-15	10	2005	1	Y	Y			Y	Y	Y	
Barrow	30	90	15-20	7	2006	1	Y	Y			P			
Burbo Bank	25	90	0-6	7	2007	1	Y	Y			P			
Lynn & Inner Dowsing	54	194	6-11	5	2008	1	Y	Y				Y		
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y		Y	Y	Y	Y	
Gunfleet Sands II						2	Y	Y		Y	Y	Y	Y	
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y						
Robin Rigg	60	180	0-12	11	2009	1	Y	P		Y	Y			
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y		Y				
Thanet	30	150	20-25	11	2010	2	P	Y		Y				
Ormonde	30	150	17-22	9.5	2011	1	Y	Y		Y				
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y						
Walney 1	51	367	19-30	14	2011	1	Y	Y		P				
Walney 2	51					2	Y	Y		P				
London Array	175	630	0-25	20	2012	2	Y	Y						
Teesside	27	62	7-15	1.5	2012	1	Y	Y		Y				
Gwynt y Môr	160	576	13-32	13	2013	2	Y	Y						
Lincs	75	270	10-15	8	2013	2	Y	Y		Y				
West of Duddon	108	389	17-24	15	2013	2	Y	Y						
Race Bank	91	573	6-24	27		2	Y	Y		Y				

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round (UK)	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
Burbo Bank Ext	32	254	2-14	6		2.5	Y	Y	Y	Y				
Westermost Rough	35	210	10-25	8	2015	2	Y	Y						
Humber Gateway	73	219	10-18	10	2015	2	Y	Y						
Gunfleet Sands III (Demo)	2	12	5-12	8	2013		Y	Y			Y			

Notes

Y= report available; P = partial report available

The table shows a list of 26 offshore wind farm developments in the UK. These assessments of impact and results of underwater noise monitoring are from the UK, which began large scale construction of offshore wind farms earlier than other countries, as well as having a larger availability of coastline to install them. Further details on offshore wind farms in Belgian, Danish, Dutch and German waters are referenced below.

For this list, data and reports for the environmental impact assessments, consent and any monitoring undertaken is available for most of the offshore wind farms. The data typically contains an Environmental impact assessment (EIA), although the level of detail and complexity of the assessments tends to increase in more recent years as the level of knowledge, depth of research and understanding of the subject of underwater noise impact on marine fauna has increased. There is greater general availability of EIS reports than reports detailing the monitoring of offshore wind farm construction. There have been relatively few studies for noise emissions during turbine operation compared to during construction.

Recent meta-studies, including Bailey et al. (2014) "Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future" and the 2014 study by Pondera Consult "Underwater noise caused by pile driving impacts on marine mammals, regulations and offshore wind developments" will provide a useful starting point for putting together case studies.

A selection of reports that have been acquired with additional information for countries in mainland Europe are identified below:

- Bligh Bank and Thorntonbank (Belgium). Underwater noise measurements of baseline and early construction at these two wind farms in Belgian waters;
- Anholt (Denmark). Underwater noise measurements during piling have been acquired as a validation of noise modelling;
- Alpha Ventus (Germany). Results are available for studies of the measurement of underwater noise during construction of the first offshore wind farm in German waters; and
- Egmond aan Zee (Netherlands). Reports are available for the EIA, construction and operational phases of the first large scale wind farm in Dutch waters.

4.3 POTENTIAL DATA TARGETS

Table 4.2 presents sources of other information relevant to the monitoring and measurement of underwater noise of offshore wind farms and which will be pursued to further support the case studies.

Table 12.4: Sources of Information Relevant to the Monitoring of Underwater Noise from Offshore Wind Farm Construction and Operation

<table>
<tr><th>Wind Farm Identity/ Title of Study</th><th>Type of Document (Research Paper/ Monitoring Report/ES)</th><th>Relevance to Current Study</th><th>Method of Acquisition (Data Request/Web Site)</th></tr>
<tr><td>Wikinger (Germany)</td><td rowspan="4">Environmental impact assessments</td><td rowspan="4">Further details required for other European countries, especially outside the North Sea.</td><td rowspan="4">Direct contact with local sources, web search.</td></tr>
<tr><td>Lillgrund (Sweden)</td></tr>
<tr><td>Utgrunden (Sweden)</td></tr>
<tr><td>AVEC 1 and 2</td></tr>
</table>

(Lithuania)			

Data are available from the major non UK European countries developing offshore wind capacity, namely Germany, Netherlands and Denmark, and further searches will be conducted to acquire more comprehensive information on the situation in respect to construction and operational noise monitoring in these countries' waters. No data has yet been acquired for a small number of other nations, for example Sweden, France and Lithuania, although the data is expected to be limited to EIA, and potentially baseline noise levels. Further investigations will be made through contacts in the underwater noise monitoring equipment industry in France, colleagues elsewhere in Scandinavia and in Latvia, with potential connections to Lithuania. Additional web searches will be conducted.

4.4 APPRAISAL OF DATA GAPS

Table 4.3 presents known information relevant to the monitoring and measurement of underwater noise from but which is unlikely to be accessible during the timeframe of the current study.

Table 12.5: Gap Analysis Showing Inaccessible Information on the Monitoring of Underwater Noise from Offshore Wind Farms

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Appraisal of Limitation
Race Bank	Underwater noise monitoring report during construction phase	Empirical observations during the most recent offshore wind farm installations using impact piling with very high blow energies and large piles.	Data collection either very recently undertaken or still in progress and not publically released.
Burbo Bank Extension			
Dudgeon			
Horns Rev 3			
Wikinger			
Baltica 2 and 3	EIA and proposals for underwater noise requirements	No knowledge of proposals in Poland.	No data found.
Block Island	Underwater noise monitoring report during construction phase	Comparative situation in the USA.	Permission to release data required.

Monitoring of the construction and operation of offshore wind farms in Europe are in progress in multiple locations and data is being acquired at the time of writing. The acquisition of detailed data recorded during the installation and operation of turbines was presented in reports but the raw data itself is rarely published. Within the UK this data is requested and stored by the Crown Estate via the Marine Data Exchanges (see above), although its release may not be possible within the timeline of this study.

Most of the assessment and monitoring work relating to underwater noise in Europe and the United States has been undertaken by a small number of specialist organisations such as Subacoustech and Gardline in the UK, ITAP and BioConsult in Germany, DHI and Ramboll in Denmark, MAI and TetraTech in the US. There are a number of wind farms currently under construction, including Race Bank and Burbo Bank and it may be possible to acquire reports of data not immediately available from these groups with permission from the client, or that can advise the appropriate international organisations or regulatory bodies that hold this information where distributable but not publically available. The review team has good links with the offshore wind farm developers, key amongst them

DONG Energy, and when it is understood that monitoring has been undertaken but not formally published, it will be attempted to source this data.

Considerable underwater noise data was collected by different groups during the installation of the Block Island wind farm in Rhode Island, USA both as part of the conditions for construction and under the BOEM real-time opportunity for development of environmental observations (RODEO) study. This has not yet been released publically, but it may be possible to gain permission to include it in this review.

Very few studies have been conducted during wind farm construction and operation on emissions in terms of subsea particle motion and seabed vibration. These metrics have not in general been required by regulatory consents as there are currently no available criteria to judge the severity or otherwise of impacts, nor is equipment to monitor it generally available. While data is limited, there is concern within the scientific community that noise measured as particle motion may be the most significant impact on fish. Currently, however, effects of particle motion and seabed vibration remain poorly investigated.

5. BENTHIC ECOLOGY

5.1 INTRODUCTION

This section describes the information and data currently acquired for a review of the impacts associated with offshore wind farm construction and operation relevant to benthic ecology. For the purposes of this review, benthic ecology refers to the macrofauna and flora generally larger than 1 mm in size inhabiting the seabed sediments or sediment/water interface, including the intertidal zone on installed structures.

Typical impacts addressed during impact analysis and assessment relate to the following:

- Habitat loss and disturbance;
- Introduction of hard substrata, habitat change and increase in growth of epibenthos;
- Water quality changes, sediment plumes and smothering; and
- Effects of electro-magnetic (EMF) and heat emissions from operational cables.

Benthic ecology data are typically collected in the field using several techniques based on the different benthic sub-components present including benthic grab sampling, epibenthic trawling, intertidal studies and colonization studies of introduced hard substrata (turbine foundations, and scour material). These techniques have been largely employed in a consistent manner across the different European sites although they have been performed somewhat perfunctorily with little or no regard to site specific conditions or local sensitivities, particularly in the UK. Only recently has there been a shift away from generic benthic surveys in marine licences in the UK to a more bespoke approach where developers are able to adapt and agree a survey design which references site specific impacts and concerns addressed in the EIS. This more adaptive approach is regarded as an improvement in benthic impact monitoring and impact assessment as the target feature is usually of specific interest to stakeholders and therefore relevant, results can be used to develop relevant mitigation measures and resources can be targeted more effectively.

5.2 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Table 5.1 summarizes the permitting and monitoring documents for 22 UK wind farm sites and 11 other European sites currently held by Fugro. These include EIS (including baseline monitoring data), licenses (with conditions and monitoring requirements), and monitoring reports for pre-construction, construction, and operations phases. A full set of reports is available for some sites (e.g. Barrow), while other sites are incomplete (e.g. where 3 years' operational monitoring is still ongoing, or where reports are not yet publicly available). Various other specialist studies are available for a number of the other European sites where specific research has been undertaken.

Table 12.6: Summary of Information Available for the Characterization and Monitoring of Benthos at UK Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
North Hoyle (UK)	30	60	5-12	7	2003	1	Y	Y	Y	Y	Y	Y	Y	
Scroby Sands	30	60	0-8	2.5	2004	1		Y			Y			
Kentish Flats	30	90	3-15	10	2005	1	Y	Y	Y		Y	Y	Y	
Barrow	30	90	15-20	7	2006	1	Y	Y	Y	Y	Y	Y	Y	
Burbo Bank	25	90	0-6	7	2007	1	Y	Y	Y	Y	Y	P	Y	
Lynn & Inner Dowsing	54	194	6-11	5	2008	1	Y	Y	Y			Y	Y	
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y	Y			Y		
Gunfleet Sands II						2	Y	Y	Y			Y		
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y	Y	Y	Y			
Robin Rigg E	60	180	0-12	11	2009	1	Y	P	P	P	Y	Y	Y	
Robin Rigg W						1	Y	P	P	P	Y	Y	Y	
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y						
Thanet	30	150	20-25	11	2010	2	P	Y	Y					
Ormonde	30	150	17-22	9.5	2011	1	Y	Y						
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y						
Walney 1	51	367	19-30	14	2011	1	Y	Y	Y	Y				
Walney 2	51					2	Y	Y	Y	Y				
London Array	175	630	0-25	20	2012	2	Y	Y	Y					
Teesside	27	62	7-15	1.5	2012	1	Y	Y	Y					
Gwynt y Môr	160	576	13-32	13	2013	2	Y	Y	Y					
Lincs	75	270	10-15	8	2013	2	Y	Y	Y					

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
West of Duddon	108	389	17-24	15	2013	2	Y							
Bligh Bank	55	165	12-20	46	2010									Y
Thorntonbank	54	325	10-28	26	2012									Y
Northwind	72	216	15-23	37	2014									Y
Anholt	111	400	12-19	15	2013		Y		Y					
Horns Rev1	80	160	6-11	18	2002		Y		Y		Y	Y		Y
Horns Rev 2	91	209	9-17	32	2009		Y							Y
Nysted	72	166	6-10	11	2003				Y		Y	Y	Y	Y
Alpha Ventus	12	60			2010									Y
Egmond aan Zee	36	108	15-18	10	2007									Y
Lillgrund	48	110	4-13	11	2008									Y
Utgrunden	7	10	6-15	4	2000									Y

Notes

Y= report available; P = partial report available

In addition to the permitting and monitoring reports available (see Table 5.1) there has also been considerable research on this topic as a result of the various international research initiatives identified in Section 2 above. Material from these efforts are also available and will be reviewed during the development of the subsequent case study report. A summary of the research material available is provided below.

Belgium

- COATES. D., et al. (2011). *Soft-sediment Macrobenthos Around Offshore Wind Turbines in the Belgian Part of the North Sea Reveals a Clear Shift In Species Composition. In: Offshore wind farms in the Belgian part of the North Sea: selected findings from the baseline and targeted monitoring.* pp.47-63.
- DEGRAER, S. and BRABANT, R., (2009) *Offshore Wind Farms in the Belgian part of the North Sea - State of the Art after Two Years of Environmental Monitoring.* Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, & Marine Ecosystem Management Unit.
- DEGRAER, S., et al. (2012). *Offshore Wind Farms in the Belgian part of the North Sea - Heading for an Understanding of Environmental Impacts.* Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, & Marine Ecosystem Management Unit.
- KERCKHOF, F., et al., (2011). *Offshore Intertidal Hard Substrata - a New Habitat Promoting Non-Indigenous Species in the Southern North Sea - an Exploratory Study.* In: S. Degraer et al. (ed.). Offshore wind farms in the Belgian part of the North Sea: selected findings from the baseline and targeted monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, & Marine Ecosystem Management Unit. Brussels. pp. 157.
- VANDENDRIESSCHE, S., et al., (2014). Equivocal Effects of Offshore Wind Farms in Belgium on Soft Substrate Epibenthos and Fish. *Hydrobiologia.* **756**, pp. 19-35.

Denmark

- BIRKLUND, J., (2009). *Anholt Offshore Wind Farm - Benthic Fauna – Baseline Surveys and Impact Assessment.* DHI Group.
- HOFFMANN, E., et al. (2000). *Effects of Marine Windfarms on the Distribution of FISH, Shellfish and Marine Mammals in the Horns Rev area.*
- LEONHARD, S.B., (2000). *Horns Rev 1 Offshore Wind Farm - EIA of Sea Bottom and Marine Biology.* Bioconsult.
- LEONHARD, S.B., et al. (2005). *Benthic Communities at Horns Rev Before, During and After Construction of Horns Rev Offshore Wind Farm – Annual Report 2005.* Bioconsult.
- LEONHARD, S.B., (2006). *Horns Rev 2 Offshore Wind Farm - EIA Report Benthic Communities.* Bioconsult.
- ENERGI E2 (2002; 2003; 2004). *Annual Status Reports - Nysted Offshore Wind Farm - Environmental Monitoring Program 2002 - 2004.*
- NIELSEN, S., (ed.) (2006). *Offshore Wind Farms and the Environment - Danish experience from Horns Rev and Nysted.* Danish Energy Authority.

The Netherlands

- BERGMAN, M.J.N., et al., (2010). *Impact of OWEZ Wind Farm on Bivalve Recruitment – Final Report.* NoordzeeWind.
- BERGMAN, M.J.N., et al., (2012). *Impact of OWEZ Wind Farm on the Local Macrobenthos Community.* NoordzeeWind.
- BOUMA, S. and LENGBEEK, W., (2009). *Development of Underwater Flora and Fauna Communities on HARD Substrates of the Offshore Wind Farm Egmond aan Zee.* Bureau Waardenburg b.v.
- BOUMA, S. and LENGBEEK, W., (2012). *Benthic Communities on Hard Substrates of the Offshore* (2012). *Benthic Communities on Hard Substrates of the Offshore Wind Farm Egmond aan Zee.* Bureau Waardenburg b.v.
- BRUIJS, M.C.M., (2010*). Survey of Marine Fouling on Turbine Support Structures of the Offshore Windfarm Egmond aan Zee, June 2009.* KEMA Nederland B.V.
- JARVIS, S., et al. (2004). *North Sea Wind Farms; NSW Lot 1 Benthic Fauna. Final Report.* Institute of Estuarine and Coastal Studies, University of Hull, England.
- LINDEBOOM, H.J., et al. (2011). Short-term Ecological Effects of an Offshore Wind Farm in the Dutch Coastal Zone - a Compilation*. Environmental Research Letters.* **6**, pp. 1-13.

5.3 POTENTIAL DATA TARGETS

Table 5.2 presents potential sources of other information relevant to the monitoring and measurement of effects of offshore wind farms on benthic ecology and which will be pursued to further support the case studies. Potential data targets for subsequent review under this project will comprise the most recent licence compliance monitoring reports for UK wind farm sites to complete these time series monitoring data and to update the current rationale for monitoring of the benthic ecology.

In the UK, there has been a shift from the more traditional before, after, control, impact (BACI) monitoring design of benthic communities over medium to broad spatial scales to more targeting of specific and localized habitat types and interest features, such as *Sabellaria spinulosa* (Ross worm) reefs which lie within, or close to, the predicted influences of proposed wind farm activities. Licence conditions for the construction and operation of offshore wind farms in the UK seemingly no longer require benthic ecology monitoring at medium and broad scales, but instead obligate the developer to conduct appropriate micro-siting of infrastructure to avoid direct impacts on designated or interest features together with targeted monitoring to record any change in their condition following construction of the wind farm.

Table 12.7: Sources of Information Relevant to the Monitoring of Effects of Offshore Wind Farms on Benthic Ecology

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Method of Acquisition (Data Request/Web Site)
Greater Gabbard	Licence compliance monitoring reports	Current monitoring rationale, key interest features and empirical observations.	Planning authority, lease agency and regulator web portals and information requests.
Thanet			
Ormonde			
Sheringham Shoal			
Walney 1			
Walney 2			
London Array			
Teesside			
Gwynt y Môr			
Lincs			
West of Duddon			

Up to date monitoring data from other ongoing programs across Europe will also be obtained for review and development of the case studies.

5.4 APPRAISAL OF DATA GAPS

There are already considerable quantities of research and monitoring data available on the impacts of offshore wind farm construction and operation on benthic ecology and the responses of habitats and communities are generally well understood. However, the monitoring undertaken to date has been relatively short term (up to 3 or 4 years) and has been conducted at the scale of the wind farm and surrounding seabed areas. There has been no longer term monitoring, (e.g. 5 years or more), so that the longer term effects of offshore wind farms on benthic ecology are not known. Similarly, the effects at the local turbine level are not known although some emerging research from the Belgium MUMM program provides some initial insight into possible local enrichment of soft sediment habitats. Specific research at the Block Island offshore wind farm (US) has been proposed under the current RODEO initiative to address these apparent data gaps although the results of this research are not expected to be available to this study. As such longer term and localized effects of offshore wind farms on benthic ecology remain unclear.

6. FISH ECOLOGY

6.1 INTRODUCTION

This section describes the data which have been acquired at this stage for review of impacts of offshore wind farm construction and operation on fish ecology. For the purpose of this study this topic covers fish and shellfish species and assemblages commonly found in European coastal waters and addresses aspects of ecology related to migration movements, spawning and nursery habitat and responses to underwater noise and habitat change. This topic does not cover commercial fishery issues or related socio-economic aspects.

The principal impacts identified and addressed in fish ecological impact assessments include:

- Injury, mortality and displacement due to adverse underwater noise from pile driving;
- Disturbance to, or loss of, critical fish habitat;
- Reef effects;
- Effects of electro-magnetic (EMF) and heat emissions from operational cables; and
- Water quality changes.

6.2 POTENTIAL DATA TARGETS

Similar to the benthic ecology topic above, additional fish ecology information is expected to derive from any recent relevant monitoring campaigns that have been conducted in the UK. Table 6.2 identifies operational UK wind farms for which monitoring data are absent or only partially completed and for which recent monitoring information is expected to have been conducted. A search of relevant web information portals will be conducted to identify and acquire these monitoring reports for these wind farms, where available, for review and consideration during the development of the subsequent case study report.

Table 12.8: Sources of Information Relevant to the Monitoring of Effects of Offshore Wind Farms on Fish Ecology

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Method of Acquisition (Data Request/Web Site)
Greater Gabbard	Licence compliance monitoring reports	Current monitoring rationale, key interest features and empirical observations.	Planning authority, lease agency and regulator web portals and information requests.
Thanet			
Ormonde			
Sheringham Shoal			
Walney 1			
Walney 2			
London Array			
Teesside			
Gwynt y Môr			
Lincs			
West of Duddon			

6.3 APPRAISAL OF DATA GAPS

Fish ecological monitoring at offshore wind farms have so far only been undertaken over comparatively short time frame (up to 3 or 4 years) so that the long term effects are not known. Data are currently only available for sites located in shallow water (<20 m) and extrapolating effect to larger and deeper water offshore wind farm is uncertain. In addition, there have been no studies correlating fish surveys with pile driving and so actual responses to underwater noise from construction activities remains unknown. It is also acknowledged that the effects of EMFs on migratory and electro-sensitive species is little researched.

7. BIRDS

7.1 INTRODUCTION

This section describes the data which have been acquired at this stage for review of the impacts of offshore wind farm construction and operation on seabirds.

For the purposes of this study this topic chapter encompasses all birds that have been assessed as being potentially affected by the construction and operation of offshore wind facilities including the following groups:

- Seabirds (auks, petrels, gulls, terns, gannets and skuas);
- Sea ducks (eider, scoter, mergansers etc.);
- Water birds (shorebirds, loons and grebes);
- Wildfowl (other species of duck, geese and swans);
- Passage birds that might travel through a site of a wind farm array either locally on a daily basis or during national or international migration; and
- Terrestrial species including passerines.

Impacts of offshore wind facilities on birds and which are typically addressed in impact assessments relate to:

- Visual and noise disturbances during construction and operational phases;
- Barrier effects to migration movements;
- Avoidance and displacement from preferred feeding and roosting areas;
- Collision with offshore infrastructure;
- Adverse effects on water quality and prey availability; and
- Provision of offshore roosting platforms.

This is a dynamic topic in terms of evolving data collection and treatment techniques. Examples of the evolution of these methodologies include the greater use of aerial surveillance and high definition imaging over vessel based observers for characterization surveys and monitoring as well as the development and acceptance of established guidelines for the use of predictive techniques such collision risk modelling. Radar tracking and thermal imaging techniques are also being trialed as to their effectiveness in monitoring changes in bird behavior within and around offshore wind turbine arrays for possible wider application on the future. An account of the different survey equipment and analysis methodologies, and their relative merits, is outside the scope of the forthcoming review. However, it is worth noting that the majority of the characterization and monitoring data currently available to inform the case studies has been collected using traditional vessel based observers while data from future monitoring campaigns will be derived from a combination of vessel observers and aerial surveillance or from aerial and other imaging technologies alone.

7.2 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Table 7.1 below summarizes the information currently available on the characterization and monitoring of birds at offshore wind farms sites. Currently, information is available for 22 UK wind farms although this may not necessarily include a full suite of monitoring reports for each individual wind farm site. This is primarily due to some wind farms not yet completing their monitoring programs and subsequent reporting, while some reports are not yet publically available.

Table 12.9: Summary of Information Available for the Characterization and Monitoring of Birds at Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
North Hoyle	30	60	5-12	7	2003	1	Y	Y	Y	Y	Y	Y	Y	
Scroby Sands	30	60	0-8	2.5	2004	1	N	Y	Y	Y	Y	Y		
Kentish Flats	30	90	3-15	10	2005	1	Y	Y	Y	?	Y	Y	Y	
Barrow	30	90	15-20	7	2006	1	Y	Y	Y	Y	Y	Y	Y	
Burbo Bank	25	90	0-6	7	2007	1	Y	Y	Y	Y	Y	Y	?	
Lynn & Inner Dowsing	54	194	6-11	5	2008	1	Y	Y	Y	Y	Y	Y	Y	
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y	Y	Y	Y	?	?	
Gunfleet Sands II						2	Y	Y	Y	Y	Y	?	?	
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y	Y	Y	Y	Y	?	
Robin Rigg E	60	180	0-12	?	2009	1	Y	P	Y	Y	Y	Y	Y	
Robin Rigg W						1	Y	P	Y	Y	Y	Y	Y	
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y	P	P	Y	Y	?	
Thanet	30	150	20-25	11	2010	2	P	Y						
Ormonde	30	150	17-22	9.5	2011	1	Y	Y	Y	Y				
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y						
Walney 1	51	367	19-30	14	2011	1	Y	Y	Y	Y				
Walney 2	51					2	Y	Y	Y	Y				
London Array	175	630	0-25	20	2012	2	Y	Y						
Teesside	27	62	7-15	1.5	2012	1	Y	Y						
Gwynt y Môr	160	576		13	2013	2	Y	Y	Y	Y				
Lincs	75	270	10-15	8	2013	2	Y	Y						
West of Duddon	108	389	17-24	15	2013	2	Y	Y						

Table 7.1 presents the monitoring data currently held by Fugro on the operational offshore wind farms in the UK. All of these developments have been subject to the EIA process, prior to the granting of development consent. The ES and ornithological chapters have been acquired by Fugro for the majority of the wind farms, as well as many of the associated technical appendices relating to ornithology.

Following development consent, developers have been required to discharge their consent conditions, for which every project has included a form of ornithological monitoring. A significant number of the UK offshore windfarms, notably the Round 1 developments, have completed their monitoring programs which span the pre-construction, construction and post-construction phases. Typically, developers have been obligated to undertake operational monitoring for a duration of three years, post-construction.

There is some concern that the monitoring period should be extended, as a 5-year period of monitoring might not be of a long enough duration to detect a population change as some seabird species are long lived, do not reach sexual maturity until age five and raise only one chick per annum. At present no offshore wind farm has been obliged to undertake extended monitoring.

7.3 RELEVANT RESEARCH

In addition to the licence condition monitoring that has taken place, a number of research initiatives have been funded and completed in Europe to determine the environmental impacts of offshore wind facilities. The following provides a summary of relevant research that has been conducted to further enhance understanding of the potential impacts of offshore wind farms on birds.

COWRIE

The Crown Estate established a fund in 2001 to start a research program looking at generic environmental issues effecting all offshore wind farm developments. Subject areas covered by COWRIE and papers that are available and relevant to impacts on birds include:

- Predicting the displacement of common scoter *Melanitta nigra* from benthic feeding areas due to offshore wind farms;
- Disturbance, barrier and displacement effects on wintering populations of trans-Atlantic species of sea duck; and
- Guidelines for the conduct of vessel based bird surveys.

Strategic Ornithological Support Services (SOSS)

The Crown Estate established the Strategic Ornithological Support Services (SOSS) group in 2010 to identify key ornithological issues relating to the expansion of the UK offshore wind industry, principally due to the Round 3 licensing round with potentially 25 GW of development. SOSS, with representatives from developer organisations, regulators and advisory bodies, oversaw a program of work to address these issues and inform the planning and consenting process. The key aim was to reduce the consenting risk posed by current critical gaps in knowledge of the effects of offshore wind farms on birds. Areas of work were as follows:

- *SOSS-01A: Collation and review of bird survey data from existing offshore wind farm sites to assess data suitability for estimating bird displacement rates:* this project assessed whether bird monitoring data from existing offshore wind farms could be used to estimate change in the use of the wind farm area by different bird species following construction. The project focused on a small number of offshore wind farms to see if analyses were possible and develop methods. The results showed that existing survey methods had low power to detect displacement, and made recommendations on how better to distribute survey effort (without spending more time/money) to allow better estimation of displacement in the future;
- *SOSS-02: A review of methods to estimate the risk of bird collisions with offshore wind farms:* this project provided a tool and guidance to standardize the way collision risk modelling is used and the way results are presented in EISs. Flight height distribution curves, which can be used to test the effect of different turbine designs on bird collision risk, were produced by combining information from surveys of many sites. A review of studies of avoidance rates was also produced;
- *SOSS-03A: Developing methods to monitor collisions of birds with offshore wind farms:* this project investigated potential methods to monitor collisions (or avoidance) of birds at existing offshore wind farm sites, and the sample sizes that would be required to improve estimates of avoidance rates and quantify how they may vary in response to environmental factors such as weather and season. It also estimated the monitoring time needed to achieve these sample sizes, provided information to help identify suitable study sites and bird species for any future study to focus on. The Crown Estate has produced a scope of work for a follow-up project to test the methods identified in the work, to monitor collision/avoidance of birds at existing offshore wind farm sites, and to calculate improved estimates of avoidance;
- *SOSS-04: Gannet population viability analysis (PVA) to assess the cumulative effect on the population from collisions with existing and planned offshore wind farms:* this project assessed the cumulative impact of all existing and consented offshore wind farms on UK gannet populations, and determined a threshold mortality rate that could be sustained from the cumulative effects of collisions with existing and future wind farm developments without causing population decline. It also developed guidance on the use of population viability analyses for birds at offshore wind farm sites; and
- *SOSS-05: Assessing the risk of offshore wind farm development to migratory birds designated as features of UK Special Protection Areas (and other Annex 1 species):* this project reviewed available information on over-sea migration routes, timings and the flight heights of migrating birds, water birds and terrestrial birds that are features of UK Special Protection Areas, and how these vary, for example in response to weather conditions. It has provided recommendations as to how this information should be used to assess the risks to migrants in the EIA process for offshore wind farm developments, and where further data collection would be required to assess the effects.

Offshore Renewables Joint Industry Programme (ORJIP) – Bird Collision Avoidance Study

The Offshore Renewables Joint Industry Programme (ORJIP) is a joint industry project involving the Carbon Trust, the Department of Energy and Climate Change (DECC) (now Dept. of Business Environment & Industrial Strategy), Marine Scotland (MS), the Crown Estate and offshore wind developers. ORJIP commissioned a 'Bird Collision Avoidance Study', which used a highly innovative methodology in an attempt to quantify and understand avoidance behaviors of bird species in and around offshore wind farms. It is hoped that the study will enable the verification of current avoidance and collision rates.

A combination of radar, digital and thermal cameras, and observers with laser rangefinders have been deployed during a 5-year study at Thanet offshore wind farm, due to reach completion in early 2017. The aim is to provide empirical data on macro, meso and micro avoidance of wind turbines by birds at an offshore wind farm. The key species studied include northern gannet, herring gull, lesser black-backed gull, great black-backed gull and black-legged kittiwake. The study will be fully reported in 2017 when it will become available in the public domain. Interim reports are restricted to client sponsors and are not publically available. A summary of the project by Ward et al. (2016) is available in the Proceedings of the BOU's 2015 Annual Conference (http://www.bou.org.uk/bouprocnet/avian-tracking/).

Natural England/The Crown Estate Bird Flight Heights Research

A steering group comprising statutory advisory bodies, the Royal Society for the Protection of Birds (RSPB), offshore wind farm developer organisations and avian surveyor contractors was set up to critically assess the various methods available in determining flight bird heights (Thaxter et al, 2015) and data modelling (Johnston and Cook, 2016).

Other important research that has helped inform assessment of the potential impact of offshore wind facilities on birds is provided in Thaxter (2012) and includes a study of the foraging ranges if birds.

7.4 GEOGRAPHICAL SCOPE AND QUALITY OF THE INFORMATION AVAILABLE

The monitoring reports and research so far available to this study have all originated from UK wind farm sites. However, other monitoring information is available from wind farms in Denmark, Netherlands, Germany and Belgium. Studies undertaken by the respective state authorities and developer organisations in each of these countries will be targeted during the subsequent data collation stage to help inform the case studies (see Table 7.2 below).

The most useful case studies will be those that have drawn upon relatively long time series monitoring data using consistent monitoring techniques to document changes in bird populations and behaviors. In this respect, the monitoring data for a number of the earlier and smaller wind farms such as Nysted (Denmark) and North Hoyle, Barrow, Burbo Bank, Robin Rigg (UK), may be most suitable as these comprise observations over three and four years following construction, providing evidence of the short to medium term impacts of offshore wind farm construction and operation on birds.

The monitoring data collected at the Horns Rev offshore wind farm in the Baltic Sea in Denmark on displacement displayed in long-tailed duck (old squaw) has been peer reviewed and offers opportunity to describe a specific type of impact with high confidence during the subsequent case study development.

The experience of the developers at the London Array offshore wind farm, located in the outer Thames Estuary, UK, may be of particular interest as a case study. Predicted adverse effects to protected red-throated diver (loon) led to the wind farm to be developed in two phases as well as the imposition of a ‘Grampian Condition’ and thus could provide a useful case study for reference during future NEPA reviews.

7.5 POTENTIAL DATA TARGETS

Table 7.2 presents sources of other information relevant to the monitoring and measurement of effects of offshore wind farms on birds and which will be pursued to further support the subsequent development of the case studies. These include more recent monitoring at offshore wind farm sites to update the current collection of monitoring studies already available to the project.

Table 12.10: Sources of Information Relevant to the Monitoring of Effects of Offshore Wind Farms on Birds

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Method of Acquisition (Data Request/Web Site)
Greater Gabbard	Yr. 3 monitoring report	Empirical monitoring data.	Planning authority, lease agency and regulator web portals and information requests.
Thanet	Pre, post, yr. 1 – 3 monitoring reports		
Ormonde	Yr. 1 – 3 monitoring reports		
Sheringham Shoal	Pre, post, yr. 1 – 3 monitoring reports		
Walney 1	Yr. 1 – 3 monitoring reports		
Walney 2	Yr. 1 – 3 monitoring reports		
London Array	Pre, post, yr. 1 – 3 monitoring reports		
Teeside	Pre, post, yr. 1 – 3 monitoring reports		
Gwynt-y-Môr	Yr. 1 – 3 monitoring reports		
Bird Tagging studies	Mainly short term duration at RSPB reserves	Reinforce foraging ranges Thaxter et al (2012).	Direct contact with researcher.
Sheringham Shoal	Research report	Observations of bird avoidance.	Direct contact with researcher.

7.6 APPRAISAL OF DATA GAPS

It can be seen from Table 7.1 that only three sites are beyond 20 km distance from the shore. This is significant as the current round of larger sites in pre-construction (Round 3 and Scottish Territorial Waters developments) in the UK are generally located much further offshore, are being developed in deeper water, and are much larger both in turbine size and number of turbines. This brings with it some possible separate issues which will not have been addressed from the earlier assessment and monitoring reports, such as differences in species composition, increased barrier and collision risk, greater potential for cumulative impacts.

Table 7.3 identifies sources of other information relevant to the monitoring and measurement of effects of offshore wind farms on birds but which is not expected to be obtained during the conduct of this study and thus represent data gaps.

Table 12.11: Gap Analysis Showing Inaccessible Information on Monitoring of Effects of Offshore Wind Farms on Birds

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Appraisal of Limitation
Thanet Bird Collision Avoidance Study	Research report	Empirical evidence of macro, meso and micro bird avoidance and collision.	Final report will not be available until early 2017. This study is the only one of its kind.
Gwynt y Môr	Research report	Observations of barrier effect on common scoter.	Data won’t be available within current project timescale.

8. MARINE MAMMALS

8.1 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Table 6.1 summarizes the permitting and monitoring documents currently held by Fugro for 22 UK wind farm sites. Documents include EIS (including baseline monitoring data), licenses (with conditions and monitoring requirements), and monitoring reports for pre-construction, construction, and operations phases. A full set of reports is available for some sites (e.g. Barrow), while other sites are incomplete (e.g. where 3 years' operational monitoring is still ongoing, or where reports are not yet publicly available).

Table 12.12: Summary of Information Available for the Characterization and Monitoring of Fish at UK Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
North Hoyle	30	60	5-12	7	2003	1	Y	Y	Y	Y	Y	Y	Y	
Scroby Sands	30	60	0-8	2.5	2004	1		Y						
Kentish Flats	30	90	3-15	10	2005	1	Y	Y	Y		Y		Y	
Barrow	30	90	15-20	7	2006	1	Y	Y	Y		Y	Y	P	
Burbo Bank	25	90	0-6	7	2007	1	Y	Y	Y		Y		Y	
Lynn & Inner Dowsing	54	194	6-11	5	2008	1	Y	Y	Y		Y	Y	Y	
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y	Y	Y	Y	Y		
Gunfleet Sands II						2	Y	Y	Y	Y	Y	y		
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y	Y	Y	Y			
Robin Rigg E	60	180	0-12	11	2009	1	Y	P	Y	Y	Y	Y		
Robin Rigg W						1	Y	P	Y	Y	Y	Y		
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y						
Thanet	30	150	20-25	11	2010	2	P	Y	Y					
Ormonde	30	150	17-22	9.5	2011	1	Y	Y						
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y	P					
Walney 1	51	367	19-30	14	2011	1	Y	Y	Y					
Walney 2	51					2	Y	Y	Y	Y				
London Array	175	630	0-25	20	2012	2	Y	Y	Y					
Teesside	27	62	7-15	1.5	2012	1	Y	Y	Y					
Gwynt y Môr	160	576	13-32	13	2013	2	Y	Y	Y					
Lincs	75	270	10-15	8	2013	2	Y	Y	Y					
West of Duddon	108	389	17-24	15	2013	2	Y	Y						

Wind Farm	**Number of Turbines**	**Capacity MW)**	**Depth (m)**	**Distance Offshore (km)**	**First Generation**	**Licence Round**	**Environmental Statement**	**Licence**	**Pre-Construction**	**During Construction**	**Op Yr1**	**Op Yr2**	**Op Yr3**	**Other**
Bligh Bank	55	165	12-20	46	2010									Y
Thorntonbank	54	325	10-28	26	2012									Y
Northwind	72	216	15-23	37	2014									Y
Horns Rev1	80	160	6-11	18	2002		Y		Y		Y	Y		Y
Horns Rev 2	91	209	9-17	32	2009		Y							Y
Nysted	72	166	6-10	11	2003				Y		Y	Y	Y	Y
Alpha Ventus	12	60			2010									Y
Egmond aan Zee	36	108	15-18	10	2007									Y
Lillgrund	48	110	4-13	11	2008									Y
Utgrunden	7	10	6-15	4	2000									Y

Notes:
Note: “Y” = obtained; “P” = partial report

There has also been considerable research attention on the effects of offshore wind farms under the various research initiatives identified in Section 2 above and particularly under the Belgium MUMM program, the Dutch Monitoring and Evaluation Program at the Egmond aan Zee offshore wind farm, the Danish Energy Agency monitoring program at Nysted and Horns Rev offshore wind farms and UK COWRE. These have primarily focused on the impacts of EMF emissions from operational cables, impacts of underwater noise of percussive piling activities on fish health and distributions, effects to significant economic species, such as sole and cod and migratory species, such as salmon, eel and trout and the influence of the presence of turbines and foundations as fish aggregating devices and associated reef effects. Research outputs from these studies are also available and will be reviewed during the development of the subsequent case study report. A summary of this research material available is provided below.

Belgium

There are three wind farms currently operating offshore the Belgian coast at Bligh Bank, Thortonbank and Northwind (see Table 6.1) from relevant information may be acquired. Relevant publications include:

- DEGRAER, S. and BRABANT, R., (2009) *Offshore Wind Farms in the Belgian part of the North Sea - State of the Art after Two Years of Environmental Monitoring.* Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, & Marine Ecosystem Management Unit.
- DEGRAER, S., et al., (2012). *Offshore Wind Farms in the Belgian part of the North Sea - Heading for an Understanding of Environmental Impacts.* Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, and Marine Ecosystem Management Unit.
- REUBENS, J., et al. (2011). Spatial and temporal movements of cod (*Gadus morhua*) in a wind farm in the Belgian part of the North Sea using acoustic telemetry, a VPS study. In: S. Degraer et al. (ed.). Offshore wind farms in the Belgian part of the North Sea: selected findings from the baseline and targeted monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, and Marine Ecosystem Management Unit. Brussels. pp. 157.
- VANDENDRIESSCHE, S., et al., (2014). Equivocal effects of offshore wind farms in Belgium on soft substrate epibenthos and fish assemblages. *Hydrobiologia.* **756**, pp. 19–35.

Denmark

Under the Danish program research is focused at the Horns Rev 1 and Horns Rev 2 and Nysted offshore wind farms. Relevant research material available is summarized as follows;

- HOFFMANN, E., et al., (2000). *Effects of Marine Windfarms on the Distribution of Fish, Shellfish and Marine Mammals in the Horns Rev area.* Baggrundsrapport nr. 24. Danish Institute for Fisheries Research.
- HVIDT, C.B., et al., (2005; 2006). *Hydroacoustic Monitoring of Fish Communities in Offshore Wind Farms - Horns Rev Offshore Wind Farm – Annual Report 2004 & 2005.*
- JENSEN, H., et al., (2004). *Sandeels in the Wind Farm Area at Horns Reef.* Danish Institute for Fisheries Research.
- JENSEN, H., et al., (2006). *EIA Report – Fish: Horns Rev Offshore Wind Farm 2.* Bioconsult.

- LEONHARD, S.B., et al., (ed.) (2011). *Effect of the Horns Rev 1 Offshore Wind Farm on Fish Communities - Follow-up Seven Years after Construction.* DTU Aqua Report No 246-2011. National Institute of Aquatic Resources, Denmark.
- STENBERG, C., et al., (2015). Long-term Effects of an Offshore Wind Farm in the North Sea on Fish Communities*. Marine Ecology Progress Series.* **528**, pp. 257–265.
- VAN DEURS, M., et al., (2012). Short- and Long-term Effects of an Offshore Wind Farm on the Species of sandeel and their Sand Habitat. *Marine Ecology Progress Series.* **458**, pp.169–180.
- SEAS, (2001). *Nysted Offshore Wind Farm at Rødsand - Annual Status Report for the Environmental Monitoring Program.* SEAS Wind Energy Centre.
- ENERGI E2 (2002; 2003; 2004). *Annual Status Report - Nysted Offshore Wind Farm - Environmental Monitoring Program 2002 -4.*
- NIELSEN, S., (ed.) (2006). *Offshore Wind Farms and the Environment - Danish Experience from Horns Rev and Nysted.* Danish Energy Authority.

The Netherlands

The Egmond aan Zee offshore wind farm is the focus of research in the Dutch sector. Relevant material available includes the following:

- GRIFT, R.E., et al., (2004). *Baseline studies North Sea Wind Farms: Final Report Pelagic Fish.* Netherlands Institute for Fisheries Research (RIVO). Report number: C047/04.
- HILLE RIS LAMBERS, R., et al., (2009). R*efugium Effects of the MEP-NSW Windpark on Fish: Progress Report 2007.* IMARES Wageningen UR.
- LINDEBOOM, H.J., et al. (2011). Short-term Ecological Effects of an Offshore Wind Farm in the Dutch Coastal Zone - a Compilation. *Environmental Research Letters.* **6**, pp. 1-13.
- TIEN, N., et al. (2004). *Baseline Studies Wind Farm for Demersal Fish.* Royal Haskoning.
- VAN HAL, R., et al., (2012). *Monitoring and Evaluation Program Near Shore Wind Farm MEP-NSW - Fish Community.* IMARES Wageningen UR.
- WINTER, H.V., et al., (2010). *Residence Time and Behaviour of Sole and Cod in the Offshore WIND FARM Egmond aan Zee (OWEZ).* IMARES Wageningen UR. Report number OWEZ_R_265_T1_ 20100916.
- YBEMA, M.S. et al. (2009). *OWEZ - Pelagic fish, progress report and progression after T1 - interim Report.* IMARES Wageningen UR.
- BOON, A., et al., (2010). *Monitoring and Researching Ecological Effects of Dutch Offshore Wind Farms.* Deltares.

In addition to the UK licence compliance monitoring campaigns, there has been considerable independent research on the effects of offshore wind construction and operation on fish. In particular, research effort in this regard has focused on the effects of underwater noise and EMF emissions from operational cables and impacts on migrating species, such as eels, salmon and trout which are of significant nature conservation and socio-economic interest in Europe. The following summarizes the research outputs available for review to inform the subsequent case study report.

- DREWERY, H.M., 2012. *Basking Shark (Cetorhinus maximus) Literature Review, Current Research and New Research Ideas.* Marine Scotland Science Report No 24/12.

- GILL, A. and BARTLETT, M., (2010). *Literature Review on the Potential Effects of Electromagnetic Fields and Subsea Noise from Marine Renewable Energy Developments on Atlantic Salmon, Sea Trout and European Eel.* Scottish Natural Heritage. Commissioned Report No.401.
- HARDING, H., et al., (2016). *Measurement of Hearing in the Atlantic salmon (Salmo salar) using Auditory Evoked Potentials, and effects of Pile Driving Playback on salmon Behaviour and Physiology. Scottish Marine and Freshwater Science Report Vol 7.*
- LINLEY, E.A.S., et al., (2007). R*eview of the Reef Effects of Offshore Wind Farm Structures and Potential for Enhancement and Mitigation.* Report from PML Applications Ltd and the Scottish Association for Marine Science to the Department for Business, Enterprise and Regulatory Reform (BERR), Contract No: RFCA/005/0029P.
- MARMO, B., et al. (2013). *Modelling of Noise Effects of Operational Offshore Wind Turbines Including Noise Transmission Through Various Foundation Types*. Marine Scotland, Edinburgh.
- RUSSELL, D.J.F., et al. (2014). Marine Mammals Trace Anthropogenic Structures at Sea. *Current Biology.* **24**, pp. 638–639.
- THORLEY, J., (2013). *Potential Influence of Robin Rigg Wind Farm on the Abundance of Adult and Juvenile Atlantic Salmon.* A Poisson Consulting Ltd. Report prepared for Marine Scotland Science, Pitlochry, Scotland.
- WILSON, S.J.K., (2007). *Offshore Wind Farms: Their Impacts and Potential Habitat Gains as Artificial Reefs, in Particular for Fish.* MSc dissertation, University of Hull.

8.2 INTRODUCTION

This section describes the data which have been identified at this stage for review of impacts of offshore wind farm construction and operation on marine mammals.

For the purposes of this study, this topic chapter covers all whale, dolphin, porpoise and seal species that occur in European waters as either residents or seasonal visitors. Species that do not occur in Europe are not addressed here. Dugongs and manatees are similarly not addressed in impact assessments for European offshore wind facilities and will not be covered in this study.

Potential effects of offshore wind facilities on marine mammals and which are typically addressed in environmental impact assessments of offshore wind facilities relate to:

- Underwater construction noise, particularly from percussive piling activity;
- Increases in vessel traffic and associated increased collision risk;
- Displacement from preferred feeding areas or migration pathways;
- Visual disturbances;
- Changes to water quality; and
- Changes to prey availability.

8.3 AVAILABLE DOCUMENTS, REPORTS, PUBLICATIONS AND DATA

Table 8.1 summarizes the marine mammal monitoring data reports currently available and which will be used to inform the subsequent case studies. Most of these reports have used information gathered as part of the bird surveys undertaken from boat or light aircraft. Reports of the monitoring of marine mammals during construction stages are available for 11 wind farm sites. Post-construction monitoring reports of marine mammals are available for six offshore wind farms sites.

It is generally regarded that the characterization data acquired during the earlier Round 1 and Round 2 characterization and monitoring studies were limited in terms of the relative low abundance of the species encountered. The low encounter rate was generally attributed to the greater use of vessel based observers adopted, which may have failed to accurately record individual marine mammals in marginal sea conditions, where the sea swell and waves may have obscured individuals on the surface, while those individuals swimming just below the water surface at the time of the observations would have been missed. Consequently, the data from the early offshore wind farm characterization studies may not have provided an accurate census of true population densities as sightings of marine mammals were quite rare. This made post-construction comparisons with baselines very difficult as the data were often statistically very weak.

The introduction of aerial reconnaissance and imaging techniques is regarded as an improvement over vessel based observations as it overcomes issues associated with marginal sea conditions and the recording of submerged individuals. After early trials of equipment and sensors along the North Norfolk coast, UK, in 2008, aerial surveying has become more commonly employed to characterize marine mammal, and bird, distributions in support of some of the later Round 2 sites and for the larger UK Round 3 sites which are currently in planning or which have recently been consented. The development and use of enhanced methodologies for monitoring marine mammals at offshore wind farm sites will be explored within the subsequent case study report with examples of census counts from vessel and aerial observations for comparison.

In addition to site observation, UK studies have also used broad scale databases such as those developed under the small cetacean abundance in the North Sea and adjacent waters (SCANS and SCANS II) initiative. These surveys were carried out by teams of observers onboard research ships and small aircraft to collect data to determine the numbers of animals in the area, as well as test survey and monitoring methodologies. The UK experience in using these broad scale data in conjunction with the site specific census counts will be discussed in the case study report.

The UK Joint Nature Conservation Committee (JNCC) advocates an international cooperative approach for long term surveillance and monitoring of cetaceans in UK waters and the wider northeast Atlantic and leads a collaborative project, the Joint Cetacean Protocol (JCP), which aims to deliver information on the distribution, abundance and population trends of cetacean species occurring in this area. Current findings of the JCP is that the data provided do not provide sufficient power to demonstrate a decline in a species over a 6-year period, but that it is able to demonstrate so over longer time sets. Despite this, modelled density data showed that declines of 0.3% to 2.2% per year, over a 6 year reporting period, could be detected for harbor porpoise, common bottlenose dolphin and short-beaked common dolphin although this was only possible in data rich areas.

Recent advances particularly in remote sensing such as seal tagging have advanced the knowledge of species behavior in and around constructed windfarms. While digital aerial photography has allowed the recording of species under the water which would have previously been missed and is not intrusive on the animal’s behavior.

Some dedicated marine mammal surveys are also produced in support of specific European protected species (EPS) licence conditions associated with incidental harassment assessments which might occur during certain types of activities such as clearance of unexploded ordnance (UXO). The monitoring undertaken during this type of monitoring has tended to be more targeted than the more generic construction and operation licence monitoring as the survey effort is more intense as the surveyors will have a continuous presence on the site. Also, the survey vessel will tend to be stationary at the site of the activity which increases the efficiency of the data collected by the passive acoustic monitoring (PAM) systems compared to surveys when the PAM equipment is towed. The duration of these more intense observation periods, however, tend to be comparatively short, a matter of hours or days, lasting for the duration of the activity for which the EPS licence was issued. Furthermore, the area of coverage will tend to be very limited, typically 500 m to 1 km away from the activity, so they will not be able to demonstrate far field avoidance by marine mammals.

Table 12.13: Summary of Information Available for the Characterization and Monitoring of Birds at Offshore Wind Farm Sites

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
North Hoyle	30	60	5-12	7	2003	1	Y	Y	Y	NR	Y	Y	Y	
Scroby Sands	30	60	0-8	2.5	2004	1	N	Y	Y	Y	Y	Y	NR	
Kentish Flats	30	90	3-15	10	2005	1	Y	Y	NR	NR	NR	NR	NR	
Barrow	30	90	15-20	7	2006	1	Y	Y	NR	Y	NR	NR	NR	
Burbo Bank	25	90	0-6	7	2007	1	Y	Y	NR		NR	NR	NR	
Lynn & Inner Dousing	54	194	6-11	5	2008	1	Y	Y	Y	Y	NR	NR	NR	
Gunfleet Sands I	48	300	2-15	7	2009	1	Y	Y	NR					
Gunfleet Sands II						2	Y	Y	NR					
Rhyl Flats	25	90	4-15	8	2009	1	Y	Y		Y				
Robin Rigg E	60	180	0-12	?	2009	1	Y	P	NR	Partial	Y	Y	Y	
Robin Rigg W						1	Y	P	NR	Partial	Y	Y	Y	
Greater Gabbard	140	504	20-32	23	2010	2	Y	Y	Y	Partial	**			
Thanet	30	150	20-25	11	2010	2	Partial	Y	Y					
Ormonde	30	150	17-22	9.5	2011	1	Y	Y	NR	Y				
Sheringham Shoal	88	300	12-24	23	2011	2	Y	Y	NR					
Walney 1		367	19-30	14	2011	1	Y	Y	Y	Y				
Walney 2						2	Y	Y	Y	Y				
London Array	175	630	0-25	20	2012	2	Y	Y						
Teesside	27	62	7-15	1.5	2012	1	Y	Y						
Gwynt y Môr	160	576		13	2013	2	Y	Y	Y	Y				Y
Lincs	75	270	10-15	8	2013	2	Y	Y						

Wind Farm	Number of Turbines	Capacity (MW)	Depth (m)	Distance Offshore (km)	First Generation	Licence Round	Environmental Statement	Licence	Pre-Construction	During Construction	Op Yr1	Op Yr2	Op Yr3	Other
West of Duddon	108	389	17-24	15	2013	2	Y	Y						
Egmond aan Zee														
Nysted														
Horns Rev														

Notes:
Note: “Y” = obtained; “P” = partial report, NR = not recorded

Useful data provided in the monitoring reports of the wind farms is limited as they are usually based on the effectiveness on the mitigation applied rather than focusing on the observed impacts of offshore wind construction and operation on marine mammals. Mitigation typically employed includes the use of marine mammal observers (MMOs) and passive acoustic monitoring (PAM) devices to detect the presence of marine mammals close to offshore construction areas throughout the construction period so that a stop on noisy activities, such as percussive piling, can be placed. In this way, potential adverse effects on marine mammals can be avoided.

Despite the paucity of empirical observation of impacts, a few sites have been specifically monitored for marine mammals and offshore wind farm effects. These include Scroby Sands offshore wind farm (UK), where the licence conditions required specific monitoring of effects of wind farm construction on a local seal haul out site, and the Greater Gabbard offshore wind farm (UK) where pre-, during and post-construction monitoring has been undertaken. Some monitoring of marine mammals has also been undertaken at the Egmond aan Zee (Netherlands), Alpha Ventus offshore wind farm (Germany) and Nysted and Horns Rev offshore wind farms (Denmark). The effects of impacts piling on the distribution of harbor porpoise have been modelled at Thorntonbank offshore wind farm (Belgium).

Targeted research has also been undertaken on the behavior of harbor seals at some offshore wind farm sites and will be reviewed in the subsequent case studies. This includes displacement effects during construction and foraging during wind farm operation.

Cork Screw Deaths

The Sea Mammal Research Unit (SMRU) recently produced a report to the Scottish Government on predation by adult grey seals on grey seal pups and raised the question as to whether this could explain apparent corkscrew injury patterns seen in the unexplained seal deaths. An adult grey seal was observed attacking and feeding on a seal pup leading to a corkscrew pattern of injuries on the pup. This study is relevant to offshore wind activities as previous theories associated with corkscrew injuries on seals assumed vessel propellers, particularly ducted propeller types commonly used by offshore wind construction vessels, were potentially to blame. This could have had implications on limiting type of a vessel available during construction, operation and maintenance although now a more natural explanation has come to light. Fugro will review and describe the report on recently documented adult grey seal behavior as an example of a natural effect over an apparent wind farm impact and will pursue the status of any follow up work.

8.4 POTENTIAL DATA TARGETS

Table 8.2 presents sources of other information relevant to the monitoring and measurement of effects of offshore wind farms on marine mammals and which will be pursued to further support the case studies. This includes the results of recent monitoring of marine mammals during and following construction of the comparatively larger offshore wind farms (140 to 160 turbines) at Greater Gabbard and Gwynt-y-Môr. Both sets of monitoring data are now within the public domain and can be obtained via web information portal and direct request to the data owners. Given the paucity of empirical observation over the years, these studies are regarded as particularly important in crystalizing the understanding of likely offshore wind farm impacts on marine mammals.

Table 12.14: Sources of Information Relevant to the Monitoring of Effects of Offshore Wind Farms on Marine Mammals

Wind Farm Identity/ Title of Study	Type of Document (Research Paper/ Monitoring Report/ES)	Relevance to Current Study	Method of Acquisition (Data Request/Web Site)
Greater Gabbard	Pre-, during and post-construction monitoring reports	Monitoring of effects of construction activities on harbor porpoise.	Web search Data requests
Gwynt -y-Môr	Pre- and during construction monitoring reports	Monitoring of effects of construction activities on harbor porpoise.	Web search Data requests
Thorntonbank	Monitoring report	Modelled predictions for the displacement of harbor porpoise	Data request
Nysted	Monitoring reports	Monitoring of effects of piling on harbor porpoise.	Web portal
Horns Rev	Monitoring reports	Monitoring of effects of piling on harbor porpoise.	Web portal
Scroby Sands	Monitoring report	Monitoring data for a local seal haul-out site	Data request
Egmond aan Zee	Monitoring report Research paper	Monitoring of effects of piling on harbor porpoise.	Web portal
Various	Research papers	Observations on the tolerances and behaviors of marine mammals to offshore wind construction activities.	Web search Data requests

Other information available relevant to the impacts of offshore wind on marine mammals include the outputs from collaborative industry studies including the Offshore Renewables Joint Industry Partnership (ORJIP) study relating to marine mammals and noise and the study on the disturbance effects on the harbor porpoise population in the North Sea (DEPONS) as outlined below.

DEPONS (Disturbance Effects on the Harbor Porpoise Population in the North Sea)

The DEPONS initiative was set up by Vattenfall (Swedish wind farm developer), with financial support from other developers of offshore wind farms in the North Sea in response to increasing concerns that the large scale offshore wind farm construction activities expected over the coming decade might have negative effects on the North Sea harbor porpoise population. The DEPONS group meet annually and includes representatives from five developers in the North Sea, statutory UK, German and Dutch consultees and experts from academia.

Harbor porpoises have been found to respond to underwater noise generated by piling of wind farm foundations at large distances. While they have also been found to return once construction activity ceases, the significance of piling noise disturbance to the survival and reproduction of harbor porpoises is not understood. The result is considerable uncertainty for the industry and governments alike in the planning of offshore wind farms. The DEPONS project aims to improve current understanding of the impacts of piling noise in support of the future further expansion of offshore wind power in a cost-effective and timely manner in balance with a long-term viable North Sea harbor porpoise population.

The project is ongoing at this time with future plans including the collection of behavioral responses of porpoises to simulated pile driving noise and the fitting of high resolution tracking devices to individuals to monitor their movements before and after exposure to noise. Data are also being gathered on the relative population densities in different distances from wind farms

Offshore Renewables Joint Industry Programme (ORJIP)

The Offshore Renewables Joint Industry Programme (ORJIP) is a collaboration between government departments and the offshore wind farm industry. It aims to identify and address evidence gaps to assist the consenting of offshore wind farms in the UK through the greater understanding of potential adverse effects. With regard to marine mammals, research to date has been conducted on the availability of acoustic deterrent devices (ADDs) and their applicability for use during construction of offshore wind farms.

8.5 APPRAISAL OF DATA GAPS

MMO (2014) points out that it is currently uncertain whether it is auditory injury from piling or disturbance/displacement during periods of construction which has the most severe consequence for marine mammals and highlights that it is likely that the balance will differ between species and sites. The planned initiatives outlined above are aimed at reducing this uncertainty over the coming years but these will rely on empirical data being collected during future construction and which is currently unavailable. Currently, the associated research effort is related to technologies that mitigate for potential auditory damage by either deterring marine mammals from areas of proposed construction (acoustics deterrents), soft start procedures prior to full energy pile driving and use of dampening devices, such as bubble curtains, which may be of interest in the US (BOEM, 2013).

There are no large scale, commercial floating wind farms in operation and thus impacts of these facilities on marine mammals are not known. However, the Hywind floating demonstration project, comprising five floating turbines, (east coast of Scotland) has recently been awarded consent with final commissioning due on 2017. Opportunities for the monitoring and measurement of potential interactions with marine mammals therefore exist in the future, although these data will not be available within the current timeline of this project. Despite the absence of any relevant empirical observation, the Environmental Statement supporting the consent application of the Hywind project is accessible and will be reviewed to identify and describe the predicted impacts of offshore wind construction and operation on marine mammals within the subsequent case study report. In addition to the consented Hywind project further floating wind arrays for the east and north coasts of Scotland (Kincardine and Dounreay offshore wind farms respectively) are currently in planning and provide further opportunity for future monitoring of effects on marine mammals. Scoping opinion from regulators regarding these projects are available for review and may provide insight as to the current stakeholder concerns relating to the potential environmental impacts of floating wind farms.

9. CONCLUSIONS

This report has summarized the information currently available, together with other documents and reports that may be available, all of which will be collated, to help case study building and to inform the subsequent case study report. This includes permitting and monitoring reports, which have been prepared as part of developer's licence obligations, as well as outputs from specific academic research and joint industry projects.

An exhaustive data search and collation exercise is unlikely to be achieved due to the large number of operational wind farms present across Europe and the correspondingly large quantity of monitoring information available as well as in progress. In addition, not all reports are readily available; for example, while Germany has a comparatively large number of operational wind farms, associated environmental monitoring reports are not publically available.

Information readily available to Fugro relates primarily to comparatively smaller wind farms (30 turbines) located in shallow water (< 20 m). Efforts in the subsequent study phase will focus on completing time series data for these wind farms and acquiring new monitoring data for the larger arrays recently constructed and commissioned.

Current uncertainties concerning environmental impacts have been recognized within the limits of the available data. These generally relate to the lack of information on longer term (i.e. > 5 years), localized and cumulative effects, EMF and heat emissions, effects of particle motion as a component of underwater noise and certain aspects of avian and marine mammal behavior. Some specific collaborative research and joint industry project has been undertaken to address these issues the results of which will be subject to review during the case building. It was also noted that some caution may need to be exercised when transposing European experiences onto the US situation as most environmental monitoring relates to monopile foundations which are different to the jacket type foundations currently installed in the US.

Despite the differences and limitations of available data, the opportunity to streamline NEPA permits through a consolidation of available impact and mitigation data should still prove to improve the stakeholder understanding of comparable work done in Europe, reducing uncertainties associated with current state-of-the-practice knowledge in the US and identifying critical data gaps requiring further and more detailed study specific to US conditions.

Further, the efforts of this scope will provide a template for applying future case study results to NEPA permitting.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.