Biodiversity Series

Review of the Current State of Knowledge on the Environmental Impacts of the Location, Operation and Removal/Disposal of Offshore Wind-Farms

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1 This report was last edited in April 2006 and is published as a living document to be reviewed in the light of new available literature.

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

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Executive Summary/Récapitulatif

This paper aims to review existing information to determine our current state of knowledge on the ecological impacts of Offshore Wind-Farms (OWFs), so that future research can be prioritised and better targeted on key issues of concern.

Le présent document a pour objectif d'étudier les informations existantes afin de déterminer l'état actuel de nos connaissances sur l'impact écologique des parcs d'éoliennes offshore (OWF). Il sera alors possible de classer les recherches futures selon les priorités et de mieux les orienter vers des questions préoccupantes.

The paper is structured to include the key stages of any OWF development (i.e. construction activities; physical presence; operation and decommissioning) and, for each of these stages, discusses the various associated impacts, what has been done to assess them, what conclusions can be made and identifies knowledge gaps.

Ce document comporte les étapes clés du développement d'un OWF (c'est-à-dire sa construction; sa présence; son exploitation et son déclassement). Il discute, pour chacune de ces étapes, des divers impacts qui y sont associés et des mesures prises pour évaluer ces impacts. Il étudie également les conclusions que l'on peut tirer et détermine les lacunes dans les connaissances.

As there are subtle differences in the associated impacts, a distinction is made between physical presence and operation.

On fait une distinction entre la présence physique des OWF et leur exploitation car les impacts qui leur sont associés varient légèrement.

This overview is published as a living document on the OSPAR website. The initial Comprehensive Reference List of Documents Pertinent to the Assessment and Review initially attached to this document is now available on the website for exchange of marine environmental information on renewable energy (www.environmentalexchange.info).

Le présent récapitulatif est un document actif du site internet d'OSPAR. La liste bibliographique exhaustive préliminaire de documents pertinents à l'évaluation et à l'étude qui était, à l'origine, jointe au présent document est maintenant disponible sur le site internet pour l'échange d'informations environnementales marines sur l'énergie renouvelable (www.environmentalexchange.info).

Contracting Parties to OSPAR are responsible for keeping the information they have provided (including links to websites) up-to-date, and they submit by 1 February each year details of any new or updated relevant information to the UK, so that the UK updates the Status Report as appropriate. In preparing this work, the UK takes into account the outcome of associated research and relevant Workshops as advised by other Contracting Parties.

Les Parties contractantes d'OSPAR ont la responsabilité de maintenir à jour les informations qu'elles ont communiquées (notamment les liens vers les sites internet). Elles doivent présenter au Royaume-Uni, chaque année et au plus tard le 1er février, toute information pertinente nouvelle ou mise à jour. Le Royaume-Uni actualise alors le rapport d'avancement en tant que de besoin. Lors de ces travaux, il tient compte du résultat des recherches associées et des ateliers pertinents que lui indiquent les autres Parties contractantes.

0. Introduction

Offshore Wind Farms (OWFs) and similar developments cause a change to the environment. The challenge is to understand such changes and to ensure that all activities in the marine environment are assessed consistently and that any impacts are acceptable. There are three main aspects in determining and assessing environmental impacts: learning from other activities, from pre-construction models and predictions, and from measurements taken at operational and under-construction offshore wind farms.

Knowledge about offshore wind farms and their associated marine environmental impacts is improving all the time and this paper provides a snapshot presenting the current state of knowledge, using results from published and unpublished environmental studies. This paper uses information on activities in a range of European and OSPAR countries, primarily Denmark, plus Germany, Sweden and the UK. Although there is a paucity of published peer-reviewed articles on the environmental impacts of offshore renewable energy devices (Gill 2005) there has been a great deal of work to improve our knowledge and understanding of the physical and ecological consequences. Environmental statements provide most of the knowledge on design and construction of offshore wind farms and the identification of potential environmental impacts. Environmental monitoring studies at existing offshore wind farms and regulator-sponsored research and development initiatives provide good data on specific impacts; the authors have reviewed all the available data. The final source are studies on similar activities that have analogous impacts and the authors have, wherever possible, included references to these where they add to the current state of knowledge for offshore wind farms. A lot of information is therefore available, albeit not all from peer-reviewed sources. Consideration of marine environmental impacts forms a critical part of the consents decision-making process. Additionally it is hoped that it will provide a useful guide to developers and professional advisors.

This paper aims to review the existing information to determine our current state of knowledge on the ecological impacts of OWFs so that future research can be rationalised and better targeted on those unique issues of concern. There are synergies with the EU funded Concerted Action for Offshore Wind Energy Deployment (COD) project (www.offshorewindenergy.org/cod), which this paper is intended to compliment, but this review is extended to cover other non-wind energy literature that is of relevance to understanding the environmental impacts. It considers what assumptions and conclusions can be made from the available information with a view to determining which issues are genuine causes for concern and which issues can effectively be discounted if sufficient evidence exists to suggest that the impacts are acceptable. It also looks at how future data may best be gathered, i.e. from site-specific monitoring studies at each wind farm or as generic studies. It is hoped that regulators can use this paper to move towards a more coordinated approach to the assessment and review of the ecological impacts of OWFs and the exchange of information internationally.

The paper is structured to include the key stages of any OWF development and for each of these discusses the various associated impacts, what has been done to assess them, what conclusions can be made and identify where the knowledge gaps are. The key stages of an OWF are:

1. construction activities;
2. physical presence;
3. operation;
4. decommissioning.

As there are subtle differences in the associated impacts a distinction is made between physical presence and operation.

By way of a simple introduction there are 4 main components of any OWF:

- Foundations (monopile, multi-pile or gravity base/caisson) used to secure structures to the sea bed;
- Towers, nacelles (containing generation units, gearing etc) and rotor blades;

- Power cables;
- Scour protection.

Additional structures such as meteorological masts and sub-stations (onshore and, in some cases, offshore) can also be associated with OWFs. Associated features such as navigation lighting may also be relevant when considering potential environmental impacts. Each of these will cause a change to the marine environment and therefore will have associated impacts. These impacts can be separated into those above and below the waterline (this distinction is made throughout this review). Impacts below the water may create impacts above it, either directly or as a secondary impact, for example; alterations to marine habitats may impact negatively or positively on seabird feeding (Kaiser, 2004).

Where knowledge gaps remain these are described at the end of each section. There are significant gaps in understanding, most notably in the area of construction noise, bird displacement, seabed morphology, public perceptions/acceptance and cumulative impacts (the assessment of which, although required under the Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) Directives is notoriously difficult). The interaction between marine renewable projects and other marine activities such as shipping, oil and gas exploration, aggregate extraction and fishing also requires further study. This is particularly relevant to impacts on sites protected under the Habitats Directive where “in combination” effects must be considered as part of any Appropriate Assessment.

Establishment of a workable method of assessing cumulative effects and creation of guidance to industry is required.

It should be noted that not all knowledge gaps can be directly attributed to offshore wind farm developments because in many cases there are large gaps in our knowledge in respect of very basic elements of the marine environment. Species responses and behaviours are often not well known and knowledge of distribution and abundance can be sparse. It is alluded to elsewhere in this report but is worthy of separate note that significant data gaps exist for basic temporal and spatial environmental data such as migration routes, migration times, spawning/breeding areas, spawning/breeding times, distribution and abundance etc for key species of birds, fish and mammals. Although some areas and species have been studied in detail many others have not. Many of the sensitivity maps used to underpin decision-making are often based on broad scale data sets with inferred temporal and spatial scales to ‘join-the-dots’. The resolution of such data sets could be greatly improved (e.g. MESH, SCANS etc) so that we have a much better overview of the marine environment. However, the practicalities and logistics of this could be problematical and it will never be possible to have total knowledge of the marine environment. Spatial and temporal variability has to be considered and related to the rationale for collecting the data in the first place to ensure that the data requirements are proportionate.

Impacts in the context of natural change may also need to be considered. Recent studies have suggested that climate change is impacting on the marine environment around the shores of OSPAR countries. Seemingly small-scale human impacts may be magnified when taken in combination with larger-scale influences. Two issues not unique to OWF but requiring separate discussion are the assessment of cumulative impacts and data.

1. Construction

1.1 Impacts Below Sea Level

- Increased turbidity and smothering from resuspended sediments;
- Noise;
- Construction plant movements;
- Pollution incidents.

1.1.1 Increased turbidity and smothering from resuspended sediments

Gravity base and caisson foundations require a level platform on which to sit. Their installation therefore requires the sea bed to be dredged to create a flat platform. This dredging activity will result in the mobilisation of seabed sediments into the water column, increasing turbidity temporarily and, as the sediments settle out of suspension, will deposit a new layer of fine sediment. Similarly, driven or drilled monopiles will also cause sediments to be remobilised. Cable-laying operations will also disturb sediments from the sea bed. The extent of any sediment plumes from these activities depends on sediment type, grain size distribution and the hydrodynamic regime and thus can vary greatly between sites. All effects from suspended sediment are expected to be limited to the construction phase. Prudent activities thus include pre-construction hydrodynamic modelling, as part of a site-specific environmental impact assessment to predict the importance of this issue at each site, and in areas with species sensitive to smothering (e.g. shellfish beds) a simple monitoring programme of suspended sediments during the construction to validate predictions. In sensitive areas (e.g. if adjacent to important bivalve or other filter-feeding populations) more stringent monitoring and mitigation may be required as smothering and increased turbidity could affect the survival of such organisms.

KNOWLEDGE GAPS:

Because gaps in knowledge are likely to be at a site specific level it is not considered that there is a need for generic or large-scale studies. A thorough EIA, including assessment of suspended sediment concentration and hydromorphological modelling and, where appropriate, post construction monitoring e.g. in sensitive areas such as shellfish beds will usually address such gaps.

1.1.2 Noise

Noise associated with the construction of offshore wind farms could affect marine organisms in several ways Nedwell et al (2003) identifies three possible categories of effect:

- Primary effects – immediate or delayed fatal injury, often caused by "barotraumas" arising from gas embolisms. Such impacts may be greater on fish than marine mammals because adaptations to diving provide resilience to pressure changes.
- Secondary effects – injury such as deafness which may impact upon survival, particularly among species that hunt by acoustic methods.
- Tertiary (behavioural) effects – these effects may be milder but experienced over a greater area. This may include avoidance which may arise from pain or discomfort (although these terms are of course subjective).

It is possible that noise from construction activities at some OWFs could give rise to all three of these effects. Noise will be produced by a variety of construction activities including pile driving, cable laying and boat traffic. It is in respect of pile-driving that the greatest levels of noise are likely to arise (Nedwell et al 2003). The extent to which such noise source levels would give rise to an impact upon marine animals is dependent upon a number of factors including the level of noise produced at the piling source, the frequencies at which the sound is produced, the rate at which sound attenuates (which will vary for different frequencies and environmental conditions), the varying sensitivities of different species and individuals to different volumes and frequencies of noise and the piling methods and thickness of piles utilised.

Table 1 shows source noise levels arising from pile driving during the construction of offshore wind as well as other maritime activities. To the best of our knowledge no measures to reduce the noise output of these activities were utilised therefore the values cited are peak values at a given distance from the source level.

Table 1. Comparison of different noise source levels from a variety of activities

Noise level	Distance for source (m)	Depth of measurement (m)	Location	Reference
272 dB re 1 µPa	1		Kentish Flats OWF, UK	Nedwell et al 2005
260 dB re 1 µPa	1	5	North Hoyle OWF, UK	Nedwell et al 2003
262 dB re 1 µPa	1	10	North Hoyle OWF, UK	Nedwell et al 2003
188 dB re 1 µPa	30	-	Kalmarsun OWF, Sweden	ØDS[1] 2000
203 dB re 1 µPa	30	-	Utgrunden OWF, Sweden	Knust et al 2003
259 dB re 1 µPa	1	-	Seismic air guns (large array)	Nedwell & Howell 2004
225,7 dB re 1 µPa	1	10	Douglas hydrocarbon facility, UK	Nedwell et al 2003
200 dB re 1 µPa	-	-	Civil engineering activities, UK	Nedwell et al 2003
195 dB re 1 µPa	1	5	Douglas hydrocarbon facility, UK	Nedwell et al 2003
178 dB re 1 µPa	1	-	Cable laying, North Hoyle, UK	Nedwell et al 2003

The noise levels measured at North Hoyle (Nedwell et al 2003) and Kentish Flats (Nedwell et al 2005) are similar to measurements of pile-driving source noise from the Kalmarsund (ODS[1] 2000) and Utgrunden (Knust et al 2003) OWFs in Sweden and are in excess of sound levels for other civil engineering activities (Nedwell et al 2003) and comparable to levels created by a large array of seismic survey air guns (Nedwell & Howell 2004).

The frequencies of the noise arising from pile driving at OWF construction cover a broad spectrum but are within the hearing sensitivities of most marine animals (Nedwell et al 2003). Such sensitivities will vary between species and individuals. Additionally, underwater environments are naturally noisy, with noise being created by wind, wave breaking and movement of sandy and gravelly sediments. As a result many marine fish and mammals have evolved hearing far less sensitive than that of humans and can tolerate much higher levels of noise (Nedwell et al 2003). One approach adopted to aid comparison of noise impacts upon different species is the use of the dB_{ht} (species) metric (Nedwell and Turnpenny, 1998). This approach utilises published audiograms for different species to act as a “filter” allowing assessment of their relative sensitivity to sounds across a broad frequency range, thereby providing a concept of perceived “loudness” for a species.

Although primary and secondary effects may occur, impacting upon organisms in the near field (within a few hundred metres of the piling activity) it is expected that tertiary (behavioural and other) effects will affect more individuals over greater areas, because they occur at much lower noise levels. A noise level of 90 dB_{ht} (species) has been suggested as a threshold at which a significant avoidance reaction will occur (Nedwell et al 2003). By assessing the rate at which noise at the relevant frequencies attenuates Nedwell et al 2003 have calculated the possible distances around a pile within which such reactions occur. These are listed for three UK OWF projects in Table 2 below. This shows that avoidance could occur at several kilometres from the noise associated with the piling activities. However, it must be stressed that these are extrapolations from a relatively small dataset and they have not been tested in the field.

Table 2. Calculated ranges at which certain organisms will demonstrate significant avoidance behaviour from piling noise as a function of species (from Nedwell et al 2003, Nedwell et al 2005).

Species	Calculated range for significant avoidance reaction (m)	Calculated range for significant avoidance reaction (m) at Kentish Flats for 4,3m diameter piles	Calculated range for significant avoidance reaction (m) at Greater Gabbard for 6,5m diameter piles
Salmon	1400	460	1100
Cod	5500	-	-
Dab	1600	-	-
Bass	-	450	-
Herring	-	1630	-
Bottlenose Dolphin	4600	-	-
Harbour Porpoise	7400	15000	94000
Common Seal	2000	2760	-

As will be noted from the table, another important factor affecting noise from piling is pile diameter. The greater effort required to sink the larger piles that may be required for the latest generation of wind turbines result in much higher levels of noise over greater distances. Modelling in respect of piles 6,5 m in diameter has been calculated as creating avoidance reactions in harbour porpoise at a distance of up to 94km (Nedwell et al, 2005), however, it should be noted that noise levels created by driving 6,5m piles are only predictions and the levels given in Nedwell et al (2005) are extrapolations from operations at Kentish Flats involving smaller piles and as such need to be tested and the significance assessed. Additionally the work did not include full acoustic modelling of transmission loss over the far larger ranges involved. Transmission loss (the measure of the rate at which sound energy is lost) is very important when evaluating the impacts of noise in the marine environment. Sound from a source activity, e.g. pile driving or cable laying can travel through the water directly, through substrate or by multiple bounces between the surface and seabed so sea bed topography, seabed geology and the state of the sea can all affect transmission. Nonetheless even the 15km avoidance reaction distance modelled for Kentish Flats suggests an avoidance behaviour might occur in an area some 700 km^2 around each driven pile. As technology improves and developers seek to install OWFs in deeper waters larger piles may be required. The use of alternative pile designs (for example gravity bases or multi-pile jacket designs rather than large monopile structures) should be considered in any assessment of potential noise impact.

The duration of piling operations is also highly relevant. This will depend upon the number of piles required and substrate type (because the duration of the piling activity will be shorter in soft sediments and longer in harder sea beds). Large developments will require many months of continuous daily piling possibly over several seasons. Long-term displacement of species from an area is likely to represent a more significant impact than short-term displacement.

There are no peer-reviewed studies investigating the effects of pile driving on fish and the results of those studies on the effects of other noise on fish are variable with no certainty to which sounds will affect fish or how they will be affected (Hastings and Popper, 2005). The difficulty of transposing data from other noise sources to pile driving because the description of the signals is not directly comparable is also described by Hastings & Popper (2005). The degree of damage is not directly related to the distance of the fish from the noise source but to the received level and duration of the sound exposure (Hastings and Popper, 2005). There have been no studies examining the longer term effects of exposure to pile driving noise such as delayed mortality or behavioural responses of individuals or populations (Hastings and Popper, 2005). Therefore, although we may be able to define a zone of influence around the focus of the pile driving noise we just do not know what the other effects (e.g. behavioural changes) will be. Indications are that offshore wind farms act as fish aggregating devices with fish numbers within the wind farms greater than outside, which suggests that fish populations may recover from noise impacts during construction. However, data on abundance, distribution and species composition are currently lacking so the extent of such impacts cannot yet be determined.

To date, few data are available on behavioural responses. A strong response of Harbour Porpoise to pile-driving operations with a shift in behaviour (recorded over distances up to 15 km from the source) from non-directional swimming (often associated with feeding) to directional swimming (often associated with avoidance) is reported in Tougaard et al (2003). However, it should be noted that devices were used to deter animals before and during the pile driving operations. Although the frequency of porpoise encounters, recorded by acoustic data-loggers, returned to normal levels within 3-4 hours of piling and the deterrent devices ceasing, the impact on individuals and the nature of porpoise activity after the cessation of piling was not considered. Porpoises were observed within the operational Horns Rev wind farm (Tougard et al 2004). The difficulties in determining the effects of the Horns Rev wind farm due to the large variation in abundance of porpoises and technical problems with the acoustic data loggers is described in Tougard et al 2005. Baseline data has not yet been included in the spatial modelling analysis so it is not possible to separate the effects of the wind farm from a natural higher or lower abundance of porpoises in the wind farm area (Tougard et al 2005). Although, the correlation between observations and distance to wind farm was very weak, so indicating little effect of the wind farm on harbour porpoise abundance, further analysis is required before any conclusions can be reached on the scale of impact on porpoises from the wind farm (Tougard et al 2005). Acoustic dataloggers showed that harbour porpoise abundance decreased over the entire area during the study period, however, too many confounding factors exist for any cause and effect relationships from the wind farm to be established. Teilmann et al (2004) showed increased inactivity of the acoustic data-logger during construction at Nysted OWF, of up to 6 times greater than in a reference area 10km away from the site. Piling activities led to periods of data-logger inactivity of between 4 and 41 hours in both the construction and reference areas, indicating that harbour porpoises largely avoided the wind farm area during the construction period.

An overview of studies on seals at Horns Rev and Nysted is given in Miller (2005), where seals were shown to stay in the water with fewer landings (haul-outs) during pile driving but little difference after construction compared to before. Edren et al (2004) stress that wind farm areas are small compared to the range of most of the seals tagged at Nysted. However, areas of particular sensitivity, such as haul-out sites or those containing pups, require further consideration.

Noise will also occur from other construction activities, including boat traffic and cable laying. In addition to the piling at North Hoyle, about 20 hours of drilling for each foundation piece was also required. Although drilling noise was detectable up to 7 km away from the source, the low level (below $90db_{ht}$) indicates less probability of a behavioural effect. Cable laying may also produce noise which will arise from cable-laying vessels, jetting or ploughing equipment and other associated activities. Although these levels may be high (178dB measured at North Hoyle) their relatively short duration is likely to be less of a concern than piling.

The available evidence described above suggests that the noise generated by pile driving and cable laying are at levels that could elicit behavioural responses in marine animals (fish and mammals) over a wide area from which animals could be displaced during construction works. Fatalities or physical injury from piling is limited to within a relatively small distance of the source so, because the numbers of organisms impacted in this way will be relatively low, this is likely to be more of an animal welfare issue than an ecological or population level effect (although it should be noted that under Annex IV of the Habitats Directive species are protected from deliberate disturbance at the level of the individual. Displacements from, for example, feeding areas caused by extended periods of construction, together with impacts on behaviour caused by cumulative and/or in-combination construction impacts from other wind farms could amount to significant impacts on populations in the vicinity of a wind farm site.

Although the studies described above indicate that populations may return to areas after submarine noise from construction activities has ceased, evidence for long-term impacts remains limited. Given the extended construction times, of twelve months or more, and the likelihood of noise impacts from multiple construction sources and other marine users such as aggregate extraction, shipping and oil and gas production, the possibility of long-term impacts arising from submarine noise should not be discounted.

It should be noted that there is not always a clear understanding of the abundance, distribution and relative importance of the biota in any proposed development area, particularly in respect of highly mobile species such as marine mammals and fish. Our knowledge of impacts of submarine noise on various receptors is low. Research projects currently being carried out for oil and gas activities in the UK are likely to provide information on noise source characterisation and species impacts but it is unlikely that full knowledge of noise impacts will ever be understood (particularly in respect of the large areas that may be impacted upon from >5m piles).

Our knowledge of the efficacy of mitigation measures is limited, however (Nedwell et al, 2005), being based only on operations in relatively small spatial areas (e.g. coast protection works, harbour developments and offshore hydrocarbon developments) and of relatively short duration (e.g. days or weeks). The space covered (hundreds of square kilometres) and duration (over months or years) of piling activity for offshore wind farms has the potential to have a major ecological effect. The suite of existing mitigation measures used to date is not extensive. Some measures such as soft start (involving a gradual build up in the noise intensity to trigger flight responses before more severe impacts can occur) and avoiding sensitive times (spawning/breeding etc) may assist with reduction of impacts, but their efficacy has not been properly assessed. Species and individual responses to such basic mitigation measures are likely to vary considerably. Possible mitigation measures may include alternative pile design and driving methods, the use of bubble curtains (which can be effective in more sheltered waters) and other barriers to noise transmission. Such approaches may be particularly effective because reducing noise at source is more likely to be effective than attempting to mitigate impacts over a wider area (Nedwell et al, 2005). “Pingers” and “scrammers” could be used to deter marine species from entering an area of predicted noise impacts. However, in respect of these active deterrents, further information is required as to both their impact on species and their efficacy (e.g. habituation, attraction etc). Because the use of such devices may constitute deliberate harassment their deployment may require specific licensing.

An article on the construction of the Canada Place Cruise Ship Terminal, Vancouver (www.piledrivers.org) describes proposals on methods to mitigate the pressure effects of pile driving based on consultation with experts in North America and the UK. The proposals include:

- Acoustic or strobe light fish deterrent systems
- Temporary fixed or floating barriers
- Rubber or foam bladders wrapped around each pile
- Changing the frequency of the shock wave generated during pile driving by filling the pile with dense material
- Use of an alternate hammer or cushion between the hammer and the pile
- Large coverage air bubble mats installed on the sea floor
- Small manifold bubble curtains

All worked well in theory but the favoured option on cost effectiveness and performance was the small manifold bubble curtain. The bubble curtain reduced underwater overpressure during pile driving from 22 pounds per square inch to 3 pounds per square inch.

KNOWLEDGE GAPS:

Prediction of levels of underwater noise during construction as part of the environmental impact assessment process requires improvement. More complex models taking account of differing site conditions (substrate type, bathymetry etc) and how these affect transmission loss are capable of informing the process while monitoring schemes implemented as part of projects due to commence construction in the near future may help to inform future EIA and verify current predictions.

Pile driving and cable laying noise are the main impacts of concern. Most notably as technologies move further offshore the use of larger (6 metre plus diameter) driven piles may create impacts over relatively large distances (15km and over). Our knowledge of impacts of sub-sea noise on various receptors remains low despite much research in this area. Although we are more aware of *physiological damage caused to some marine species by exposure to high noise levels we are less certain of impacts on behaviour. There is uncertainty surrounding "background" noise levels and the cumulative noise impacts of humankind's many marine activities.*

Research projects currently being carried out (for example those commissioned by the UK's oil and gas regulator) are likely to provide information on noise source characterisation and species impacts in the near future.

Our knowledge of indirect or secondary impacts of sub-sea noise is also incomplete. For example, noise may affect fish spawning areas with a knock-on effect on bird feeding.

Our knowledge of the efficacy of mitigation measures is limited based on operations in small spatial areas and of relatively short duration. The suite of existing mitigation measures is not extensive. Some measures such as soft start and avoiding sensitive times (spawning/breeding etc), may assist with reduction of impacts but their efficacy has not been properly assessed. Research into the efficacy of other possible mitigation measures is required. A desk-based review of mitigation measures is being proposed in the UK under the auspices of COWRIE. These measures may include alternative pile design, the use of bubble curtains and other barriers to noise and the use of "pingers" and "scrammers" to deter marine species from entering an area of predicted noise impacts. In respect of active deterrents further information is required as to both their impact on species and their efficacy (e.g. habituation, attraction etc).

All the information available to date raises serious concerns over the noise produced by pile driving. Obviously the abundance and distribution of noise sensitive species in a proposed development area is critical and in these areas one clear option is to utilise foundation designs whose construction involves much lower noise levels. Therefore in terms of noise impacts gravity bases may be a more acceptable option, however, better information is needed from detailed investigations into the feasibility in different marine environments and cost-benefits of the available foundation types.

1.1.3 Construction plant movements

Seals were observed within the Nysted wind farm throughout the construction (Edren et al (2004) and Tougaard et al (2003). However boat movements close to haul-out sites are known to impact upon the use of such sites. The long-term impact of extended presence of construction traffic on a large wind farm site for extended periods of time has not yet been assessed due to the relatively short period of time that offshore wind farms have been present.

KNOWLEDGE GAPS:

The response of marine species to frequent boat traffic is not well understood. Impacts, if any, will be dependant on the distribution and abundance of organisms at specific sites. In researching this paper we have found no data on how boat traffic could impact upon fish but would not expect these to have an adverse impact.

1.1.4 Pollution incidents

OSPAR is aware of two types of pollution incident during the construction of at least two OWFs in the OSPAR area. The first involved the accidental release of grout during the construction of two OWFs in the OSPAR area. In these cases there was a failure of the seal between the turbine transition piece and the pile resulting in a loss of approximately 30 tonnes of grout (released under pressure). Regular monitoring of the equipment and instrumentation did not identify the problem which only became apparent after completion when it was observed that only a small fraction of the grout had entered the transition piece. In both cases diver inspections after the accident failed to identify grout on the seabed. The grout used was from the OSPAR Harmonised Mandatory Control System (HMCS) list of notified offshore chemicals so its ecotoxicological properties were known. In these two examples as the accident was limited to a single turbine and the material was apparently rapidly dispersed the impacts are expected to be minimal. However, were this to have occurred at several turbines the impacts would be a greater cause for concern. OSPAR has also been informed of two incidences where the protective paint on the monopiles has failed. This was manifested by osmotic/electrolytic blistering in the splash zone due to encapsulated solvent following the application of a single thick coating of paint rather than the recommended and usual multi-layered approach in which solvent is allowed to evaporate between applications. These incidents highlight the need to use chemicals from the national HMCS approved lists of chemicals, to follow manufacturers' instructions on chemical usage and where such incidences could be anticipated to ensure that each offshore development has a mandatory Marine Pollution Contingency Plan.

1.2 Impacts Above Sea Level

- noise;
- construction plant movements.

1.2.1 Noise

Construction noise impacts above the sea level have generally not been considered to be significant to receptors such as seabirds. Construction based noise may be discernable onshore but not at levels deemed to represent a nuisance to human populations. Of course noise levels experienced onshore will be highly dependent on the distance from construction activities.

1.2.2 Construction plant movements

Video monitoring at the Nysted offshore wind farm demonstrated no discernible changes in behaviour of seals as a result of the increased boat traffic associated with the construction of the wind farm (Edren et al (2004)) although boat movements were controlled to avoid the seal sanctuary.

Certain seabird species (most notably sea duck and divers) are known to exhibit avoidance behaviour in the presence of vessels. There is the possibility at many sites that disturbance associated with construction may be greater during this period than during operation. Christensen *et al* 2004 reported no significant impact on birds in respect of construction of the Horns Rev wind farm although it is notable that bird numbers at that site were generally low. However, the occurrence of divers and Alcids were recorded in markedly lower numbers at distances over 2,5 km from the construction activities suggesting that these species avoided the area (Christensen et al, 2003). Impacts can be mitigated by timing construction activities to avoid times of high sensitivity.

KNOWLEDGE GAPS:

Certain bird species, most notably sea duck and divers, are known to exhibit avoidance behaviour in the presence of shipping. Further study of thresholds of various species tolerance of construction traffic may be required as part of environmental impact assessment but, generally, there is no requirement for generic research.

2. Physical Presence

2.1 Impacts Below Sea Level

- Loss of seabed habitat;
- Introduction of new substrate – scour protection & foundations;
- Barrier effects;
- Hydrodynamic, sediment transport & water quality;
- Socio-economic.

The components of an OWF that are placed below sea level are the: foundations, towers, scour protection and cables.

2.1.1 Loss of seabed habitat:

Habitat loss and disturbance can be caused by the footprint on the seabed of the foundations and/or any scour protection. Different foundation options are available but can be divided into 3 main groups: monopiles, multi-piles and gravity/caisson bases. The towers for offshore wind farms vary in size depending largely upon the generating capacity of the turbine, and proposals in the UK have included towers of diameter 4-6 m. However, towers of 5 m diameter would appear to be the dominant size in the environmental statements reviewed irrespective of foundation type. The expected use of larger turbines (>5 MW) in the near future is likely to lead to increased pile diameters.

A 5 m diameter monopile will have a 20 m^2 footprint on the sea bed in areas where scouring is not an issue and therefore additional scour protection is not required. Gravity-base foundations are approximately 30 m in diameter and, if the bases are assumed to be circular, occupy an area of ~700 m^2.

The flow of water around turbine bases can create scour pits in soft sediment. The Scroby Sands OWF off the East Norfolk coast of the UK is located in very dynamic waters and is considered to be the site where the extreme conditions may generate the largest scour pits around turbine foundations. Convention indicates that scour pits are limited to within ten times the diameter of the obstacle (ABPmer, 2005). Surveys at the Scroby Sands OWF confirmed predictions made during the Environmental Impact Assessment that the scour pits around individual monopile foundations developed to 5 m depth and 100 m diameter (Rees, 2006 in prep). The largest scour pits affect approximately 7850 m^2 of sea bed (Table 3).

Table 3 Potential areas of sea bed affected by scouring / scour protection for monopile foundations for different numbers of turbines, based on data gathered from Scroby Sands OWF, UK (Rees 2006 in prep).

No. Turbines	Area of seabed affected (m^2)
1	7 854
10	78 540
30	235 620
100	785 400
200	1 570 800
300	2 356 200

The work at Scroby Sands OWF also showed that scour pits for monopiles at the site are independent of one another, i.e. there is no connectivity between any two scour pits within a wind farm array. In order to optimise utilisation of wind resources turbines within a wind farm will be spaced between 500 m and 1000 m apart. This suggests that with the relatively wide spacing of turbines required for efficient operation scouring impacts are likely to remain localised and not merge into continuous areas of disturbance but instead remain as discrete and small areas separated by large areas of relatively undisturbed sea bed.

Computer modelling has also shown that the influence on hydrodynamics from a typical OWF layout is localised to individual structures and at stages of peak flow (ABPmer, 2005). The ABPmer (2005) study also showed that the combined consequence of the modified flow regime and presence of a large number of small physical obstacles to a sediment pathway would appear to have minimal influence on the net deposition patterns predicted for sand transport and for different grades of sediment and also that the structures have little effect on waves.

Although, the scour pits at Scroby Sands OWF have been shown to be independent of one another, scour tails were identified in the more exposed areas (Rees, 2006 *in prep*). These features extend to connect adjacent foundations and require further study and definition so that the zone of impact on the sea bed can be quantified. Investigation into the consequences for benthic habitats from these scour tails is required as currently our understanding of this is limited. Such effects are likely to be limited to the near field around the OWF array as the impacts on sea bed sediments are limited to within a few hundred metres of the wind farm array (Rees 2006 *in prep*). The areas of sea bed disturbance at Scroby Sands are in a habitat where it would be expected that the benthic organisms are adapted to living in highly mobile sediments so it may be that significant impacts are minimal, particularly as the increases in loads of suspended sediment concentrations from scouring there are very low when compared to background (Rees, 2006 *in prep*). Studies at Horns Rev were unable to demonstrate any changes to benthic infauna within the wind farm array arising directly from the construction of the wind farm (Bioconsult A/S, 2003b). Mobile sediment habitats are by their nature dynamic environments and the organisms that live within them are adapted to cope with sea bed perturbations. No information on actual or potential scouring around gravity bases is available. Because of their larger footprint the hydrodynamic disturbance from these and multi-pile foundations are likely to be greater than for monopiles, so that further investigations are required to quantify the effects on the sea bed and biota.

Cables are laid in trenches in soft sediments or across the surface on hard substrates. Where cables are laid on the surface they will require protection with rock or concrete. The trench or any protection will be 1-2 m wide. The cables which link the individual wind turbines are several hundreds of metres in length whereas the cables to shore will be several kilometres or tens of km in length (in Germany some proposals have cables 160 km in length). Cables are laid in an almost continuous length from specialised equipment towed by a sea going vessel. Cables are buried by plough, trencher or a jetting device (where water released at pressure cuts a trench). Impacts will be increases to suspended sediment concentrations (described above) and loss or disturbance of sea bed habitat. Boyd et al (2004) describe that sites exposed to low levels of aggregate dredging show signs of recovery 2-3 years after cessation. As OWF cable laying is a less intense activity parallels may be drawn for recovery times from the disturbance. Soft sediment recolonisation following disturbance is dependant on larvae settling from the water column or post-settlement life stages (larvae and adults) laterally advecting across the seabed (Whitlach et al, 2001). The rate of recovery from disturbance is proportional to the adult:larval recruitment rate (Whitlach et al 2001) with the communities in which most of the colonists are at the post-settlement life-stages predicted to recover faster than communities in which recruits are primarily from the larval pool. Given the narrow dimensions of the zone of disturbance from cable burial it may be postulated that lateral advection of post settlement life-stages could be the dominant form of recolonisation. Cable-laying may also impact upon more sensitive or designated habitats such as biogenic reef (most notably that formed by *Sabellaria spinulosa* and *Modiolus modiolus*) and coastal/estuarine habitats.

The area of the United Kingdom Continental Shelf (UKCS) is ~ 870 000 km^2 (Koen Vanstaen, Cefas *pers comm*.). In the UK if all the proposed developments were constructed there would be 540 turbines from Round 1 and 1874 turbines from Round 2. From the above calculations, if we assume that all these turbines had monopile foundations, an area of sea bed of 14,7 km^2 would be lost to foundations and scour protection. Active aggregate extraction on the UKCS covers an area of 144 km^2 (data for 2003, from www.thecrownestate.co.uk), dredged material sea disposal sites cover 310 km^2 (Koen Vanstaen, Cefas *pers comm*.) and cuttings piles produced by the offshore hydrocarbon industry cover 1605 km^2 (www.ukooa.co.uk). So in relative terms the 14,7 km^2 from the combined total footprint of all monopile foundations and scour protection from Round 1 and Round 2 proposals amounts to very small areas of habitat loss or change indeed.

The significance of such losses does, however, need to be assessed on a site-specific basis (i.e. the sensitivity and biological importance of the area needs to be assessed in the environmental impact assessment). In particular in European waters Natura 2000 habitats such as biogenic reef *Sabellaria spinulosa* reef, *Modiolus modiolus* reef, submerged sandbanks and other features listed in Annex 1 of the Habitats Directive will require additional consideration given their protected status.

KNOWLEDGE GAPS:

- *The size, shape, depth of scour pits, sediment transport and hydrodynamic impacts for gravity, caisson or multipiles are not known. Work to investigate these is being planned in the UK by the DTI Research Advisory Group (RAG).*

- *Effectiveness and design of scour protection needs further investigation – guidance is required on design and installation to reduce secondary impacts, including foundation designs that minimise the need for scour protection.*
- *Better predictive models are required to determine the effects of scouring to account for differences in sediment supply, hydrodynamics etc.*
- *A better understanding of scour pans and secondary scour is required so that the overall impact on the sea bed can be quantified.*
- *For impacts on benthos from scouring and scour protection it is not thought that generic or large-scale studies are required. Impacts are site specific so a thorough EIA and where necessary post construction monitoring for each site may in many cases suffice. Depending on the location of wind farms further research may be required in respect of impacts on, for example,* Sabellaria spinulosa *reef or the stability of sandbanks.*

Although in percentage terms habitat loss from offshore wind farm developments is low there is currently insufficient information on the distribution of spawning / nursery areas for priority marine species to know what the impact of loss of seabed habitat in any one area may be. Sensitivity mapping projects currently underway are likely to assist in this respect.

Loss of seabed habitat may impact upon marine species, particularly those feeding in the area of the development. Most notably, areas of seabird feeding grounds may become effectively sterilised if birds are displaced from the wind farm area. The extent to which displacement occurs is not well known. Such a response is likely to vary between species. The importance of such effects and the need for further study are site specific. This issue is considered further below.

2.1.2 Introduction of new substrate – scour protection & foundations:

For monopiles and multipiles the foundations are made of steel whereas gravity bases are more likely to be made of concrete, perhaps with a steel skirt. For all OWFs the towers tend to be made of steel. Both steel and concrete are commonly used in the marine environment, in ports/harbours, sea defences, and hydrocarbon platforms, so that a strong knowledge base exists within these industries to help determine how the introduction of these types of materials into the marine environment changes the substrate and how the biota react. Many OWFs are sited in areas of soft sediment. In these areas introducing scour protection (rock, concrete mattresses, grout bags etc) or gravity bases will change the sea bed characteristics from mobile sediments to a harder substrate. Similarly, the steel monopiles introduce a hard substrate into the water column, and provide a surface that can be colonised by species that might not ordinarily be present in soft sediment environments. Bacchiocchi & Airoldi (2003) studied the colonisation of coast-protection structures along the soft sandy coastline of Emilia Romagna, Italy, where one explanation given for the low diversity of colonising species is the distance (more than 100 km) from natural rocky reefs. The relatively short distances that larvae and propagules will disperse is also described in Reed et al (2000). Colonisation would thus appear to be primarily dependant on the proximity to other natural or anthropogenic hard substrates.

A description of the colonisation species of hard substrates based on observations and the available literature is given in Hiscock et al (2002). The stylized zonal communities likely to colonise structures within 10 km of the coast and in water deeper than 15 m are described as:

- Intertidal: predominantly barnacles and ephemeral algae (e.g. *Semibalanus balanoides*, *Elminius modestus*, *Ulva lactua*, *Enteromorpha intestinalis* and *Porphyra spp*).
- Kelp Zone (~1-2 m): Kelps, foliose red seaweeds, barnacles and encrusting sea mats with *Mytilus edulis* sometimes dominant below the kelps.
- Shallow subtidal (~2-6 m): Could be either large individuals of *Metridium senile* with groups of *Sagartia elegans* and patches of hydoids (*Tubelaria larynx*) and sponges (*Halichondria panicea*), or dominated by *Mytilus edulis* with scattered elements of the above and *Asterias rubens* as predators.

- Main column to scoured area: Dominated by *Metridium senile*, *Sagartia elegans*, *Alcyonium digitatum*, *Obelia spp*., *Kirchenpauria pinnata*, *Tubilaria indivisa*, *Amphilectus fucorium* and *Ascidiella spp*.
- Base of structure (scoured areas and scour protection): Dominated by *Pomotoceros triqueter*, and *Balanus crenatus* with encrusting bryozoan sea mats. Reef species such as *Labrus bergylta*, *Trispterus luscus*, *Homarus gammarus, Cancer pagurus* and *Conger conger* may be attracted.

A study of fouling communities at four North Sea oil platforms over an eleven-year period, although in deeper waters than the planned offshore wind farms, recorded similar results (Whormesley & Picken 2003). Vertical zonation was similar on all installations even though water depths varied from 80 to 169 m. In the surface 0-20 m subtidal zone *Mytilus edulis* dominated with hydroids initially dominating the zone below. After 3-5 years *Alcyonium digitatum* and *Metridium senile* began to recruit below the mussel zone and after 8-11 years *Metridium senile* became dominant in the 30-80 m zone with hydroids dominating the deeper areas. *Alcyonium digitatum* appeared in patches in the 40-100 m zone (Whormesley & Picken 2003).

The primary fouling organisms of mussels, hydroids and tubeworms observed in Whormesley & Picken (2003) show r-selected life-history strategies (i.e. opportunistic and short-lived) with high fecundity, rapid growth, sexual maturity at a young age and the ability to release large number of larvae (Barnes and Hughes, 1999). The later colonists (e.g. *Metridium senile*) show k-selected life-history strategies as they are more competitive, resistant to predation, have greater longevity and are capable of reproducing repeatedly in successive seasons (Barnes and Hughes, 1999).

That *Mytilus edulis* dominates the shallower depths is probably the result of wave action (Little and Kitchen, 1996). Few predators were observed by Whormesley & Picken (2003) so predation was unlikely to be a dominant factor in their observations. *Metridium senile* dominated the middle zones where there was limited physical disturbance so the most likely cause for their dominance was competition for space and food (Whormesley & Picken, 2003). The further offshore structures are installed the larval supply from inshore hard stratum may be reduced and elements of deep-water communities may occur (Hiscock et al, 2002).

The above section on loss of sea bed habitat showed that, if monopiles are used relatively small areas of sea bed will be modified from the introduction of scour protection, and that the footprint of a gravity base is relatively small (Table 2). The towers of a wind turbine are made of steel and the surface area submerged is directly proportional to the water depth (Table 4).

Table 4. The surface area of a single 5 m diameter pile available for colonisation by epifouling organisms in various water depths.

Water depth (m)	Surface Area (m^2)
1	15,71
10	157,1
15	235,65
20	314,2
25	392,75

Seasonal differences in abundance and biomass of benthic and colonising organisms mean that it is important to sample at similar times of the year to ensure the comparability of datasets (Bioconsult A/S, 2001). The OWF foundations at Horns Rev and Nysted have been readily colonised with epifouling communities, causing a local increase in biodiversity compared to that recorded before construction (Bioconsult A/S, 2003a; Energi E2 A/S, 2004). These studies also showed significant annual variations in the epifouling communities, indicative of ecological succession. The vertical zonation identified in Bioconsult A/S (2003a) and Energi E2 A/S (2004) is consistent with the stylised representation described in Hiscock et al (2002). The most numerous species found colonising the underwater structures at the Horns Rev offshore wind farm was the amphipod *Jassa marmorata* (Bioconsult A/S 2004[2] and 2005). *Mytilus edulis* was dominant in the 2-3 m below the surface of the water and seven species of fish were identified the majority of which are typically associated with hard substrates. Bioconsult A/S (2005) describes the species observed colonising the Horns Rev turbines, including:

- Littoral zone: *Mytilus edulis, Balanus crenatus, Balanus balanus, Enteromorpha intestinalis, Ulva linza, Ulva lactua, Petalomia fascia* and *Petalomia zosterifolia.*
- Lower zone: *Pomatoceros triqueter, Tubelaria indivisa, Facelina bostoniensis, Metridium senile, Sagartia troglodytes, Alcyonium digitatum, Polycera quadrilineata* and *Electra pilosa.*

The predator *Asterias rubens* was identified to control the distribution of common mussels and barnacles. Some of the primary colonisers were less abundant in later surveys at Horns Rev, possibly the result of predation and/or competition for space (Bioconsult A/S 2005). The stability of the fouling communities was not expected within the next 5-6 years. Two red list species not previously recorded were identified in the post-construction surveys at Horns rev, *Sabellaria spinulosa* and *Sertularia cupressina* (Bioconsult A/S 2005). It is suggested that the hard substrate acts as a hatchery for *Cancer pagurus* as the numbers of adults and juveniles increased markedly between 2003 and 2004 (Bioconsult A/S 2005). All changes following the introduction of the hard substrate were explained by natural succession, predation and recruitment (Bioconsult A/S 2005).

There appear to be no significant differences in the epifouling organisms in the vertical aspect of the foundations and scour protection as a result of hydraulic regimes at the Horns Rev and Nysted OWFs (Bioconsult A/S, 2003a; Energi E2, 2004). A marked increase in the diversity of fish fauna was identified at Horns Rev, where, in addition to benthic fish species, shoals of cod and bib were observed. Artificial structures tend to change the patterns of distribution (composition and/or abundance) of locally abundant epibenthic species (Bacchiocchi & Airoldi, 2003). They do not necessarily increase species diversity.

Studies on oil platforms in the Gulf of Mexico (Carney, 2005) show that the colonising community is a dynamic system, with organisms continually accreting and being shed, and that settlement depends on changes in larval supply. Predation, competitive exclusion and bioerosion either directly remove the colonising matrix or sufficiently weaken it so that it is removed by currents or waves. Many of the environmental statements for OWFs claim that the growth of biota on the foundations will increase biodiversity, however, in most of these documents, it is also stated that the increased drag caused by epifouling organisms could affect the integrity of the foundations necessitating periodic cleaning campaigns (or use of a biofoulant treatment). Regular cleaning activities designed to combat bio-fouling will prevent climax communities from arising on hard substrate introduced to wind farm sites. In such cases predicted changes in biomass and biodiversity are likely to be short lived. So the colonisation of offshore wind farm foundations is analogous to that (in terms of species and timeframes) observed for other submerged structures.

Although the pre and post construction benthic surveys at Horns Rev identified significant differences in the infauna on the sea bed (Bioconsult (2003b), these same differences in community structure and sediment grain size were also observed in the reference area, suggesting natural change as the likely mechanism, rather than the construction and presence of the wind farm.

Given the sedentary nature of most species that colonise hard substrates, the relatively small surface areas available for colonisation (Tables 2 and 4) and the large spatial separation between individual turbines within a wind farm, it may be concluded that these changes to the biota will be restricted to within 50 metres (the radius of a scour pit) of any turbine and, if national planning regulations ensure that wind farms are not located in areas with sensitive and/or protected species and habitats, such changes may not have wider consequences. Such a conclusion depends upon the effective design and use of scour protection and/or foundation type and should not be taken to be an endorsement of larger-scale rock dumping or introduction of alien substrate when, as in most cases, more sensitive engineering solutions are both feasible and appropriate. In summary, the available evidence indicates that ecological succession and zonation on the submarine infrastructure of OWFs is likely to proceed in an analogous way to that observed on other structures and although some site specific monitoring on the first few wind farms constructed to validate this would be prudent any large-scale studies would seem unnecessary.

OWF arrays may act as fish aggregating devices (FAD). An 8-fold increase in biomass available as food resource for fish was observed around the foundations and scour protection at Horns Rev when compared to the original soft sediment habitat (Bioconsult A/S, 2003a). The analysis of stomach contents of fish caught within FAD shows that the fish did not feed on the organisms encrusting the submerged materials but on free floating organisms present in the water suggesting that fish use FAD for reasons other than food (Ibrahim et al 1996). Shape, geographical area, different environmental conditions and the ecology and behaviour of different species are crucial determinants in what organisms colonise areas surrounding artificial structures and these conditions can be transposed to FAD (Baine 2001). With an offshore wind farm the scope for different shapes is very limited. Aggregation of fish around North Sea oil platforms, particularly cod and saithe is described in Soldal et al (2002). Attraction of fish to offshore oil and gas structures in the Adriatic is also described in Fabi et al (2004) with higher species richness, diversity and catch rates recorded.

The reasons why FADs attract fish are largely unexplained but research suggests that shelter and protection from predators (including fishers) and orientation (i.e. fish using the FAD as a reference point in a sea otherwise devoid of such markers) are the most likely (Anderson and Gates, 1996). Species-specific fish behaviour is the key determinant and fish have been observed to aggregate during the day and leave to feed at night (and vice versa). Fish can spend days or weeks associated with an FAD before other urges eventually cause them to move on to be replaced by other individuals (Anderson and Gates, 1996).

As it will never be possible to collect data on every fish a representative sample needs to be taken. Anderson and Gates (1996) suggest the data needed to measure the effectiveness of FAD are: fishing area; fishing methods used; time spent using each method; total number, size and weight of each species of fish caught by each method. This provides information on catch per unit effort. Analysis of the individual lengths and weights will show relative changes in the nature of the fish resource over time (Anderson and Gates, 1996).

Exclusion of fishing activities within an offshore wind farm is dependant on national regulations, but irrespective of these controls fishing activities will be restricted due to limitations on gear and vessel manoeuvrability within the array. Any changes in fishing activity could have ecological consequences.

Closure of the predominant fishing activity within an area can benefit the target fish species as the impacts of fishing activity (fish mortality) are reduced (Horwood et al 1998, Rogers 1997) but there are a multitude of other parameters involved that will influence the distribution and abundance of fish. If wind farms do act as FAD they will do so in the short to medium term not by increasing fish numbers but by redistributing fish from the surrounding areas. At Horns Rev the average density of sandeels (all species) increased 300% within the wind farm array with a corresponding 20% decrease in the reference area (Jensen et al 2004) allowing the conclusion that sandeels were not negatively impacted by the construction and presence of the wind farm. Fishers displaced from areas closed to fishing, if not controlled, will have an increased impact on fish populations and the environment outside the area (Dinmore et al 2003).

KNOWLEDGE GAPS:

The species observed to colonise these structures are as expected so further generic or large-scale studies are not thought to be required. Impacts are site specific so a thorough EIA and where appropriate post construction monitoring for each site may often suffice although further research may be required in respects of protected sites or sensitive habitats where changes in species composition may be more significant.

With regards to the effects of biofouling on the integrity of structures (increased drag) is there a need for regular cleaning? If so, what are the longer-term consequences for biomass or biodiversity?

2.1.3 Barrier effects

The size and spacing of offshore wind turbines on the sea bed are unlikely to create a physical barrier to fish movements or migration routes. In researching this paper we have located no evidence to suggest that offshore wind farms or any other similar offshore structures (e.g. oil and gas platforms) form a barrier to fish, although the potential barrier effect from electromagnetic fields from the power cables is discussed under operational impacts. Miller (2005) summarises the findings of the studies at Horns Rev and Nysted that showed no changes in seal behaviour between pre and post-construction. Studies at Horns Rev and Nysted show Harbour porpoises within the wind farm array post-construction (Damsgaard Henrikson et al 2004 and Tougaard et al 2004) suggesting that these structures do not create a physical barrier for larger marine animals.

2.1.4 Hydrodynamic, sediment transport & water quality:

The Scroby Sands studies (Rees, 2006 in prep) demonstrated over a six month period the excavation of approximately 5 000 m^3 for a typical scour hole and approximately 20 000 m^3 from each of the less frequently occurring tails. Natural change in sediment budget during the same time period was between 100 000 and 400 000 m^3, so by comparison scoured material is low. Rees (2006, in prep) also demonstrates from measurements of the crests of bed-forms that there is very little movement in the position, size and shape pre and post construction indicating that apart from local impacts continuous bed-forms running through the site are unaffected by the wind farm. The background suspended sediment concentrations at Scroby Sands are high so the relative impacts of remobilised sediments is low, however, in areas where suspended sediments are relatively low the increased suspended sediment load could be a problem if there are sensitive organisms within the plume. In a companion study at the Scroby Sands offshore wind farm Cefas observed that wave shape, form and direction were unimpaired by the presence of the wind farm and recommended that there was no further need to monitor waves to assess wave diffraction and interference effects from monopile foundations on coastal erosion (Cefas, 2006 in prep).

2.1.5 Socio-economic

In some OSPAR countries fishing activities will be excluded within offshore wind farm developments. In the UK fishing is not excluded but it is acknowledged that certain activities will be restricted due to the presence of the turbines and sub sea infrastructure. Studies are underway in the UK to investigate what fishing activities can safely be undertaken within and offshore wind farm and the socio-economic impact on fishers should their activities be restricted. These will assist in the assessment of socio-economic impacts on fishers but until these studies have reported there is little that can be included in this paper.

KNOWLEDGE GAPS:

OWF in constrained areas may be close to dredged navigation channels. In areas where such channels migrate, what are the consequences for shipping if a channel migrates into an offshore wind farm? Further studies seem appropriate and are being planned in the UK by the DTI Research Advisory Group.

If fishing is excluded or activities restricted within OWF this may have a socio-economic impact on fishers. The full implications of displacement (economic and environmental) are unknown. Certain, fishing gears and techniques may in some circumstances be able to be deployed safely within a wind farm. Socio-economic and fishing activity studies are underway in the UK and are due to report shortly.

All the available information indicates that offshore wind farms will act as fish aggregation devices (FAD) by redistribution of fish from surrounding areas to within a wind farm array. The implications of a reduced area available for fishing and possibly fewer available fish (i.e. fishermen excluded from the wind farm but fish aggregated within it) needs further consideration. Consideration of synergies between offshore wind farms and other activities, e.g. fish farming although not a priority, merit investigation so that potential benefits can be properly assessed.

Consideration of the other benefits of offshore wind farms is required at the site specific level, e.g. investigation of refuge effect / value, the effects of excluding activities from a wind farm site, aquaculture facilities. There are already a large number of existing studies on artificial reefs, recolonisation, exclusion of activities so generic studies are unnecessary.

2.2 Above Sea Level

- Physical presence – barrier;
- Navigation – collision & radar etc interference;
- Seascape, visual impacts and public perception.

The components of an OWF that are placed above sea level are the: towers, nacelles and blades together with associated safety lighting

2.2.1 Physical presence – barrier:

We know from corpses found at terrestrial wind farms that turbines and blades can give rise to significant bird (and bat) mortality and it is blade/turbine strike that features strongly in the public perception of windfarm impact on birds. However two other issues, barrier effect and displacement may, in fact, be more significant, at least in respect of offshore wind. These three issues are all considered further below as operational impacts.

KNOWLEDGE GAPS:

The physical presence of offshore wind farms is known to impact upon seabirds (Stewart et al, 2004). Gaps in our knowledge of this issue are considered below under "operation".

2.2.2 Navigation – ship collision & radar etc. interference:

All offshore wind farm developments in all OSPAR countries have to undertake collision risk assessments and have to be appropriately lit and marked according to international standards. In the UK the Maritime and Coastguard Agency has produced interim guidance to mariners operating in the vicinity of offshore wind farms and has released a consultation paper on navigational safety issues for UK offshore renewable energy installations (available at www.mcga.gov.uk). Howard and Brown (2004) report the results of investigations into the effects operating offshore wind farms have on radar, communications and positioning systems of maritime vessels. These investigations were based at the North Hoyle offshore wind farm in the UK and came to a number of conclusions:

- Global Positioning Systems (GPS) – no evidence of impact on basic reception or positional accuracy;
- Magnetic compasses – no evidence of compass deviation;
- Loran C – signals received without any apparent degradation;
- Helicopter radar and communication systems – see later comments;
- VHF and other communications – no evidence of effects from the structures on any voice communications systems, however, VHF direction finding and other similar equipment did not function properly when within 50 meters of the structures;
- Automatic Identification System (AIS) – fully operational on the survey vessels within the wind farm;
- Small and large vessel and shore based radar performance – range and bearing discrimination was limited and the turbines produced blind and shadow areas in which other turbines and vessels could not be detected. Bad weather conditions are likely to compound such effects.

Most of the above are not anticipated to compromise marine navigation or safety. However, because of the strong vertical signal ship borne and shore based radar is compromised with regards to ship-to-ship collision avoidance when operating close to offshore wind farm structures. To a degree such impacts can be mitigated if wind farms are located away from shipping lanes and if mariners are forewarned extra due care can be taken, the exception being in periods of bad weather and poor visibility.

Brown (2005) reports the results of helicopter search and rescue trials at the North Hoyle offshore wind farm. This study demonstrated that radio communications from sea to helicopter (and vice versa) and VHF homing systems operated satisfactorily. In dry weather conditions turbines, vessels and humans were clearly identifiable by the aircraft's thermal imaging system, however, these were limited in mist and precipitation. Radar detection was compromised when vessels were within 100 meters of a turbine. Tracking of the aircraft around the wind farm was poor from both ship and shore based radar. Increased aircraft power was also required downwind of the wind farm. Air rescues within a wind farm in restricted visibility could therefore prove difficult.

2.2.3 Seascape, visual impacts and public perception

Offshore wind farms are generally assumed to be less visually intrusive than their terrestrial counterparts, largely because of their distance from land-based observers. Relatively little work has been carried out on the visual acceptability, or otherwise, of these developments. The Guide to best practice in seascape assessment (Hill et al, 2001) was the first publication in the UK on seascape and forms a key reference here. It provides a method to divide the seascape into a set of spatial planning units, primarily based on visual character. Scottish Natural Heritage used the spatial planning principles set out in Hill et al, 2001 in relation to offshore wind farms in Scotland (Scott et al, 2005). Further to this, guidance has been produced on seascape and visual impact assessment (DTI, 2005) to assist offshore wind farm developers take seascape and visual impacts matters into account in the EIAs.

Locating wind farms offshore offshore, i.e. away from such landscapes, can be a good idea in principle, if it has the effect of lessening visual impacts and therefore reducing opposition. Most of the current built or proposed offshore wind farms are still visible from the coast and all are visible from vessels at sea. The sea is a featureless, flat, exposed visual environment in which wind turbines tend to be particularly visually conspicuous, particularly in contrasting lighting conditions.

Although offshore wind turbines are not actually on land, they can be in the visual setting of highly valued and protected landscapes. There is a visual sensitivity relationship between areas of land and areas of sea and by inference, some areas of sea are more visually sensitive to offshore wind farm developments than other areas.

KNOWLEDGE GAPS:

Further study into the impact of offshore wind farm projects on coastal communities and marine users (particularly recreational and tourism uses) is required. Hill et al, 2005 touch on this, together with historic and archaeological aspects of seascape, though there is scope for further work. English Heritage has also recently commissioned some work on the historical and archaeological aspects of seascape based on Liverpool Bay.

The particular issue of public acceptance of offshore renewable energy developments is not well understood, partly because such development is a relatively new phenomenon. It is not known how public perception of them is affected by climate change and sustainable development agendas, but, there is quite a lot of transferable work done for onshore wind farms.

The general conclusions from terrestrial wind farm public attitude studies are that a substantial majority of people support renewable energy development in principle. However, some of these studies, in concentrating on the question of the principles behind the development, have been prepared so that they can be conveniently taken forward and used as evidence as support for a particular development proposal. This confuses two issues and fails to recognise that the public can become sensitised to individual development proposals in or near particular (especially highly scenic) landscapes. The recent Whinash terrestrial wind farm proposal in Cumbria, UK went to public inquiry after which consent was refused because of its impact on the landscape. Anecdotally, it appears that many if not the majority of terrestrial wind farm public inquiries centre around public objection to the visual impacts, something not explained by studies showing general support for renewable energy developments in principle. Very, few terrestrial wind farm wind farm *public attitude surveys concentrate on the latter issue, i.e. what is it about the landscape that people value and this needs to be rectified.*

Collation of public perception studies, understanding tolerance limits and what matters to people and why are all factors worthy of further consideration.

In respect of most seascapes there is currently a lack of a baseline for strategic planning for the siting of renewable energy developments. Methodologies could be drawn up assessing the capacity of regional seascape units to accommodate change. In Wales a project is underway to provide this assessment (due for completion March 2007).

However, public acceptance is likely to include factors beyond merely visual intrusion. Tourism, quality of life and job creation may all be relevant factors here. For example, can possible fish aggregating impacts provide benefits for sport fishing?

Further information about the spatial and temporal uses of coastal seas for recreation and potential conflicts of renewable energy projects with recreational user groups (yachting, sport fishing etc) is required.

3. Operation

3.1 Impacts Below Sea Level

- Noise & Vibration;
- Electromagnetic Fields;
- Maintenance activities.

3.1.1 Noise & Vibration

The studies discussed suggesting that wind farm structures do not create a physical barrier for larger marine animals also suggest that noise and vibration from the operation of wind farms does not adversely impact on those species. Further work on the characterisation of subsea noise brought about by wind turbine operation is being carried out under the auspices of COWRIE (see www.offshorewind.co.uk). The impacts of larger developments forming linear barriers to migration or foraging routes are unknown.

KNOWLEDGE GAPS:

Measurements of underwater noise from the operation of generation units are ongoing but to date assessment of the data is not yet fully available.

While the physical presence of turbine towers in the water is unlikely to create a barrier to marine species, noise from generation units conducted into the water via those towers may be of such a level that it deters movement into and through a site. This may particularly be of concern with larger developments and the displacement of marine mammals from migration routes or feeding areas. Further research is required in this respect. An existing project carried out in the UK under the auspices of COWRIE may deliver some data on noise levels in this respect.

Knowledge about noise and vibration from maintenance trips, their timing and impacts on marine species is lacking.

3.1.2 Electromagnetic Fields

The impact of the electric and magnetic fields produced by sub sea power cables on marine wildlife has only recently begun to be studied. It is only in the last few years that awareness and consequently the profile of this potential problem has increased. The number and networks of cables associated with offshore wind farms and international export cables has raised the profile of this issue and research in Denmark and the UK has greatly improved our understanding of the fields generated.

The Danish studies based at the Nysted offshore wind farm targeted all fish species. Using pound nets either side of the cable the objective of the study was to ascertain if the electric and magnetic fields produced by the cable created a barrier to fish movements (Bioconsult A/S 2004). Comparisons of the data showed that catches in the pound nets from the west of the cable were not statistically different from those on the east. The study also concluded that the distribution of Common Eel, Baltic Herring, Atlantic Cod, Eelpout, Short Spined Sea Scorpion and Flounder was not changed beyond the differences expected from natural variation following the installation of the cable.

Although different species of fish and shellfish are sensitive to electric and magnetic fields it is the elasmobranchs that are most sensitive so it is this group of organisms that have been targeted for study in the UK. The ampullary electrosense of elasmobranchs can be used in the detection of prey, mates and predators (Sisneros et al 2003). Elasmobranchs demonstrate attraction responses to DC electric fields of between 0,005 and 1 μV/cm and avoidance responses at 10 μV/cm (Kalmijn 1982). Avoidance responses by *Scyliorhinus canicula* from electric fields of 1000 μV/cm and attraction at 0,1 μV/cm have been demonstrated (Gill & Taylor 2001).

In the UK two studies were progressed to improve knowledge and understanding of electric and magnetic fields from sub sea power cables and how these may effect the behaviour of elasmobranchs (COWRIE 2003 and COWRIE 2004). The COWRIE (2003) study involved computer modelling of fields produced by a 132 kV XPLE three-phase submarine cable buried at 1 metre depth and direct measurements. The modelling showed that a cable with perfect shielding does not produce an electric field directly but that a magnetic field is generated in the near field to the cable by the alternating current. This magnetic field generates an induced electric field of approximately 0,9 μV/cm that is within the range detectable by electrosensitive fish. This induced electric field is also similar for cable with or without perfect shielding. Burial was shown to be ineffective in dampening the field although the increased distance from source to electroreceptors could provide some mitigation against the impact on elasmobranchs. Another observation in the COWRIE (2003) study was that the reduced current in 132 kV cables produces a lower induced electric field compared to 33 kV cables. So the studies have shown that the fields produced by the sub sea power cables used in offshore wind farm developments are within the ranges that could affect the behaviour of electrosensitive fish but to date no information is available on the importance of any such changes in behaviour.

Further work to assess the importance of these behavioural effects using electronically tagged fish in a mesocosm experiment is under preparation in the UK.

KNOWLEDGE GAPS:

If it is demonstrated to be an adverse impact identification of key species and their sensitivity to EMF needs to be established, including consideration of different life cycle stages. Research in the UK under the auspices of COWRIE has delivered some answers to these questions and a further stage of research on behavioural impacts that addresses these issues is proceeding. See www.offshorewindfarms.co.uk for further details.

3.1.3 Maintenance activities:

Maintenance activities carried out by boat have not been shown to have a significant effect on fish or marine mammal populations. The risk of harm to individuals through propeller strike or other collision has not been assessed.

KNOWLEDGE GAPS:

Such traffic could be sea based vessel or helicopters. Further study of thresholds of various species tolerance of maintenance traffic, not just in terms of presence but also the associated noise, may be required as part of environmental impact assessment but, generally, there is no requirement for generic research. The ability of species to habituate to increased vehicle traffic is known in many cases but different sensitivities will occur in respect of different sites.

3.2 Impacts Above Sea Level

- Noise & Vibration;
- Maintenance activities;
- Barrier effect, collision and other impacts on birdlife.

3.2.1 Noise & Vibration

In researching this report we have located no evidence to suggest that operational noise from offshore wind farm will impact terrestrial (including airborne) organisms.

3.2.2 Maintenance activities

Maintenance activities carried out by boat have not been shown to have a significant effect on fish or marine mammals although studies have not specifically been conducted in this respect. Frequent boat based maintenance activity within a large wind farm site could create barrier-type effects although the extent of this (and the extent to which marine animals might habituate to such activities) is not known.

Many bird species (most notably diver and seaduck) are known to exhibit a flight response in the presence of boats and are absent from areas of heavy vessel traffic. As discussed above in the section on construction, the impact of the increased presence of maintenance traffic at a larger wind farm site has not been considered. It may be difficult to isolate the impact of maintenance trips from the physical presence of turbines when assessing the extent of any seabird displacement.

In many cases planning of maintenance trips can be used to mitigate impacts on sensitive sites (e.g. seal haul-outs) or particular times of vulnerability (sea duck moults etc). The use of helicopters to service wind farms (particularly in respect of the next generation large generation units) may give rise to other impacts.

3.2.3 Barrier effect, collision and other impacts on birdlife

As discussed above, the presence of operational wind turbines may give rise to three main impacts on bird populations - blade/turbine strike, barrier effect / avoidance behaviour and displacement.

Generally speaking rates of turbine strike have been less than expected prior to construction while avoidance and displacement impacts have been more pronounced than expected. For some species an attraction effect has been observed.

Assessing rates of strike is problematic, not least because the main method used in respect of terrestrial wind farms (corpse counts) is unlikely to yield reliable results at sea. However studies suggest that risk of turbine/blade impact is low. Pettersson (2005) suggests that around one bird per turbine per year would be killed by collision with the two wind farms in the Southern Kalmar Sound, a maximum of 11-14 birds per year out of around 500,000 waterfowl migrating past the sites each spring and 800,000 each autumn

Remote monitoring techniques have been used with some success to detect impacts (Desholm et al 2005), most notably thermal imaging. Thermal imaging has generally revealed extremely low rates of strike from seabirds although such results may need to be treated with some caution as coverage of only a very small proportion (in some cases only a percentage of a single turbine's blade sweep) of affected area is possible because of the limited field of vision of such devices. Additionally, strike mortality is likely to vary according to site specific issues, not least the location of migratory routes and species composition, with varying flight heights between species increasing or decreasing the risk of impact. Furthermore, flight height will decrease in bad weather conditions and when visibility is low under which circumstances there could be a corresponding increased risk of collision.

Low strike rates may be attributable to avoidance behaviour to wind farms exhibited by seabirds. Thermal imaging at Nysted showed low probabilities of large birds approaching within 100m of the monitored turbines. Radar studies show many species avoid flying into wind farms. Fox et al (2003) found that flying water birds altered flight trajectories in response to the Horns Rev and Nysted wind farms. Desholm & Kahlert (2005) suggest that less than 1% of ducks and geese migrated close enough to the turbines at Nysted to be at any risk of collision. Pettersson (2005) showed migratory paths shifting by around 2km to avoid the Utgrunden and Yttre Stengrund wind farms. Generally the energy loss caused by shifting path is not seen to be significant in respect of overall migratory distance (Pettersson 2005) although it should be noted that, at least in respect of the two Kalmar Sound study sites, the wind farms were relatively small (7 turbines and 5 turbines).

Avoidance behaviours may also displace bird species from sites used for foraging or resting prior to construction of a wind farm. Divers, common scoter and guillemot/razorbill showed an increased avoidance of the wind farm after the wind turbines were erected. In contrast herring gull and little gull showed an increased preference for the wind farm area. Following construction, long-tailed duck and eider exhibited reduced preferences for feeding within the Nysted site. Radar studies at Nysted showed 9% of tracked flocks entering the wind farm area compared with 24-48% of flocks in the pre-construction baseline period. (Petersen 2005). At North Hoyle Common Scoter were displaced from the site (although such displacement during the operational phase was not as marked as that observed during the construction period, Innogy 2003).

The variation of responses between species is again an issue here with some species exhibiting strong avoidance behaviour and being displaced from large (2-4 km) areas (Petersen 2005) around wind farms and other species (such as Cormorant and Gull sp.) increasing their presence.

The extent to which birds habituate to OWFs is not yet known. Such information may be provided by ongoing studies. It should also be noted that at the three operational sites where bird surveys have taken place (Horns Rev, Nysted and North Hoyle) bird numbers were relatively low prior to construction, none of these sites being particularly notable in conservation terms. The issue of site selection may therefore be central in determining impacts on bird species.

KNOWLEDGE GAPS:

Wind farm development is known to impact upon seabirds. However there are gaps in our knowledge in this respect.

Knowledge of the distribution and abundance of birds at sea is incomplete. Such knowledge can be enhanced by the use of various techniques, including aerial and boat-based survey, radar observation etc.

The ability to monitoring bird populations in inaccessible and often hostile environments is limited. In the UK research carried out for COWRIE discusses the various pros- and cons of different techniques including thermal imaging, radar etc. Practical appraisal of such systems is urgently required if they are to reliably inform EIA.

Although blade/turbine strike is probably the best known of the potential impacts of wind generation on bird populations there remains much uncertainty as to the nature, scale and range of impacts, how to predict them and how to monitor for them. Further research is required into, long-, medium and close-range avoidance behaviour and impacts during poor visibility, e.g. bad weather and at night. Collision risk models require improvement because in many cases they are relatively primitive, allowing for only a limited number of factors. It is not well known what the impact on a population of an estimated mortality rate will actually be because population viability analysis (PVA) of seabirds has not, generally, been carried out, but this is known to be technically very difficult and may not be possible to assess. Even small impacts on relatively long-lived seabird species may be important. Development of mitigation and best-practice in design would be desirable – are certain array designs more problematic than others? Finally, methods for monitoring actual impacts and mortality require consideration – corpse counting is unlikely to be a useful indicator at sea while current remote techniques (such as thermal imaging) may not offer full coverage of an individual blade sweep, let alone an entire wind farm.

It appears from current limited research based on radar observations that birds may avoid operational wind farm areas. Wind farms may therefore act as a barrier, blocking migrational routes *or paths between feeding areas. Energy requirements of flying birds may increase if they are to go around the perceived barrier. Further information from ongoing monitoring studies is required although technical limitations (discussed above) on remote monitoring and the nature of site specifics may make the applicability of such data problematic.*

The issue of displacement of birds from wind farm areas needs consideration. If, as suggested above, birds are likely to avoid wind farm areas then research is required as to species-specific impacts, the extent to which birds may return to an area (if at all), the range of the displacement effect (what is the extent of the area from which birds are displaced) and the availability of suitable replacement habitat. Long term monitoring of the impact of the loss of suitable habitat should also be considered. In areas where wind farm development is likely to be intensive cumulative impacts will need to be researched.

4. Decommissioning

Decommissioning is obviously an important phase of an offshore wind farm's existence, however, apart from speculation in EIAs no data or reviews has been produced to investigate the potential impacts. In the UK marine renewable operators are required to draw-up decommissioning plans although these are currently only in the early stages of development. Certain aspects can be expected to be analogous to decommissioning of other offshore structures (e.g. oil & gas platforms) of which there are some existing reports. Impacts in many cases will be similar to those for construction with the presence of vessel movement, noise and other activities occurring at any site over extended periods of time. Given knowledge about subsea noise it is likely that the use of explosives during decommissioning would have significant adverse impacts on marine mammals and alternative approaches to the removal of piles may be required. Another adverse effect may be the potential loss of habitat where structures have become colonised with flora and fauna and knock on impacts on the FAD functions of turbine bases (with potential socio-economic effects on fishing, particularly if fishers have utilised the area around the OWF).

KNOWLEDGE GAPS:

To date no data exist on decommissioning of offshore wind farm structures. Much can be learnt and extrapolated from the offshore oils and gas industry but although not a priority issue a bespoke action plans will need to be developed for offshore wind farms.

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