North Sea Wind Power Hub

Pre-screening of potential environmental impacts

Final report

NSWPH report

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Final report

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0 Summary

The North Sea Wind Power Hub (NSWPH) consortium, consisting of Energinet, Gasunie, Port of Rotterdam, TenneT Netherlands and TenneT Germany, explores and develops the possibility of a central hub in the North Sea, where large-scale offshore wind farms can be connected to and new possibilities for exchange of power between the North Sea countries can be created. The consortium is now evaluating the potential for this vision. An important part of this work is to perform an early evaluation (a pre-screening) of the likely environmental impacts of establishing and operating the hub and the connected wind farms.

The task of DHI has been to review existing and available environmental impact assessments and consenting processes related to major infrastructure projects in the North Sea and do a preliminary mapping of vulnerable areas in the Dogger Bank area. This work is based on existing knowledge about the distribution and abundance of habitats and species, including conservation targets of Natura 2000 areas. Furthermore, the scope of work includes an evaluation of potential environmental conflicts and showstoppers for the project.

This report presents the results of the pre-screening.

Approach. The overall approach has been to review environmental assessments and map vulnerable areas based on published baseline and environmental impact assessment reports (together EIAs) as well as available spatial data on the distribution of species and habitats. Based on the review and mapping of vulnerable areas, potential environmental conflicts and showstoppers have been identified.

Reports from a total of eleven EIAs and national EIA guidelines for offshore wind projects located in the North Sea were reviewed. In addition, EIA reports published in connection with the planned fixed link across the Fehmarn Belt were reviewed, specifically in relation to assessments of impacts due to dredging during construction extending over a long period of time (multiple years). The wind farm EIAs were selected to represent wind farms located offshore (> 5 km from the coast) which submitted their EIA from the onset of offshore wind farm development in 2002 until 2018, and hence reflect the development in assessment methodologies which have taken place during that period.

Vulnerable areas in the North Sea were identified based on available data on Annex I habitats and selected species of seabirds, fish and marine mammals using data from international databases. Data included historic survey data on eight fish species, five mammal species and nine seabird species. High density areas were identified and mapped for the selected species.

Main results. The key environmental issues in connection with large marine construction works like the construction of artificial islands are mainly related to the construction phase, and the sensitivity of species and habitats to the removal of habitat and impacts of spilled sediment. The reviewed offshore wind farm EIAs showed a change in assessment methodologies over the years, due to increased knowledge about species and key environmental issues. The focus of the early EIAs from 2002 to 2010 was on a complete range of species and impacts, whereas the EIAs during the recent period focus mainly on displacement impacts on marine mammals and fish during the construction phase, and on displacement of seabirds and collision risks for birds during the operational phase.

In terms of the Annex I habitat H1110 sandbanks the planned and consented wind farms the Creyke Beck, Sofia and Teeside A projects (all granted consent in 2015), overlap with the boundaries of the designated Natura 2000 area in the UK part of Dogger Bank (Southern North Sea SAC with an area of 2,269 km^2 equivalent to 18.4% of the protected area). Hence, the potential loss of sandbanks or habitats for porpoises and seals due to the planned and

consented wind farms has in the UK been assessed as compatible with the maintenance of the ecological integrity of the SAC.

As a logical consequence of the implementation of the EU Habitats Directive, assessments of impacts of offshore wind farms have focused on the conservation targets of Natura 2000 areas. In order to establish the likely effect on a European site the effect at population level has to be estimated for the relevant conservation targets. The general advice (JNCC 2017) for estimation of population level effects is to avoid using the site population estimates, as it is necessary to take into consideration population estimates at the larger scale, i.e. management unit level to account for daily and seasonal movements of the animals (JNCC 2017). The common practice of the larger offshore wind projects like the ones planned and consented on Dogger Bank has been to use the outcome of assessment of acoustic displacement of fish and marine mammals, displacement of seabirds and collisions of birds as input to assessments of population level effects, including in-combination and cumulative effects (Creyke Beck, Sofia and Teeside A impact assessments).

The assessment of acoustic displacement of fish and marine mammals is considered a central element of the EIAs of offshore wind farms in the North Sea. Tolerance thresholds (TTS, PTS) for harbour porpoises from Southall *et al*. (2007) have been applied by virtually all offshore wind farm projects in the North Sea. Since the publication of the Southall *et al*. thresholds, further studies have investigated the sound levels that can induce the onset of PTS and have suggested that the thresholds in Southall *et al*. (2007) were too high. Given these more recent studies, new thresholds have been published by the National Oceanic and Atmospheric Administration (NOAA) (NMFS 2016), which are significantly lower than those published in Southall *et al*. Consequently, the extent and area within which the onset of either PTS or TTS is predicted to occur, based on the NOAA thresholds, may be significantly greater than previously considered. By using efficient mitigation measures such as large bubble curtains, which lead to a reduction in radiated noise, the impact ranges from pile-driving can, however, be reduced substantially.

Pelagic seabirds consistently show avoidance behaviour towards offshore wind farms, with only a few exceptions. Estimating the actual displacement range has proven a challenge, unless the variability of seabird abundance and dynamics of the local marine environment around the monitored offshore wind farm are taken into account. Displacement of the characteristic seabird species at Dogger Bank during operation of offshore wind turbines is expected to be limited to 1 km from the perimeter of the wind farms. However, in-combination displacement from the operation of other wind farms in the North Sea may result in levels of displacement which may or may not be relatively high in comparison to the size of the populations in the North Sea.

Assessment of collision mortality of birds at offshore wind farm sites has recently been carried out at all sites in the UK, Belgium, the Netherlands and Denmark using the Band (2012) collision risk model. Until recently, estimation of collision mortality rates of seabirds at planned offshore wind farms were largely based on local survey data on densities of seabirds combined with estimated avoidance rates deduced from casualty surveys at land-based wind farms. As a result, estimates of collision rates of seabirds have generally been overly precautionary. Recent empirical data on seabird avoidance and flight speeds collected during the Carbon Trust Seabird Collision Avoidance Study 2014-2018 have now made it possible to estimate more accurate and most likely significantly lower seabird collision rates.

The maps of vulnerable areas highlight the importance of the slopes of the Dogger Bank rather than the bank itself to fish, marine mammals and seabirds. This is particularly the case towards the north-west where the slope is steepest and where strong and persistent hydrographical gradients are found. This region which is entirely located in the UK sector supports the most important high-density areas in the central part of the North Sea for white-beaked dolphin, minke whale, grey seal, Northern Gannet, Black-legged Kittiwake, Common Guillemot, Razorbill, common sole and grey gurnard. The north-western slope is also important to sandeel and the sandeel fishery and harbour porpoise, yet the high-density areas for these species also cover other parts of the Dogger Bank environment. Sandeels concentrate along all the slopes of the Dogger Bank, and harbour porpoises are concentrated throughout a large coherent area which covers the entire western part and slopes of the bank. Wide areas to the south-east of the

Dogger Bank are important to European plaice, dab and herring and Lesser and Great Black-backed Gull, and this region, which is at some distance from Dogger Bank, also functions as an important nursery area to cod, sandeel and European plaice.

Conclusion. Except for the harbour porpoise, the Dogger Bank as such is not characterised by high densities of fish, marine mammals and seabirds. However, important areas for a number of seabird, marine mammal and fish species are found at the slopes of the bank in the UK sector. In the Dutch, German and Danish sectors, the environment is characterised by only few areas with high densities of the studied species. Based on this pre-screening, the north-eastern part of the Dogger Bank in the Dutch, German and Danish sectors seems to contain the least potential environmental showstoppers for a hub and related wind farms.

Based on this review of North Sea wind farm EIAs and available data on distribution of marine fish, mammals and sea birds, no definite showstoppers were identified for the construction of the hub and related wind farms on Dogger Bank. However, there are several potential showstoppers, for which further environmental studies will be needed to confirm the expectations that:

- The potential loss and disturbance of the habitat sandbanks H1110 are compatible with maintaining the ecological integrity of the protected areas in relation to Annex I habitats;
- State-of-art mitigation measures can reduce underwater noise from pile driving operations sufficiently during construction of the wind turbines;
- The long-term population level acoustic displacement impacts on fish and marine mammals, as well as population-level displacement or collision impacts on seabirds, are not significant.

0.1 Glossary and terms

ATTRACTION	Potential for a wind farm to attract birds as a result of new habitat creation, which may encourage aggregation of fish, or lighting of wind turbines which may attract birds at night (Band 2012).
AVOIDANCE BEHAVIOUR	Any action taken by a bird, when close to an operational wind farm, which prevents collision (SNH 2010). Such an action may be taken early enough to avoid entering the wind farm (macro avoidance), or taken within the wind farm, avoiding the rotor-swept zone (RSZ) (meso avoidance) or individual blades (micro avoidance).
AVOIDANCE RATE	Correction factor applied in collision risk models in order to take account of the likely degree of successful avoidance of a wind farm by a bird.
BIRD FLUX RATE	Total number of birds crossing an imaginary surface within the airspace expressed as birds / sec or birds / s per m^2. The bird flux rate is directly related to bird density but depends on the speed of the birds (if they were stationary, there would be no flux).
COLLISION RISK	Risk of individual birds to get injured or killed by an encounter or collision with turbines or rotor blades at a wind farm (Band 2012).

COLLISION RISK MODELLING	Tool used to quantify the risk of birds colliding with wind turbines (collision risk). The collision risk is expressed in terms of the likely number of birds per month or per year, which will collide with the wind farm, and the range of uncertainty surrounding that estimate.
DISPLACEMENT	A reduction in the number of birds using the area inside or adjacent to an offshore wind farm as a habitat for foraging, resting or roosting.
ICES	International Council for the Exploration of the Sea.
MACRO AVOIDANCE	Bird behavioural responses to the presence of the wind farm occurring beyond its perimeter, resulting in a redistribution of birds inside and outside the wind farm. In this study, empirical macro avoidance is quantified up to 3 km outside the wind farm.
MANAGEMENT UNIT	Larger areas of sea used for managing fisheries and human activities affecting marine mammal populations. In terms of fisheries, management units are generally set by the International Council for the Exploration of the Sea (ICES). In terms of marine mammals, management units are set by different countries, like for instance the UK in relation to harbour porpoise.
MESO AVOIDANCE	Bird behavioural response within the wind farm footprint to individual turbines (considering a 10 m buffer around the rotor-swept zone) and resulting in a redistribution of the birds within the wind farm footprint.
MICRO AVOIDANCE	Bird behavioural response to single blade(s) within 10 m of the rotor-swept zone, considered as the bird's 'last-second action' taken to avoid collision.
ROTOR	Part of a wind farm that extracts kinetic energy from the air and coverts this wind into rotational energy in the drive train. The current generation of horizontal axis turbines has rotors with three blades.
ROTOR-SWEPT ZONE	Zone swept by the rotating turbine blades of a wind farm. For Thanet Offshore Wind Farm the rotor-swept zone has a diameter of 90 m. For the purposes of analysing empirical micro avoidance, the RSZ refers to the circle drawn by the rotor blades, while the rotor refers to the ellipse representing the blades at any given time.

1 Introduction

The North Sea Wind Power Hub (NSWPH) consortium, consisting of Energinet, Gasunie, Port of Rotterdam, TenneT Netherlands and TenneT Germany, wishes to establish a central hub in the North Sea, where large-scale offshore wind farms can be connected to and new possibilities for exchange of power between the North Sea countries will be created. The consortium is now evaluating the potential for this vision. An important part of this work is to perform an early evaluation (a pre-screening) of the potential environmental impacts of establishing and operating the hub and the connected wind farms.

The task of DHI has been to review existing and available environmental impact assessments and consenting processes related to major infrastructure projects in the North Sea and do a preliminary mapping of vulnerable areas in the Dogger Bank area based on existing knowledge about the distribution and abundance of habitats and species, including conservation targets of Natura 2000 areas, and to evaluate potential environmental conflicts and showstoppers.

This report presents the results of the pre-screening.

Construction of marine infrastructure projects like artificial islands and wind farms may affect the marine habitats and species. The impacts relate both to the construction phase and the operation phase. During construction, noise from pile driving may disturb fish and marine mammals, sediment spill may cause reduced light availability for primary production and sedimentation may impact the benthic fauna. Habitats located in the area of new structures like the artificial islands and piles will be lost. During operation, there is a risk of increased mortality of birds due to collision with the wind turbines.

On the other hand, some changes may be beneficial for the marine habitats and species. New hard structures as the outer part of an artificial island and foundations of the wind turbines may serve as new hard bottom areas for colonisation of flora and fauna and create effects comparable to artificial reefs.

The significance of the impacts for the survival and function of the ecosystem depends on the area, intensity and duration of the impact as well as the importance of the impacted communities for the local, regional or larger scale ecosystems.

The aim of this pre-screening study is to collect and analyse available documentation and data and make a preliminary assessment of the environmental issues, in order to identify potential environmental conflicts and showstoppers for the NSWPH project.

1.1 Project description

The NSWPH-project is still at an early stage, which means that only a very rough project description is available, allowing for much flexibility. This also means that the NSWPH-project can be designed observing conflicts and constraints relating to the environment, when at the same time considering other relevant issues.

The purpose of the NSWPH project is to provide an efficient, affordable and reliable energy export system in the North Sea, which will contribute to both European and national climate and energy targets. The project consortium will investigate the feasibility of a NSWPH established as one or more artificial islands or platforms with energy infrastructure in the North Sea focusing on Dogger Bank in the Danish, German and/or Dutch EEZ.

The NSWPH consortium explores and develops regional socio-economic beneficial and reliable offshore infrastructure, including possible conversion into power to gas, that supports wind farm operations and interconnections between markets. The backbone of the consortium's work and analyses is scenario estimates that offshore wind power in the North Sea alone could reach between 70 and150 GW by 2040.

Central to the vision is the “hub and spoke concept” including construction of one or more hubs (possible as an artificial islands) at suitable locations in the North Sea with offshore wind farms being connecting to the hub and export corridors/interconnectors (“spokes”) going from the hub to bordering North Sea countries and markets.

One location option for a possible concrete hub and spoke project is the Dogger Bank. The shallow water of 10-30 m water depth makes the Dogger Bank area suitable for construction of a hub (possibly as an artificial island) with surrounding connected wind farms (up to approximately 30 GW). The hub/possible artificial island construction is estimated to take up to seven years and could pending further analysis and evaluation be built by or partly by using sand materials from Dogger Bank or nearby areas.

A possible construction period has not been decided yet, but a potential scenario could be that a hub construction could begin around 2025 and be ready for operation around 2030.

1.1.1 Hub

It is still uncertain whether the hub will consist of one or more islands, but so far it is assumed that it will be one island with a size of 5 ha. The island will most likely be constructed in an area with shallow water to minimize the need for materials. The island is expected to contain a large amount of energy infrastructure as the purpose of the island is to serve as a hub for energy transport in the North Sea. The energy infrastructure possibly includes a port and a heliport and/or airstrip as well as living quarters for workers and visitors and a large number of HVDC stations which can transform AC-energy from the offshore wind farms to DC-energy which is better suited for long-distance transport.

The size of the island and the installations on it will depend on several factors, including not least the maximum capacity of the offshore wind farms, and potential other energy sources, which in the future will be connected to the island.

1.1.2 Wind farms

The hub/island is a key part of this project, but the presence and placement of future cable connected wind farms are also relevant to consider when addressing the environmental impacts.

The amount of wind power which is to be connected to the hub/island is here assumed to be 16-30 GW. This could roughly correspond to an area of up to 5,500 km^2 that will be covered by wind farms connected to and surrounding the hub/island.

1.2 Project pressures

The pressures identified to potential impact marine habitats and species due to activities during the construction and operation phases are listed in Table 1-1. The construction-related pressures have a limited duration while structure- and operation-related pressures are permanent.

Table 1-1 Key-pressures potentially causing an impact on marine habitats and species in the construction and operation phases of the NSWPH project.

Phase	Pressure
Construction	Sediment spill
	Underwater noise and other disturbances
Operation	Physical structures and area occupation
	Disturbances of seabirds in operation phase
	Collision risk for seabirds

Sediment spill from dredging work in the construction phase may potentially cause changes to the habitats at the seabed and affect the mortality and growth of the fauna living in and on the seabed. Large construction works may reduce visibility for larger animals like certain sea birds that use their sight when seeking food in the water.

Underwater noise during the construction phase will primarily come from pile driving and may potentially cause displacement or injury of fish and marine mammals.

The footprints of the hub and connected wind farms will reduce the existing area of seabed habitats which may be replaced partly by hard bottom/stone reef habitats. The new reef habitats will be colonised by benthic fauna and fish characteristic for hard bottoms.

Seabirds' behaviour is affected by the physical structures, but the effect can vary from strong avoidance to strong attraction. Moreover, there is a risk of increased mortality of seabirds on long-distance migration when they collide with spinning rotors of offshore wind turbines.

1.3 Approach

The overall approach has been to review environmental assessments and map vulnerable areas in the region of the Dogger Bank based on published baseline and environmental impact assessment reports (together EIAs) as well as available spatial data on the distribution of species and habitats. Based on the review and mapping of vulnerable areas, potential environmental impacts and showstoppers have been identified.

Baseline and assessment reports from a total of 16 EIAs and national EIA guidelines for offshore wind projects located in the North Sea were reviewed (Table 1-2). An overview of all consented and built offshore wind farms in the Sea is given in Figure 1-1. In addition, EIA reports published in connection with the planned fixed link across the Fehmarn Belt have been reviewed in order to identify potential conflicts and showstoppers related to the construction and operation of the NSWPH artificial island. Specifically, the fixed link reports were reviewed for, assessments of impacts due to dredging during construction extending over a long period (multiple years). The wind farm EIAs were selected to represent wind farms located offshore (> 5 km from the coast) which submitted their EIA from the onset of offshore wind farm development in 2002 until 2018, and hence reflect the development in assessment methodologies which has taken place during that period. The review focused on identification of important species and habitats, determination of key environmental issues and the related sensitivity of species and habitats as well as identification of applied baseline and assessment methodologies.

Table 1-2 Overview of offshore wind farm project baseline and assessment reports which have been reviewed, as well as EIA guidelines included.

Country	Offshore wind projects	References
United Kingdom	Creyke Beck A and B - Dogger Bank	Brown and May Marine 2013, Brunner 2013, Mackey 2013, Royal Haskoning DHV 2013, Thornton 2013
	Sofia (former Teesside A) and Teesside B - Dogger Bank	Brown and May Marine 2014, Lewis 2014, Lowe & Henderson 2014, Mackey & Kennan 2014, Redding 2014, Thornton 2014
	Hornsea Project 1 and 2	Smart Wind Ltd. 2013a-k
	East Anglia One	ERM & East Anglia Offshore Wind Ltd. 2012a-f, East Anglia Offshore Wind Ltd. 2016
	Triton Knoll	Triton Knoll Offshore Wind Farm Ltd. 2012a-d
Belgium	North Sea Power	Volckaert et al. 2011
The Netherlands	Egmond aan Zee	Grift et al. 2004, Jarvis et al. 2004, Leopold et al. 2004, Tien et al. 2004, Scheidat et al. 2009, Lindeboom et al. 2011
	Prinses Amalia Windpark	Leewis et al. 2018
	Gemini	Gemini Offshore Wind Project 2011, Brasseur & Kirkwood 2014, Geelhoed et al. 2015, Van Bemmelen et al. 2015
Germany	EIA guidelines	Bundesamt für Seeschiffahrt und Hydrographie 2013
Denmark	Horns Rev 1	Noer et al. 2000, Danish Energy Agency 2013
	Horns Rev 2	Andersen 2006, Christensen *et al.* 2006, Leonhard 2006, Skov & Thomsen 2006
	Horns Rev 3	Mason & Barham 2013, Brew *et al.* 2014, Dorsch *et al.* 2014, Jensen *et al.* 2014, Macnaughton *et al.* 2014, Nehls *et al.* 2014
	Vesterhav Syd	COWI 2015, NIRAS 2015

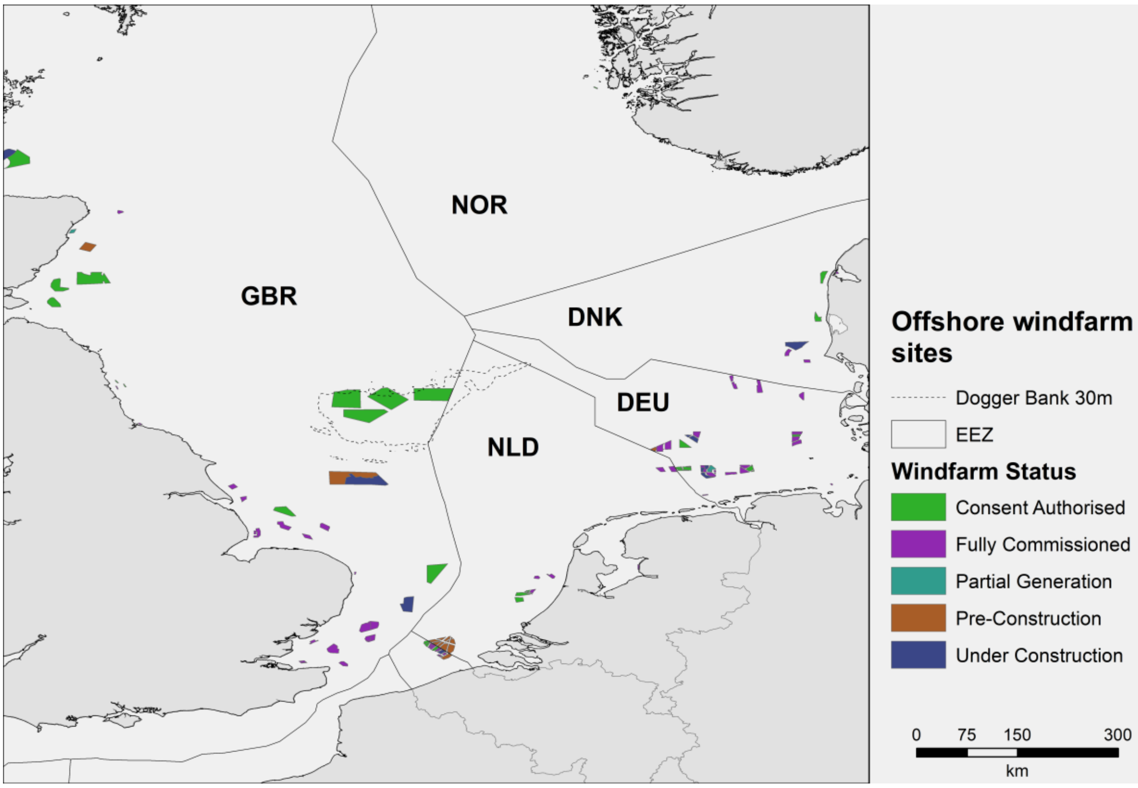

Figure 1-1 Location of offshore wind farms in the North Sea which are partly or fully commissioned, under construction or consented to be constructed. EEZ boundaries and Dogger Bank (delineated by 30 m water depth) are shown.

Data from the key international databases holding updated information on the distribution of benthic habitats, fish, marine mammals and seabirds were used to map the distribution and abundance of selected habitats and species in the North Sea in order to identify vulnerable areas in the region of the Dogger Bank. A subset of habitats and species was selected as focus for the study based on their conservation status pursuant to the Habitat Directive and their numerical importance in the region of the Dogger Bank (Table 1-3).

Special Areas of Conservation (SAC) designated by the member states under the Habitat Directive ensure the conservation of a wide range of rare, threatened or endemic animal and plant species. Some 200 rare and characteristic habitat types are also targeted for conservation in their own right. The habitat sandbanks (H1110), harbour sealand harbour porpoise are conservation targets for the Dogger Bank SACs in Germany, Netherlands and the UK, and in addition grey seal for the SACs in the Netherlands and UK (Natura 2000 Standard Data Forms).

For the identification of numerically important species around Dogger Bank, the North Sea wide distribution data were used in combination with two reviews carried out in relation to the wind farm projects on Dogger Bank (Table 1-3, Austin *et al*. 2011, EMU 2011).

Although data gaps were present (see Section 3.1), it was assessed that distribution data were available and could be analysed for all key habitats and species.

Table 1-3 Selected important species and habitats and the source for spatial distribution data used for mapping.

	Species/Habitats	Justification	Source for distribution data
Benthic habitats	Sandbanks H1110	Conservation target for Dogger Bank SACs	European Environment Agency - Article-17 status 2017
Seabirds	Northern Gannet	Numerically important	European Seabirds at Sea Database 1980-2004
	Common Guillemot	Numerically important	European Seabirds at Sea Database 1980-2004
	Northern Fulmar	Numerically important	European Seabirds at Sea Database 1980-2004
	Black-legged Kittiwake	Numerically important	European Seabirds at Sea Database 1980-2004
	Little Auk	Numerically important	European Seabirds at Sea Database 1980-2004
	Atlantic Puffin	Numerically important	European Seabirds at Sea Database 1980-2004
	Razorbill	Numerically important	European Seabirds at Sea Database 1980-2004
	Lesser Black-backed Gull	Numerically important	European Seabirds at Sea Database 1980-2004
	Great Black-backed Gull	Numerically important	European Seabirds at Sea Database 1980-2004
Seals	Grey Seal	Conservation target for Dogger Bank SACs	Marine Scotland 2018 https://data.marine.gov.scot/dataset/updated-seal-usage-maps-estimated-sea-distribution-grey-and-harbour-seals
	Harbour Seal	Conservation target for Dogger Bank SACs	Marine Scotland 2018 https://data.marine.gov.scot/dataset/updated-seal-usage-maps-estimated-sea-distribution-grey-and-harbour-seals
Cetaceans	Harbour Porpoise	Conservation target for Dogger Bank SACs	Gilles *et al*. 2016
	White-beaked Dolphin	Numerically important	OBIS – SCANS I and II survey data
	Minke Whale	Numerically important	OBIS – SCANS I and II survey data
Fish	Dab	Numerically important	ICES - DATRAS
	Cod	Numerically important	ICES - DATRAS
	Grey gurnard	Numerically important	ICES - DATRAS
	Herring	Numerically important	ICES - DATRAS
	Mackerel	Numerically important	ICES - DATRAS

	Species/Habitats	Justification	Source for distribution data
	European Plaice	Numerically important	ICES - DATRAS
	Common Sole	Numerically important	ICES - DATRAS
	Sandeel	Numerically important	ICES - DATRAS
	Plaice nursery area	Numerically important	ICES - DATRAS
	Cod nursery area	Numerically important	ICES - DATRAS
	Sandeel nursery area	Numerically important	ICES - DATRAS

1.4 Other relevant data not included in the pre-screening

Habitats

Although comprehensive spatial data on the coverage of sandbank habitats at Dogger Bank were available, and North Sea wide datasets were collected for all key species, some existing data were not included in the present pre-screening. The reason why these data were not included is either due to lack of species survey data for the whole North Sea, as in the case of the seals or the skates, due to lack of local survey data on Dogger Bank as in the case of fine-scale geo-morphological features and zoo benthos and/or due to the fact that data were not publicly unavailable.

Sensitive areas to fish include spawning and nursery grounds. This pre-screening included only one dataset on nursery grounds from a coordinated survey in the central North Sea in 1997. However, the specific locations of these sites of fish sensitivity are not static and may shrink, expand or move from one site to another over time. Anthropogenic activity may, with time, impinge upon previously un-impacted areas of sensitivity. For these reasons, historic maps of spawning and nursery grounds for fish like those of Coull *et al.* (1998) and Ellis *et al.* (2010) have not been used in this pre-screening. Currently, attempts are made to develop updated maps of sensitive sites in UK waters using species distribution modelling techniques with all available fish data (Aires *et al*. 2014).

Among the invertebrates there is evidence of key spawning sites for the commercially important brown crab on Dogger Bank (EMU 2011), yet data on the location of spawning sites in other parts of the North Sea are generally lacking and this feature has therefore not been included in the assessment. The ocean quahog and the northern hatchet shell which are protected in the UK have been recorded on Dogger Bank, but detailed data about their distribution on Dogger Bank are not available (EMU 2011).

In relation to geo-morphology there are strong indications that the habitat feature seapen and burrowing megafauna are found in the northern part of the Dogger Bank (EMU 2011). This habitat is protected by both the UK Biodiversity Action Plan and the new German Nature Conservation legislation due to its relative importance as nursery habitat for various species of fish. Due to lack of spatial data on its distribution on Dogger Bank this habitat could not be included in the assessment. Large sand waves and bedforms comprise a higher-level habitat classification within H1110 sandbanks and are considered sensitive to disturbance. They occur to the west and southwest of the Dogger Bank, but detailed maps of the distribution of these features are not available.

Seabirds

The intensive baseline surveys of seabirds which were undertaken in connection with the Dogger Bank wind farms in the UK have elucidated regular occurrence of the relatively uncommon White-billed Diver on Dogger Bank (EMU 2011). As the status of the population of this species breeding in North America and eastern Siberia is uncertain, and inadequate data on its distribution in other parts of the North Sea are unavailable, this species was not included in the assessment.

Marine Mammals

The assessment of the offshore distribution of seals relied entirely on results from tagging studies at UK colonies.

Fish(eries)

Existing fisheries data suggest that several species of skates and rays, like thornback and spotted rays, are common around Dogger Bank (EMU 2011). As for many elasmobranch species distribution data for the whole North Sea are lacking, however (ICES WGEF 2007), and therefore none of these species could be included in the assessment. Although not currently in the Annex 2 of the Habitat Directive, the elasmobranchs are listed in the UK Biodiversity Action Plan and the Wildlife and Countryside Act (Gill & Kimber 2005). In addition, species belonging to this group are also targeted in recreational fisheries (Ellis *et al*. 2005).

Mapping of the important fishing areas in the Dogger Bank region would have been a very useful addition to this pre-screening. Detailed mapping of the fishing effort would, however, require access to WMS data. With WMS data currently outside public domain databases, information on key fishing areas could not be included. However, for sandeel and sandeel fisheries, the result of an assessment of key sandeel fishing areas was received from DTU Aqua. The key sandeel fishing banks have been mapped using effort data from the Danish sandeel fishing fleet and include the western flanks of the Dogger Bank. Analyses of WMS data for the Dogger Bank region in the early 2000’s indicate that the majority of effort data was on Danish sandeel trawlers (EMU 2011). Thus, by including the sandeel fishing grounds most fishing areas have at least partly been included.

2 Review of baseline and impact assessment studies

In this chapter we review key environmental impacts and assessment methods from EIA reports and national EIA guidelines for offshore wind projects located in the North Sea.

2.1 Key environmental impacts

In this chapter the potential environmental impacts of the construction and operation of the hub and wind farms are described. The key environmental issues in connection with large marine construction works like the construction of artificial islands are mainly related to the construction phase and the direct and indirect impacts of the earth works, which may extend over relatively long periods of time. While the sensitivity of species and habitats to the removal of habitat and dispersal of sediments is well established, knowledge on the sensitivity of species and habitats to offshore wind farms is more recent and has been growing steadily since the first wind farms were constructed in the early 2000s. During the period from 2002 to 2018, the focus of impact assessments for offshore wind farms gradually changed. The focus of the early studies was on a complete range of ecological components, whereas the later studies focus mainly on the most critical impacts, namely displacement impacts on marine mammals, seabirds and fish as well as collision risks for birds.

The change in focus reflects the knowledge harvested from post-construction monitoring programmes of the first offshore wind farms like Horns Rev I and II, Butendiek, London Array and OWEZ. These studies provided evidence of negligible or low impacts related to a number of potential environmental issues. This review addresses all environmental issues which have been dealt with in relation to the selected impact assessments of offshore wind farms in the North Sea. However, more weight has been put on the evaluation of sensitivity of species and habitats related to displacement and collision risk due to the observed change in focus towards these specific aspects. It should also be noted that impacts related to marine archaeology were not included.

In the following, the knowledge gathered on the sensitivity of species and habitats to each of the potential impacts is described.

2.1.1 Habitat change and loss

Loss of habitat is manifested as a loss of seabed habitat due to the areas taken up by large infrastructures like artificial islands or turbine foundations. In general, due to the size of artificial islands the potential areas of habitat loss related to construction of these infrastructures are far greater than the areas related to construction of wind turbine foundations Therefore, the potential for habitat loss being a significant impact is greatest in relation to the construction of a NSWPH island. The significance of habitat loss is assessed against the national legal framework of protected areas and sites designated under the EU Habitat Directive. With respect to the latter, the proportion of the habitat type affected by the habitat loss will determine whether the loss is significant or not.

With respect to impacts from offshore wind farms on benthos the absence of fisheries and the presence of the new hard substratum seem to have the highest impact. In the OWEZ and Horns Rev I wind farms, the local benthos community in the sandy area between the monopiles showed no major differences, in composition, densities, overall biomass and diversity, inside the farm when compared to reference areas ((Leonhard and Pedersen 2006, Daan *et al*. 2009, Lindeboom *et al.* 2011). This indicates no clear short-term measurable effects on the benthic communities in the areas between the foundations and scour protection.

Accordingly, in relation to offshore wind farms, habitat change rather than habitat loss has been frequently in focus in several pre- and post-construction studies in Denmark, Germany and the Netherlands (Leonhard *et al.* 2011, Danish Energy Agency 2013, Gutow *et al*. 2014). The studies have provided evidence of local enrichment of benthic invertebrate communities and attraction of fish related to the introduction of hard substrate. This effect leads to higher densities of benthos and fish and diversity of fish following wind farm construction. Studies on changes in the fish communities at Horns Rev I elucidated that the introduction of hard bottom substrate resulted in higher species diversity close to each turbine with a clear spatial (horizontal) distribution. New reef habitat fish such as goldsinny wrasse (*Ctenolabrus rupestris*), viviparous eelpout (*Zoarces viviparous*) and lumpsucker (*Cyclopterus lumpus*) established themselves on the introduced reef area. Further diurnal shifts in the distribution of fish were recorded which suggests that even though the impact area offers a more diverse habitat, fish are still utilising areas outside the wind farm either due to size constrains of the park area or because adjacent areas provide alternative services (prey, refuge, physics etc.) not found in the impact area (Winter *et al.* 2010, Leonhard *et al.* 2011).

Despite the evident enrichment of benthos and fish in offshore North Sea wind farms, the potentially positive ecosystem effect on marine mammals and seabirds has not been the subject for systematic studies.

2.1.2 Acoustic displacement of fish and marine mammals during pile-driving

Impact pile driving produces very high intensity impulsive noise (Thomsen *et al*. 2006, Madsen *et al*. 2006, Diederichs *et al*. 2014). Even with some mitigation measures put in place, impulsive noise from impact pile driving can be detected at considerable distances from the pile driving site (Matuschek & Betke 2009, Skjellerup *et al*. 2015). The assessment of impacts of underwater sound on the survival and disturbance of fish and marine mammals is considered a central element of offshore wind farm EIAs in the North Sea and elsewhere. Here we review existing knowledge on sensitivity and impact thresholds for marine mammals and fish as well as the effect of bubble curtains to mitigate the impact.

Sensitivity of fish and marine mammals

In the marine environment where light attenuates rapidly, and sound propagates well over long distances (Medwin & Clay 1998), marine organisms rely heavily on sound for many parts of their lifecycle. Marine mammals, for example, rely on sound for communication, orientation and when finding prey. The perception of sound by marine mammals and fish differs in various ways. While marine mammals are sensitive to the pressure component of a sound wave, fish are generally sensitive to the particle motion component of the sound wave. Below a few hundred Hz all fish species detect mainly the particle motion (Kalmijn 1989, Sand & Karlsen 2000, Karlsen *et al*. 2004), and for fish with no swim bladders, or with little air in the swim bladder (e.g. flatfish, mackerel) this is the full range of their hearing (Sand & Enger 1973, Chapman & Sand 1974). At higher frequencies those species with a gas filled cavity (e.g. a swim bladder) can detect sound pressure, as a pressure wave impinging on a gas filled cavity causes it to vibrate, and the resulting particle motion stimulates the inner ear (e.g. gadoids, Chapman & Hawkins 1973, Sand & Enger 1973, Fay & Popper 1974). Some species even have special adaptations to detect the pressure component, which gives them a wider hearing range and lower hearing thresholds (e.g. clupeids such as herring and sprat, Enger 1967, Fay & Popper 1974).

Impact thresholds

Several studies have sought to define appropriate thresholds for effects of noise for both marine mammals and fish (Southall *et al*. 2007, Popper *et al*. 2014). Thresholds for harbour porpoises from Southall *et al*. (2007) have been applied by virtually all offshore wind farm projects in the North Sea to assess the potential for harbour porpoise to experience the onset of permanent auditory injury (Permanent Threshold Shift (PTS)), Temporary Threshold Shift (TTS) and significant disturbance. PTS is defined as a permanent elevation of hearing threshold, i.e. where a permanent loss of hearing occurs. TTS is defined as a temporary threshold shift from which a marine mammal will recover over time. Significant disturbance is defined as the area within which marine mammals will exhibit avoidance behaviour by swimming away from the sound source.

Southall *et al*. (2007) proposed that for single and multiple pulsed sound, such as that generated by piling, a Sound Exposure Level (SEL) of 198 dB re 1 µPa2s or above will be sufficient to cause the onset of PTS, and a SEL of 183 dB re 1 µPa2s sufficient to cause the onset of TTS in cetaceans. Since the publication of the Southall *et al*. (2007) thresholds, further studies have investigated the sound levels that can induce the onset of PTS. Lucke *et al*. (2009) suggested that the onset of PTS in harbour porpoise may occur at lower levels than other cetacean groups and subsequently suggested that the thresholds suggested in Southall *et al*., (2007) were too high. This work has been further supported by other more recent studies (e.g. Kastelein *et al*. 2012). Given these more recent studies, new thresholds have been published by the National Oceanic and Atmospheric Administration (NOAA) (NMFS 2016). For harbour porpoise the NOAA thresholds at which the onset of PTS is predicted to occur is 155 dB re 1 µPa2s and TTS at 140 dB re 1 µPa2s. These are significantly lower than those published in Southall *et al*. (2007) and Lucke *et al*. (2009). Consequently, the extent and area within which the onset of either PTS or TTS are predicted to occur, based on the NOAA thresholds, may be significantly greater than previously considered.

Indications of harbour and grey seal behavioural thresholds were collected from a telemetry study of harbour seals reacting to impact pile driving during construction of a wind farm (Russel *et al*. 2016, Table 2-1). The current knowledge of impact on minke whale is limited, but a study of humpback whales responding to seismic airguns (Dunlop *et al*. 2018, Table 2-1) provides a general threshold for baleen whales. For fish in general there is little information on noise effects, and only from a very limited number of species and sound sources. Popper *et al*. (2014) defined thresholds for injury in fish from impact pile driving noise, and displacement thresholds were defined by Hawkins *et al*. (2014) for sprat and mackerel, and by Myrberg *et al*. (1978) for silky sharks.

Table 2-1 Displacement criteria for marine mammals in relation to pile driving noise.

Species	Behavioural threshold (dB re 1 µPa$^{2}\cdot$s received level)	Reference
Harbour porpoise	140	*Skjellerup et al. 2015*
Minke whale	155	*Dunlop et al. 2018*
White-beaked dolphin	140	*Skjellerup et al. 2015*
Grey seal	158	*Russell et al. 2016*
Harbour seal	158	*Russell et al. 2016*

Mitigation options

To date, impact pile driving has been the predominant method of installing substructures for offshore wind turbines, and strict regulations on impulsive noise (such as pile driving noise) have been put in place by all North Sea countries. These regulations make the use of noise mitigation technologies mandatory. By using efficient mitigation measures such as large bubble curtains, which lead to a reduction in radiated noise, the impact ranges from pile driving can be reduced substantially (Verfuss *et al*. 2014). The difference in the calculated impact ranges between the two scenarios clearly demonstrates this (Figure 2-1). Ideally this means a substantial decrease in the potential number of animals affected, if the distribution of animals at the beginning is even across the area.

As an alternative to pile driving, the offshore wind industry may in future deploy low-noise foundation installation technologies, such as vibratory piling and foundation drilling. Although prototypes have been tested, these technologies have not yet been demonstrated during the construction of offshore wind farms (Verfuss 2014).

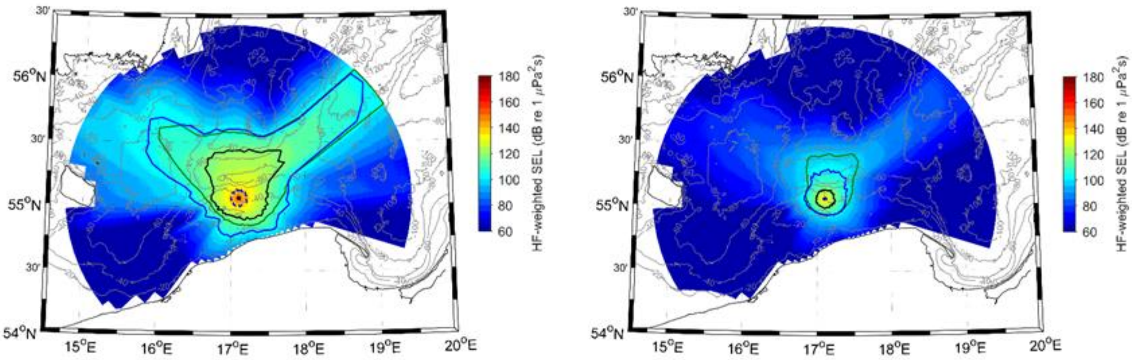

Figure 2-1 Reduction in area of Permanent Threshold Shift (PTS, black line) and Temporary Threshold Shift (TTS, blue line) impacts on harbour porpoise by application of a bubble curtain during pile driving, assessed by acoustic modelling (DHI unpublished). Left: unmitigated scenario, right: mitigated scenario.

2.1.3 Other types of displacement of fish and marine mammals

The reviewed EIAs also assess other types of displacement including displacement of top predators caused by reduced visibility during large construction works from sediment spill and disturbance caused by electromagnetic fields around cables. Although thresholds of sediment concentrations in the water column during sediment spills have been established and applied in relation to large-scale construction works like bridges and artificial islands (FEBI 2013), these thresholds are based on the apparent visual effects on sea water rather than on empirical studies. In general, sediment concentrations exceeding 10 mg/l are believed to inhibit foraging of seabirds and fish (FEBI 2013, FEBEC 2013). The thresholds have generally not been applied in relation to the construction of offshore wind farms because of the smaller volume of sediments released and dispersed during construction of wind farms.

Sensitivity of fish to electromagnetism around cables has been studied at a few offshore wind farms in Denmark and UK, and only flounder displayed a moderate displacement to the electromagnetic fields (Danish Energy Agency 2013).

2.1.4 Displacement of seabirds during operation of offshore wind turbines

The behavioural responses of seabirds to offshore wind farms show a complete range of behaviours from strong avoidance to strong attraction, but with many species showing little behavioural response. The underlying drivers behind these responses are not well known, yet the responses of individual species seem to be consistent across offshore wind farms.

Pelagic seabirds consistently show avoidance behaviour towards offshore wind farms (Krijgsveld 2014, Dierschke *et al*. 2016, Welcker & Nehls 2016), with only a few exceptions. As similar responses are also seen among closely related species, generalisations regarding displacement behaviour of seabirds have recently been made by Dierschke *et al*. 2016, who reviewed post-construction studies of 33 species of seabirds at 20 OWFs in European waters. Dierschke *et al*. (2016) found that divers and Northern Gannets showed consistent and strong avoidance behaviour/displacement, and this may also be the case for Great Crested Grebe and Northern Fulmar. Long-tailed Duck, Common Scoter, Manx Shearwater, Razorbill, Common Guillemot, Little Gull and Sandwich Tern showed less consistent displacement from offshore wind farms. Several gull species and Red-breasted Merganser showed weak attraction, while Great Cormorant and European Shag showed strong attraction to OWFs. Other species showed little response.

The responsive behaviour of seabirds to offshore wind farms seems mainly to be due to the structures and appears stronger when rotors are rotating. The observed responsive behaviour could also in part be due to boat traffic to and from the wind farms. Attraction of cormorants relates at least in part to their use of structures for roosting and for drying plumage. Also increases in food availability at offshore wind farms appears to be an important influence for several species. Model based approaches have been used for estimating the actual displacement range by taking account of the variability of seabird abundance and dynamics of the local marine environment around the monitored offshore wind farms (Skov & Heinänen 2017). The displacement range of 1 km estimated by Skov & Heinänen (2017, Figure 2-2) for Northern Gannet and Common Guillemot may also apply to other pelagic seabird species such as Northern Fulmar, Razorbill and Little Auk, for which empirical data available do not allow for safe estimation of distance of displacement effect.

Although pelagic seabirds in general show a small displacement range from offshore wind farms of approximately 1 km, divers and particularly the Red-Throated Diver display strong displacement to at least 5-6 km from wind farms (Petersen *et al*. 2014). Due to the potential impact from displacement on this species the consent application for London Array Phase 2 was turned down by the UK authorities in 2013. However, the Red-throated Diver does not occur in the region of the Dogger Bank. No Special Areas of Conservation under the EU Birds Directive have been designated in the region of the Dogger Bank in relation to any of the important seabird species in this region. In addition, the five seabird species listed by Germany as regularly occurring in the SAC area all display small displacement ranges. For these reasons, displacement of seabirds seems unlikely to become a key issue in relation to Natura 2000 site designations in the region.

The potential for cumulative displacement impacts can only be assessed once the future build out of wind farms in other parts of the North Sea is known.

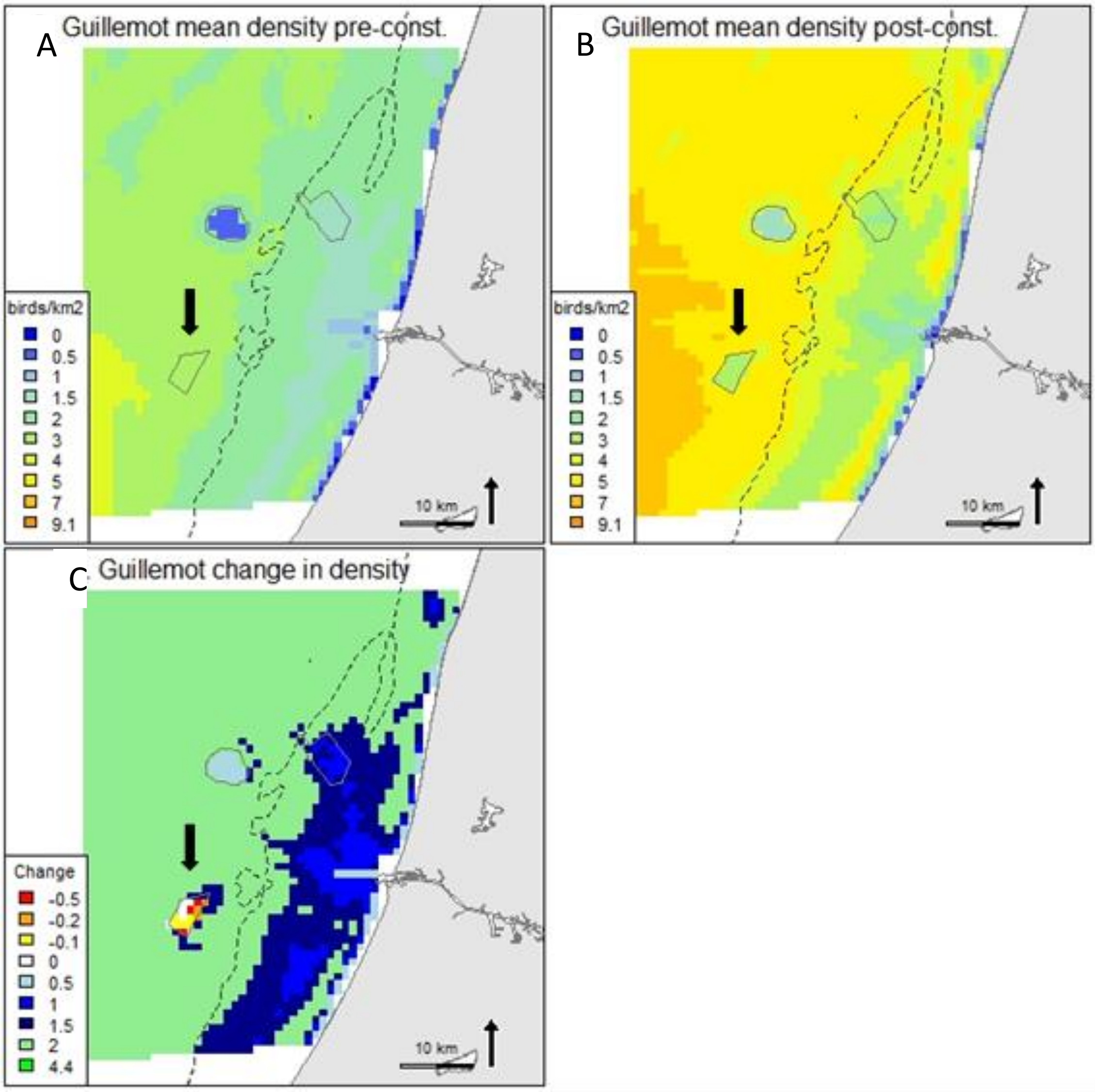

Figure 2-2 Example of model-based assessment of displacement in Common Guillemot at Luchterduinen Offshore Wind Farm (marked by black arrow, Skov & Heinänen 2017). The estimated displacement range was 2 km, with 50% occurring within 1 km from the perimeter of the wind farm. The displacement was estimated by comparing the distribution during the baseline surveys (A) with the distribution during the post-construction surveys (B). The resulting change map (C) shows the difference between pre- and post-construction periods. The model-based estimation made it possible to account for the change in distribution and abundance caused by changes in the local environment (not caused by the wind farm) at the site. For example, even if the observed abundance of Common Guillemots increased in Dutch offshore waters during the post-construction period, the model documented that local displacement of the guillemots due to the wind farm did take place.

2.1.5 Collision risk of birds with offshore turbines

The risk for individual birds to be injured or killed by an encounter or collision with turbines or rotor blades constitutes another central element of offshore wind farm EIAs. The sensitivity of seabirds and birds on long-distance migration to collide with spinning rotors of offshore wind turbines has been studied extensively. The knowledge has been used by the majority of offshore wind farm projects in the North Sea to estimate collision mortality. The Band collision model (Band 2012) has formed the basis for collision risk assessments in UK, Belgium, The Netherlands and Denmark. However, due to the difficulties collecting detailed data on bird behaviour in an offshore wind farm empirical evidence of actual collision risks has not been available until recently. Barrier effects constitute the inverse impact of collision risk. All the dominating seabird species in the region of the Dogger Bank have large foraging ranges during breeding and non-breeding periods, and hence they migrate over considerable distances. Modification of migration paths due to wind farms in the central parts of the North Sea is therefore generally not assessed as an important impact.

Estimation of collision mortality

Collision mortality is estimated from among other parameters avoidance behaviour. Avoidance rates are applied in collision risk models which estimate the number of birds which may collide by integrating information on number of birds flying through the wind farm per time unit, the morphology and flight speed of the bird species and the operational mechanics of the turbines and rotors. Avoidance behaviour can be defined as any action taken by a bird when close to an operational wind farm, which prevents collision (SNH 2010). Such action may be taken early enough to avoid entering the wind farm (macro avoidance), or taken within the wind farm, avoiding the rotor-swept zone (meso avoidance) or individual blades (micro avoidance). Avoidance rates are expressed as a fraction, and are typically high, in the order of 0.98-0.999 for seabirds (Cook *et al*. 2014, Skov *et al*. 2018).

Avoidance rates can be determined in two different ways. One way is to compare observed collision rates to the number of collisions that would be expected in the absence of avoidance behaviour, considering all bird movements within the perimeter of the wind farm. This is the method used in the past in EIAs for offshore wind farms based on carcass survey results from monitoring studies at land-based wind farms.

Relying the calculation of collision risks at an offshore wind farm on data from land-based wind farms have introduced uncertainties regarding the number of birds likely to be killed. For instance, bird behaviour may differ between onshore and offshore environments (Cook *et al*. 2014). In addition, avoidance rates rely on accurate measurement of collision mortality, which are, however uncertain, as injured birds may for example die well away from turbines (Band *et al*. 2007). Given that collision mortality has turned out to be one of the key environmental impacts associated with the development of offshore wind farms, e.g. being the reason for turning down applications like the Docking Shoal wind farm, the uncertainty surrounding the avoidance rates of seabirds has been a major constraint for the wind industry. The lack of empirical data from offshore wind farms has resulted in overly precautionary avoidance rates and overestimation of collision risks to seabirds.

The other approach to determine avoidance rate is based on actual observations of birds' avoidance behaviour. Although there are a number of studies on visual and/or radar observations (Desholm *et al*. 2005, Everaert 2014, Blew *et al*. 2008, Krijgsveld *et al*. 2011, Cook *et al*. 2012, Everaert 2014), only few have been used to calculate avoidance rates. Due to the variety of approaches used to measure avoidance, in particular the distances involved, quantification of avoidance rates has often been inconsistent and difficult to compare (Cook *et al*. 2012). Empirical data on seabird avoidance at all three spatial scales and flight speeds in an offshore wind farm were recently collected during the Carbon Trust Seabird Collision Avoidance Study 2014-2018 (Skov *et al*. 2018). Despite the availability of empirical avoidance rates for seabirds, project-wise data on seabird densities and flight activity are still necessary in order to achieve realistic collision mortality rates for seabirds.

Specific avoidance rates

The ORJIP study monitored and calculated relatively high total avoidance rates for seabirds: Northern Gannet 0.999, Black-legged Kittiwake 0.998, Herring Gull 0.999, Great Black-backed Gull 0.996, Lesser Black-backed Gull 0.998 and all large gulls 0.998 (Skov *et al*. 2018).

Avoidance is studied at three spatial scales; outside the wind farm (macro avoidance), within the wind farm array (meso avoidance) and within the rotor-swept zone (micro avoidance). In relation to macro avoidance, the majority of Northern Gannets were observed to avoid the wind farm, whereas kittiwakes and large gull species showed a variable avoidance pattern. Meso avoidance was significantly stronger than macro avoidance in all investigated seabird species and typically above 0.9. The vast majority (96.8%) of recorded seabirds avoided the turbines by flying between the turbine rows, while 3.2%, displayed meso avoidance by adjusting flight height to fly below the rotor-swept zone. Regarding micro avoidance, a micro avoidance rate of 0.950 was calculated for all seabirds recorded as a whole, slightly higher if only large gulls are considered (0.957). The high avoidance rates are also reflected in the number of bird collisions recorded. Out of 299 videos with birds recorded within the rotor-swept zone, only 6 collisions were observed. Most of the birds observed crossed the rotor-swept zone by adjusting their flight path and often flying parallel to the rotor.

These results from the ORJIP study indicate that seabird avoidance behaviour is likely to result in lower collision rates than currently applied to collision risk models.

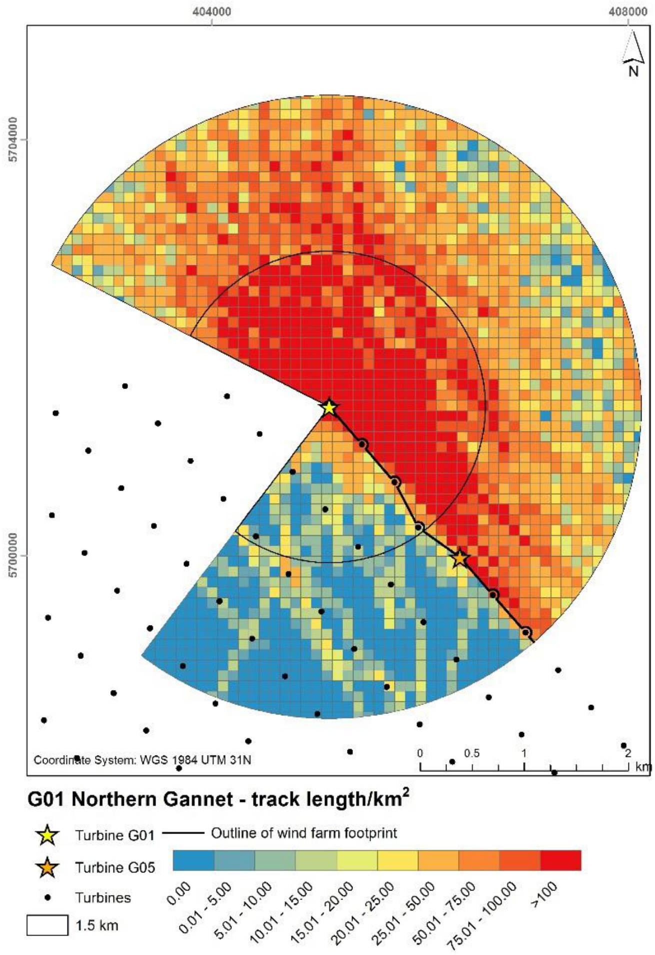

Figure 2-3 Example of macro avoidance. Flight patterns of Northern Gannet recorded by observers tracking with radar at the Thanet Offshore Wind Farm (Skov *et al*. 2018). Map shows density of tracks outside and inside the wind farm (NE corner of array). The avoidance behaviour shows as a concentration of flying birds within a 2 km zone outside the wind farm perimeter.

2.2 Baseline and impact assessment methodologies

2.2.1 Natura 2000 assessment methodologies

The European directives require that an appropriate assessment is carried out for any project which either alone or in combination with other plans or projects is likely to have a significant effect on protected habitats and species. It is the responsibility of the competent authority to decide and give consent to build. Since an EIA will also be carried out all data and facts needed to make the decision have to be available as part of the EIA.

2.2.1.1 Dogger Bank Natura 2000 sites

Large parts of the Dogger Bank are designated as a Natura 2000 site (SACs) in accordance with the EU Habitats Directive in the UK (12,331 km^2), Germany (1,624 km^2) and the Netherlands (4,715 km^2). A significant impact is considered when a project may adversely affect the integrity of the three SACs. The guidance document Managing Natura 2000 Sites (EC 2000) emphasises the conservation objectives of a site as the basis for defining adverse effect: "The integrity of the site involves its ecological functions. The decision as to whether it is adversely affected should focus on and be limited to the site's conservation objectives". The conservation objectives may refer to the target Annex I habitats (H1110 sandbanks) and Annex II species (harbour porpoise, harbour seal, grey seal), but may according to the EC guidance document also refer to species which depend on the area for their long-term survival. In practice, the assessment of site integrity is made in relation to the target Annex I habitats and Annex II species.

Spatial data on the outline of planned (consented and not yet consented) and built wind farm projects in the North Sea have been acquired from this study (https://www.4coffshore.com/, Figure 2-4). The following six consented wind farms are either being constructed or planned to be built in the Dogger Bank region (Figure 2-4);

- Creyke Beck A (UK) (consented 2015)
- Creyke Beck B (UK) (consented 2015)
- Sofia (UK) (consented 2015)
- Teeside A (UK) (consented 2015)
- Hornsea Project One (UK) (consented 2014)
- Hornsea Project Two (UK) (consented 2016)

In terms of the habitat sandbanks (H1110) offshore wind farms have achieved consent to build within these habitats in Germany, the Netherlands and the United Kingdom. The current overlap between planned (and consented) wind farms and sandbanks in the North Sea amounts to between 3.70% and 6.75%. The planned and consented wind farms like the Creyke Beck A and B, Sofia and Teeside A projects also overlap with the boundaries of the designated Natura 2000 area in the UK part of Dogger Bank (Southern North Sea SAC with an area of 2,269 km^2 equivalent to 18.4% of the protected area). Hence, the potential loss of sandbanks or habitats for porpoises and seals due to the planned and consented wind farms has been assessed as compatible with the maintenance of the ecological integrity of the SACs. It should, however be noted that the consents of the planned and consented wind farms in the UK are now being reviewed in relation to impacts on harbour porpoises in the Southern North Sea SAC. The review is expected to be finalised later in 2018 following new sound and population modelling results for assessment (https://itportal.beis.gov.uk/EIP/pages/ola.htm).

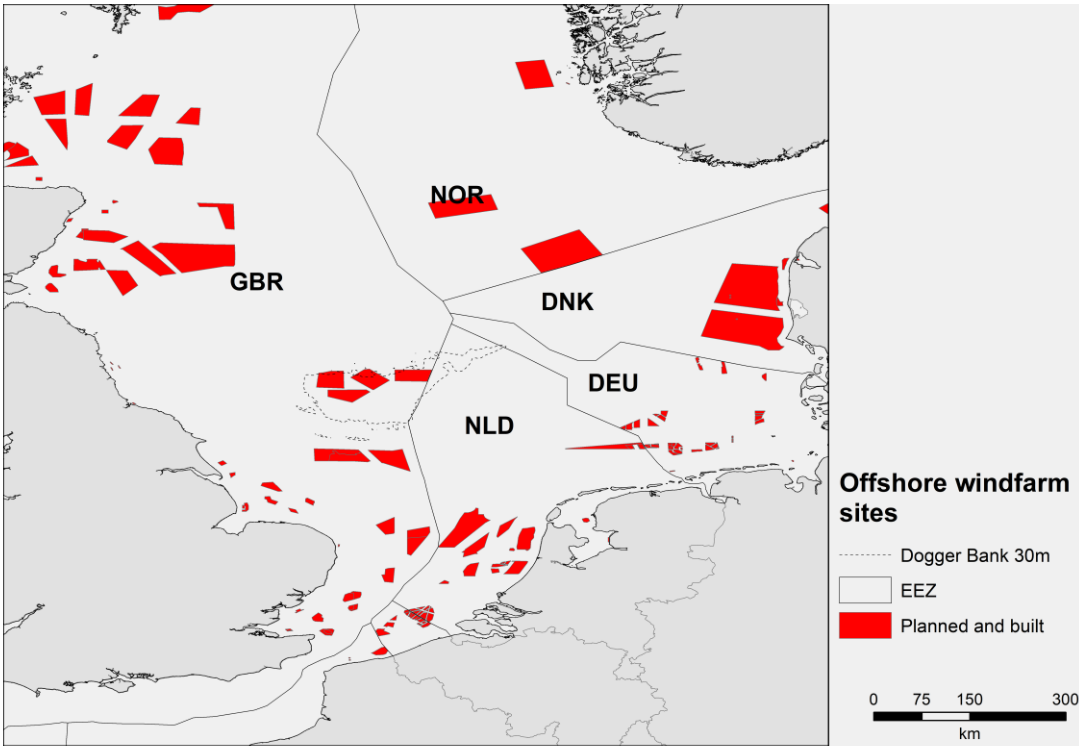

Figure 2-4 Planned (consented and not yet consented) and built OWF projects in the region of the Dogger Bank. Dogger Bank (30 m depth contour) and EEZ boundaries are indicated.

2.2.1.2 Population levels assessments

In order to establish the potential effect on seabirds, marine mammals and fish species which are conservation targets of a Natura 2000 site, the effect at population level has to be estimated. The general advice (JNCC 2017) for estimation of population level effects is to avoid using the site population estimates, but instead consider population estimates at the management unit level in order to make it possible to account for daily and seasonal movements of the animals which in many cases use larger sectors of the North Sea. The common practise as applied in for instance the EIAs for Creyke Beck, Teeside A, Sofia, OWEZ and Horns Rev 2 wind farms is to compare the estimated number of impacted animals with the population estimate for the management unit. The estimated number of impacted animals is extracted from the outcome of underwater noise modelling, collision risk modelling and seabird displacement analyses.

In order to estimate the changes in the size of the population as a result of a project, combined and cumulative impacts population models have recently been applied to estimate the population level impacts for certain offshore wind farms like London Array and Horns Rev 2. The most basic type of population level assessments calculates thresholds for sustainable removal of individuals from the population concerned (in relevant bio-geographic or management unit). Such assessments follow the so-called Potential Biological Removal (PBR) concept. The PBR is a threshold of additional annual mortality, which could be sustained by a population. Additive mortality exceeding PBR would indicate potentially overexploited populations. The main advantage of this approach is that it relies on those demographic parameters, which are easiest to obtain for most species. PBR is a conservative metric and it accounts for potential bias due to density dependence, uncertainty in estimates of the population size and stochasticity (Wade 1998; Taylor *et al*., 2000; Milner-Gulland & Akcakaya 2001).

Although the PBR approach is widely used to guide conservation and management of long-lived species like marine mammals (Wade 1998) and has been demonstrated as a useful tool to assess impacts of fisheries by-catch mortality on birds, there is an increasing criticism towards the application of the method in wind farm EIAs. More reliable estimates of population level impacts have recently been achieved in relation to wind farm EIAs using Population Viability Analyses (PVA). The PVAs estimate the long-term population trajectories with and without the relevant project. Dedicated PVA frameworks have recently been developed and applied in assessments as for example for assessing long-term population impacts of underwater noise on harbour porpoise (Booth *et al*. 2017)

A new generation of population models has recently been developed and applied. These models make it possible to describe the behaviour of individual animals and birds in response to pressures from offshore wind farms such as underwater noise and changes in food supply. The behavioural responses are transferred into energetic consequences and estimates of survival. The models also explicitly deal with cumulative and in-combination impacts with other wind farms. The so-called agent-based models (ABM) like FEBI (waterbirds) and DEPONS (harbour porpoise) have been applied in relation to larger infrastructure and wind farm projects (FEBI 2013, Heinis & de Jong 2015, van Beest *et al*. 2015).

With the development and application of population viability analyses marine infrastructure projects and offshore wind farm projects have got a tool which will enable more reliable estimation of the significance of the environmental impacts in terms of effects on the long-term survival of affected populations. One of the benefits of these analyses is their capacity to assess whether the affected population may compensate a loss of individuals and sustain a long-term survival in the project area. Population viability analyses have also provided the projects with improved means for quantifying in-combination and cumulative impacts.

2.2.2 Assessment of habitat change and loss

Both habitat loss and habitat change related to excavation and other earth works from the construction of large marine infrastructure projects are assessed using the areas of excavation. The assessment typically focuses on quantifying benthic habitat loss using data from benthic baseline mapping. Benthic baseline mapping is standard in most North Sea countries and undertakes the results from geo-physical surveys in combination with biological sampling and drop-down/diver video transects.

Quantification of the effects of earth works related to construction of offshore wind farms has been carried out at only a few sites in the North Sea. These sites like Horns Rev 1 and Scroby Sands are generally located in coastal areas with potential impacts on macrophytes and/or Sabellaria reefs.

The enhancement of benthic production associated with the introduction of hard substrate by wind farm foundations has been studied in post-construction monitoring activities at several wind farms in the North Sea like OWEZ, *Alpha Ventus* and Horns Rev 1. However, the knowledge gathered during these activities is generally not used extensively in EIAs, for example in order to assess the local increase in benthic biomass and food supply to predators. Prediction models by Miller *et al*. (2014) were used to assess how offshore wind farm installations may affect the spread of marine species. They considered the potential effects of wind installations being considered in the UK and focused on the effects on species with mobile larvae, such as barnacles, mussels and limpets. The model indicated that the installations in the proposed areas could potentially act as ‘stepping stones’, and thereby promote the spread and establishment of new species in some areas.

2.2.3 Assessment of acoustic displacement and injury of fish and marine mammals during pile driving

In chapter 2.1.2 the issues related to underwater noise impacts on marine mammals and fish during pile driving activities were described, along with the options available for mitigating these impacts. The impacts of acoustic displacement and injury in terms of PTS and TTS are assessed using noise modelling in combination with large-scale estimates of the distribution and abundance of marine mammals and fish. Noise modelling quantifies the spreading and level of sound pressures during pile driving. Large-scale population estimates are both derived from project specific surveys and international level surveys like the co-ordinated ICES fish surveys and the SCANS cetacean surveys.

The modelling has only been carried out for the construction period as underwater noise impacts are considered insignificant during the operational phase. Other activities associated with construction of offshore wind farms, e.g. geophysical surveys and UXO clearance, have typically used information from existing noise modelling studies. Measures are often put in place to mitigate the intense noise produced by impact pile driving (Diederichs *et al*. 2014, Andersson *et al*. 2016), and noise modelling is often carried out including a scenario in which noise levels are reduced, e.g. by 15 dB using large bubble curtains (Diederichs *et al*. 2014). No noise modelling for other activities have generally been undertaken for the wind farm EIAs or EIAs for extended construction works related to artificial islands or similar (FEMM 2013).

All developers of wind farms in the North Sea have included sound modelling studies as part of their EIA and undertaken detailed assessments on the potential impacts from noise on marine mammals and fish. The modelling covered a period of 1-3 years using the best available methods at the time.

Different approaches for assessing the onset of injury or extent of disturbance have been used in the various EIA projects. The approaches have included assessments based on weighted thresholds that consider varying hearing abilities of marine mammals and include Sound Exposure Level (SEL) and sound pressure perceived by species (dBht) as well as unweighted thresholds based on SEL and SPL metrics. The thresholds selected within each application also differ. The variation in SEL and SPL reflects the development of assessment standards, and thus assessments of acoustic impacts during the first wind farm EIAs like those at Horns Rev 1 and Butendiek used different thresholds than the more recent EIAs.

Until recently, the thresholds have, with respect to PTS and TTS, been predominantly based on the thresholds published in Southall *et al*. (2007). More recent EIAs have used alternative thresholds for harbour porpoise based on the studies published by Lucke *et al*. (2009). The latest published NOAA thresholds were not available for assessments prior to 2016.

The consequences of the different approaches to noise modelling are that estimated areas of effect are not easily comparable across. It is likely that future assessments will be required to use the NOAA thresholds for sound modelling.

An alternative approach is to assess the possible extent of disturbance based on the assumption that there is an effective deterrent radius arising from piling offshore wind farms of 26 km. This follows a suggested approach proposed by the JNCC, not yet applied in offshore wind farm EIAs (JNCC 2017), - an approach which may be altered with future improved options for mitigation.

2.2.4 Assessment of other types of displacement of fish and marine mammals

Displacement of fish and seabirds related to sediment spill from the construction works of large marine infrastructure projects with long-term sediment spills is assessed using modelling of the spreading and concentration of sediment particles combined with data on the distribution and abundance of seabirds and fish (FEMA-FEHY 2013, FEBI 2013). The assessment typically focuses on quantifying the exceedance of tolerance thresholds for feeding fish and seabirds. Subsequently, the exceedance statistics are used to estimate the size of displacement zones.

Quantification of the effects of sediment spills by numerical modelling related to construction of offshore wind farms has only been carried out at a few sites in the North Sea. These sites are generally located in coastal areas.

Displacement of fish due to electromagnetic fields is typically assessed at a low level using experience from the few studies available (e.g. Nysted).

2.2.5 Assessment of displacement of seabirds during operation of offshore wind turbines

As described in chapter 2.1.3 displacement of the characteristic seabird species at Dogger Bank during operation of offshore wind turbines is expected to be limited to 1 km from the perimeter of the wind farms. However, in-combination displacement from the operation of other wind farms in the North Sea may result in levels of displacement which may or may not be relatively high in comparison to the size of the seabird populations in the North Sea.

Baseline survey campaigns for seabirds at offshore wind farms cover between one and two, rarely three years. Baseline surveys in Denmark are only carried out by aerial surveys, in the Netherlands and Belgium only by ship-based surveys, in Germany and United Kingdom by a combination of ship-based and aerial surveys. For aerial surveys digital survey techniques are replacing standard visual survey techniques in the UK and Germany.

In order to use the survey data in estimation of population level consequences it is necessary to generalise the transect counts into maps of average seasonal densities. These generalisations of distribution patterns cover large sectors around the project site and need to demonstrate temporal variability in the densities of the key species of seabirds. In most large-scale infrastructure and wind farm projects like Fehmarn Belt Fixed Link, Horns Rev I, Horns Rev II, OWEZ, London Array, Creyke Beck A and B, Sofia and Teesside A generalisation of distribution patterns of seabirds has been achieved using distribution (habitat) modelling with the available survey data (Leopold *et al*. 2013, FEBI 2013, Petersen *et al*. 2014).

At the current time the potential build-out of offshore wind farms in the North Sea over the following 15 years cannot be safely assessed. Thus, it is uncertain whether in-combination and cumulative impacts of seabird displacement from the wind farms of the NSWPH will approach critical levels for any species. In-combination displacement impacts have resulted in consent applications of offshore wind farms in the North Sea being refused (London Array Phase II, three planned projects in Dutch waters). Due to the small scale of displacement, the impacts from the NSWPH wind farms alone will most likely not result in significant population level impacts.

2.2.6 Assessment of collision risk to birds from offshore turbines

Calculation of collision mortality rates of birds at offshore wind farm sites has recently been carried out at all sites in the UK, Belgium, the Netherlands and Denmark using the Band (2012) collision risk model.

In Denmark, Germany, The Netherlands and Belgium detailed data on bird movements are collected as part of baseline, whereas in the UK estimates of bird flux in the wind farm are deduced from ship-based surveys. The detailed bird movement surveys enable separate estimations of the flux of local seabird and of birds on long-distance migration, and typically entail either observers on platforms/transition pieces or ships assisted by radars.

Until recently, as described in section 2.1.4, estimation of collision mortality rates of seabirds at planned offshore wind farms were largely based on local survey data on densities of seabirds combined with estimated avoidance rates deduced from casualty surveys at land-based wind farms. As a result, estimates of collision rates of seabirds have generally been overly precautionary. Recent empirical data on seabird avoidance and flight speeds collected during the Carbon Trust Seabird Collision Avoidance Study 2014-2018 (Skov *et al*. 2018) have now made it possible to estimate more accurate and most likely significantly lower seabird collision rates.

3 Evaluation of vulnerable areas

3.1 Habitat and species distribution data

In order to assess the importance of the region at the Dogger Bank to habitats and species, vulnerable areas in the North Sea have been mapped. Vulnerable areas in the North Sea were identified based on all available data on selected habitats and species of fish, marine mammals and seabirds from international databases. The data covered eight species of fish, nine species of seabirds and five species of marine mammals.

Spatial data on habitats and Natura 2000 sites have been obtained from the European Environment Agency. For migratory species, North Sea wide distribution data were selected and processed as GIS files. Species distribution maps present density per area and are based on available recent, quality-assured survey. Most distribution maps displayed densities aggregated into larger standard units. Except for marine mammals, extrapolation or spatial modelling was not applied. Extrapolation and modelling were applied for marine mammals due to the low number of observations available from recent, standardised international survey databases.

Spatial data on fish densities were obtained from ICES International Bottom Trawl Survey 2008-2014 (winter and autumn seasons) and aggregated into 40x40 km squares. Densities of fish were extracted as catch rate per hour from DATRAS, the Database of Trawl Surveys maintained by the International Council for the Exploration of the Seas, (ICES) (http://www.ices.dk/marine-data/dataportals/Pages/DATRAS.aspx). Densities of juvenile plaice, cod and sandeel were obtained from ICES coordinated survey of nursery areas in the central North Sea in 1997 (Munk *et al*. 2002). Densities of seals were obtained from Marine Scotland's estimated at-sea distribution of grey and harbour seals tagged in UK colonies (https://data.marine.gov.scot/dataset/estimated-sea-distribution-grey-and-harbour-seals-updated-maps-2017). Spatial data on harbour porpoise were modelled seasonal densities for the southern and central North Sea based on aggregated observations from selected data in UK (SCANS II, Dogger Bank), Belgium, the Netherlands, Germany, and Denmark (Gilles *et al*. 2016). Spatial data on white-beaked dolphin and minke whale were generated by interpolating observations from SCANS1 and SCANS2 surveys available on OBIS (http://iobis.org/data/). Seasonal seabird densities from the period 1980-2004 were obtained from the European Seabirds at Sea Database (ESAS) and aggregated into 40x40 km squares.

Table 3-1 Species included in the assessment of vulnerable areas, the number of seasons covered, and the years represented.

	Species	Number of seasons	Years
Seabirds	Northern Gannet	3	1980-2004
	Common Guillemot	3	1980-2004
	Northern Fulmar	2	1980-2004
	Black-legged Kittiwake	2	1980-2004
	Little Auk	1	1980-2004
	Atlantic Puffin	2	1980-2004
	Razorbill	3	1980-2004
	Lesser Black-backed Gull	2	1980-2004
	Great Black-backed Gull	1	1980-2004
Seals	Grey Seal	1	1991-2016
	Harbour Seal	1	1991-2016

	Species	Number of seasons	Years
Cetaceans	Harbour Porpoise	1	2005-2013
	White-beaked Dolphin	1	1994, 2005
	Minke Whale	1	1994, 2005
Fish	Dab	2	2008-2014
	Cod	2	2008-2014
	Grey gurnard	2	2008-2014
	Herring	2	2008-2014
	Mackerel	2	2008-2014
	European Plaice	2	2008-2014
	Common Sole	2	2008-2014
	Sandeel*	1	2000-2016
	Plaice nursery area	1	1997
	Cod nursery area	1	1997
	Sandeel nursery area	1	1997

As all analysed species of fish, marine mammals and seabirds are wide-ranging within the North Sea, this analysis was made focusing on the areas with the highest densities of each species in the entire North Sea. High-density areas were identified using the 90th percentile, which is widely regarded as a robust and transparent method for estimating the upper part of the distribution of densities (Engineering Statistics Handbook 2018) and for identification of high-density areas e.g. in relation to Natura 2000 (Heinänen & Skov 2015). In the cases where mean species densities were available for more than one season, high density areas were first estimated for each season before merging estimated areas into one map. An example of the identification of high-density areas by using the 90th percentile is shown in Figure 3-1. As no reliable density maps are available for sandeel, key sandeel fishing grounds mapped by DTU Aqua (DTU Aqua pers. com.) were used as indicative for areas with the highest densities of sandeel.

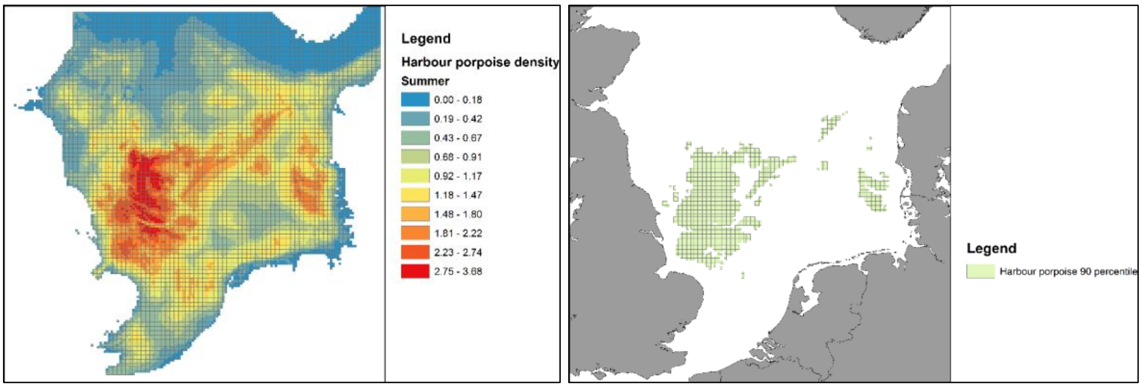

Figure 3-1 Example of application of 90th percentile for identification of high-density areas in this pre-screening study. Harbour porpoise density (number of animals/km^2) during summer (left) and identified high-density area (right).

3.2 Vulnerable areas in the Dogger Bank region

As pointed out in the section on the approach of the project, the assessed habitats and species have either been selected based on their status in relation to the three designated SACs at Dogger Bank or based on their numerical importance on Dogger Bank. Hence, the maps of the extent of Annex I habitats and the location of high density areas to species can be seen as representing the most vulnerable areas related to the construction and operation of the hub and associated wind turbines.

3.2.1 Annex 1 habitat H1110 sandbanks

Large areas of the protected habitat type H1110 sandbanks are identified in the region of the Dogger Bank, and the majority of these are included in the SACs under the EU Habitats Directive designated by Germany, the Netherlands and the United Kingdom (Figure 3-2). The mapped areas of sandbanks and Natura 2000 sites disclose that sizable areas of sandbank habitats and protected areas are found within the perimeters of planned and consented wind farms in this part of the North Sea.

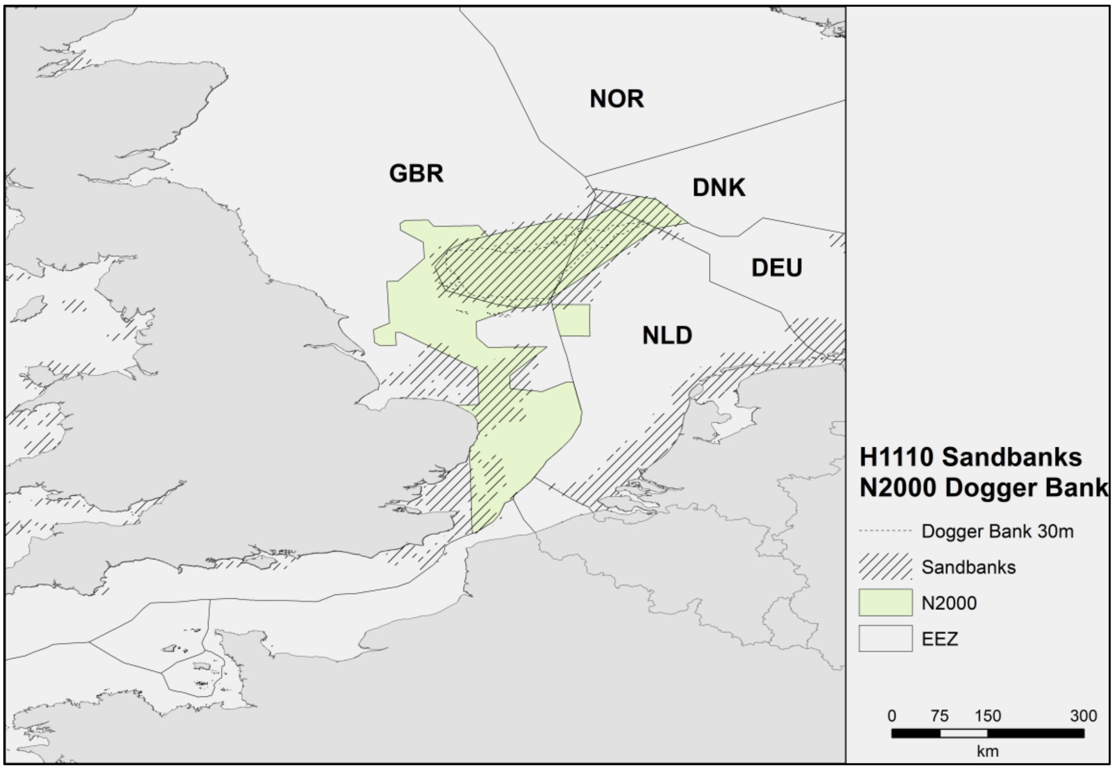

Figure 3-2 Map of H1110 sandbanks in the region of the Dogger Bank (Data source: European Environment Agency 2017 https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1/).

3.2.2 Marine mammals

High-density areas of marine mammals are shown in Figure 3-3. The high-density areas of grey seals are located in the offshore areas associated with the main colonies for this species in Scotland and in the Humber and Thames estuaries. Smaller patches of higher densities of grey seal are found along the western and northern flanks of the Dogger Bank, whereas no high-density areas are found east and southeast of the Dogger Bank. Harbour seal is more concentrated in the Humber and Thames regions, and the smallest distance between the main high-density area and Dogger Bank is around 100 km. Small high-density patches for harbour seal are located at the north-western corner of the Dogger Bank.

The distribution of high-density areas of minke whale and white-beaked dolphin is rather similar showing a large area stretching from NE Scotland to the north-western flanks of the Dogger Bank. The high-density areas of harbour porpoise overlap to some extent with the main areas used by the other two species of cetaceans, yet it is focused more on the region to the south-west, west and north-west of the Dogger Bank, including the whole western part of the bank. Patches of high porpoise density are also located along the eastern flanks. Regions without high-density areas of harbour porpoise are found north and southeast of the Dogger Bank.

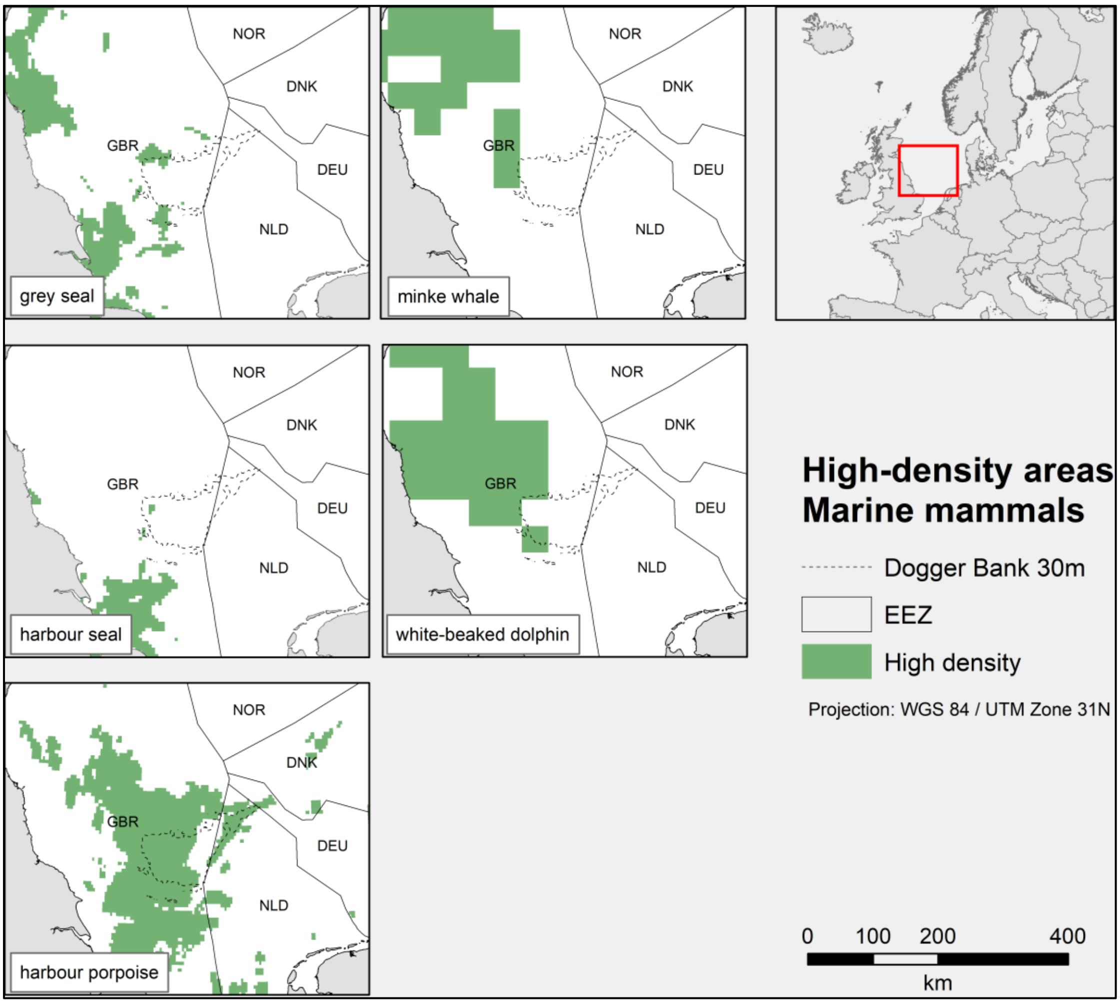

Figure 3-3 High-density areas of grey seal, harbour seal, harbour porpoise, minke whale and white-beaked dolphin in the region of the Dogger Bank (sources: https://data.marine.gov.scot/dataset/updated-seal-usage-maps-estimated-sea-distribution-grey-and-harbour-seals, Gilles *et al*. 2016, SCANS I and II).

3.2.3 Seabirds

High-density areas for seabirds are shown in Figure 3-4. The high-density areas of pelagic species of seabirds which are mainly recruited from breeding colonies in Scotland, like larger auk species and Northern Gannets, are located in a coherent region stretching from NE Scotland to the north-western flanks of the Dogger Bank. Hence, these high-density areas overlap extensively with the high-density areas identified for marine mammals. Areas immediately to the east and north of Dogger Bank are characterised by only few high-density areas of pelagic seabirds.

The Little Auk has a more offshore distribution, and high densities are mainly found north of Dogger Bank. The largest coherent area of high densities of Northern Fulmar is found south of the Norwegian Trench, while the Lesser and Great Black-backed Gull are most concentrated south and south-east of Dogger Bank.

Figure 3-4 High-density areas for Northern Gannet, Common Guillemot, Northern Fulmar, Black-legged Kittiwake, Little Auk, Atlantic Puffin, Razorbill, Lesser Black-backed Gull and Great Black-backed Gull in the region of the Dogger Bank (source: European Seabirds at Sea Database).

3.2.4 Fish

High-density areas for fish are shown in Figure 3-5. Large regions of high-densities of European plaice, dab and herring are located south-east of Dogger Bank, while high-density areas of common sole and grey gurnard are found more to the north-west of Dogger Bank, and high-density areas of mackerel north of Dogger Bank. The more detailed data on sandeel fishing grounds highlight the importance of areas on the edges of the Dogger Bank, and further along the 40 m curve stretching from Dogger Bank to the Fisher Banks, areas south-west of Dogger Bank and areas off the Firth of Forth.

The results for fish nurseries shown in Figure 3-6 show a remarkable degree of overlap between areas used by plaice, cod and sandeel. The high-density nursery areas are located to the south-east and south-west of the Dogger Bank, while no high-density areas are located on the Dogger Bank itself.

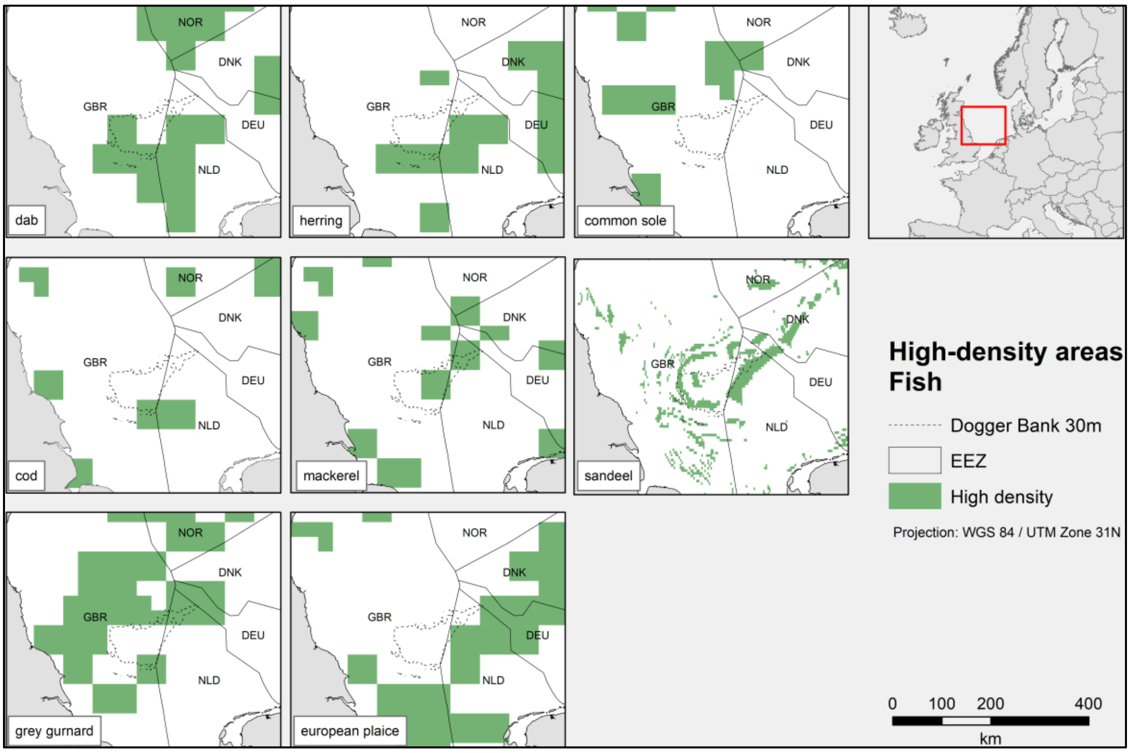

Figure 3-5 High-density areas for dab, cod, grey gurnard, herring, mackerel, European plaice, common sole and sandeel in the region of the Dogger Bank (source: ICES DATRAS).

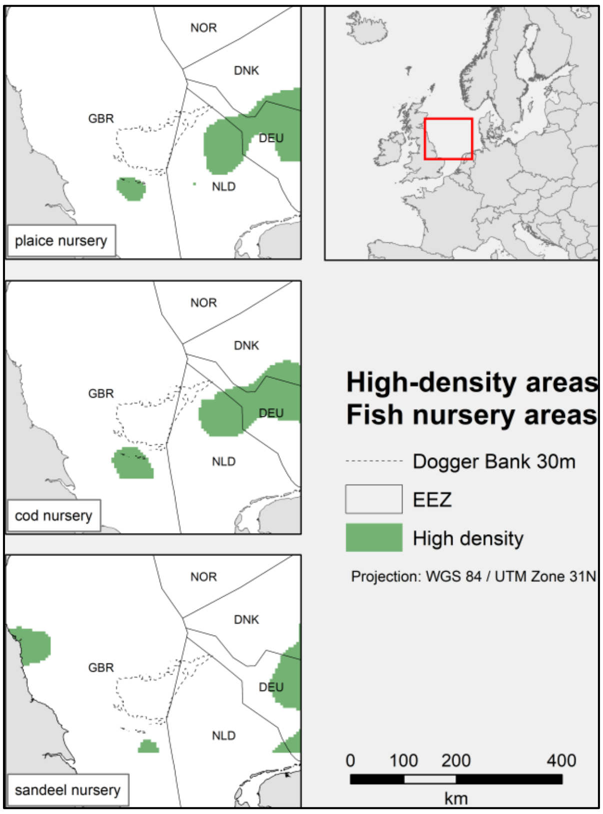

Figure 3-6 High-density areas for European plaice, cod and sandeel nurseries in the region of the Dogger Bank (source: Munk *et al*. 2002).

4 Potential showstoppers

Consented plans for offshore wind farms already exist within the protected habitat Sandbanks and designated Natura 2000 sites in Germany, the Netherlands and the United Kingdom. Whether the potential further loss of sandbanks due to a power hub and wind turbines will be regarded as incompatible with the maintenance of the ecological integrity of the SACs and hence a potential showstopper for the project cannot be judged at this time. Liaison with Dutch, German and UK regulators would be required to clarify this issue.

Displacement impacts from underwater noise on marine mammals and fish from the construction of the NSWPH wind farms and in combination with other projects can be significantly reduced using advanced mitigation measures. Based on existing acoustic model tests it is expected that the mitigated acoustic disturbance of fish and marine mammals is compatible with the maintenance of the ecological integrity of the SACs. However, more detailed assessments are required to verify the efficiency of mitigation measures for a potential project.

This pre-screening review of EIAs and species distribution data does not suggest any significant impacts related to seabirds from the NSWPH project on its own. Collision impacts on birds on long-distance migration and seabirds using the wind farm area are expected to be minor or moderate given perceived low densities of migrating birds and results from recent studies on avoidance rates for seabirds. More detailed assessments are, however, needed to verify the perceived low population level consequences of the operation of the hub and the wind turbines for potentially impacted seabird species.

5 Conclusion

With the exception of the harbour porpoise, the Dogger Bank as such is not characterised by high densities of fish, marine mammals and seabirds. However, important areas for a number of fish, marine mammal and seabird species are found at the slopes of the bank in the UK sector. In the Dutch, German and Danish sectors the environment is characterised by only few areas with high densities of the studied species. Based on this pre-screening, the north-eastern part of the Dogger Bank in the Dutch, German and Danish seems to contain the least potential ecological showstoppers for a hub and related wind farms.

Based on this review of North Sea wind farm EIAs and available data on distribution of marine fish, mammals and sea birds, no definite showstoppers were identified for the construction of the hub and related wind farms on Dogger Bank. However, there are several potential showstoppers, for which further environmental studies will be needed to confirm the expectations that:

- The potential loss and disturbance of the habitat sandbanks H1110 are compatible with maintaining the ecological integrity of the protected areas in relation to Annex I habitats;
- State-of-art mitigation measures can reduce underwater noise from pile driving operations sufficiently during construction of the wind turbines;
- The long-term population level acoustic displacement impacts on fish and marine mammals, as well as population-level displacement or collision impacts on seabirds, are not significant.

6 References

Aires, C., González-Irusta, J.M., Aires, R.W. 2014. Updating fisheries sensitivity maps in British waters. Scottish Marine and Freshwater Science Report Vol 5 No 10. Marine Scotland.

Andersen, P. 2006. EIA Report. Water Quality. Horns Rev 2 Offshore Wind Farm. Bio/consult, CarlBro & DHI.

Andersson, M.H., Andersson, S., Ahlsén, J., Andersson, B.L., Hammar, J., Persson, L.K.G., Pihl, J., Sigray, P., Wikström, A. 2016. A framework for regulating underwater noise during pile driving. A technical Vindval report, ISBN 978-91-620-6775-5, Swedish Environmental Protection Agency, Stockholm, Sweden.

Austin, G.E., Newson, S.E., Cook, A.S.C.P., Ross-Smith, V.H., Thaxter, C.B. & Burton, N.H.K.., 2011. Assessment of ornithological survey protocols and focal species in relation to the proposed Dogger Bank Wind Farm Development. BTO Research Report No. 571 to Forewind Ltd. BTO, Thetford, UK.

Band, W., Madders, M. and Whitfield, D.P. 2007. Developing field and analytical methods to assess avian collision risk at windfarms. In De Lucas M, Janss G and Ferrer M (eds) 'Birds and Wind Power'. www.quercus.ptBand.

Band, W. 2012. Using a collision risk model to assess bird collision risks for offshore windfarms. The Crown Estate, 62pp, available at: https://www.bto.org/sites/default/.../Final_Report_SOSS02_Band1ModelGuidance.pdf.

Blew, J., Hoffmann, M., Nehls, G. and Hennig, V. 2008. Investigations of the bird collision risk and the response of harbour porpoises in the offshore wind farms Horns Rev, North Sea and Nysted, Baltic Sea, in Denmark. Part 1: Birds

Booth, C.G., Harwood, J., Plunkett, R, Mendes, S, and Walker, R. 2017. Using the Interim PCoD framework to assess the potential impacts of offshore wind developments in Eastern English Waters on harbour porpoises in the North Sea. Natural England Joint Report, Number 024 York.

Brasseur, S. & Kirkwood, R. 2014. Seal monitoring and evaluation for the Gemini offshore windpark: Pre-construction, T0 - 2014 report. Imares

Brown and May Marine. 2013. Dogger Bank Creyke Beck Environmental Statement - Chapter 13 Fish and Shellfish Ecology. F-OFC-CH-013. Forewind Application Reference 6.13.

Brew, D.S., Nguyen, H., Hu, Keeming, Page, Krista. 2014. Horns Rev 3 Offshore Wind Farm. Hydrography, sediment spill, water quality, geomorphology and coastal morphology. Orbicon A/S.

Brown and May Marine. 2014. Dogger Bank Teesside A & B Environmental Statement Chapter 13 Fish and Shellfish Ecology. F-OFC-CH-013. Forewind Application Reference 6.13.

Brunner, P. 2013. Dogger Bank Creyke Beck Environmental Statement Chapter 33 - Cumulative Impact Assessment. F-OFC-CH-033. Forewind Application Reference 6.33.

Bundesamt für Seeschiffahrt und Hydrographie. 2013. Standard. Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment (StUK4). BSH.

Chapman, C.J. & Hawkins, A.D. 1973. A field study of hearing in the Cod, *Gadus morhua* (L.). Journal of comparative physiology, 85: 147-167.

Chapman, C.J., Sand, O. 1974. Field studies of hearing in two species of flatfish *Pleuronectes platessa* (L.) and *Limanda limanda* (L.) (Family Pleuronectidae). Comp. Biochem. Physiol. 47(A): 371-385.

Christensen, Thomas Kjær, Petersen, Ib Krag & Fox, Anthony D. 2006. Effects on birds of the Horns Rev 2 offshore wind farm: Environmental Impact Assessment. National Environmental Research Institute.

Cook, A.S.C.P., Humphreys, E.M., Masden, E.A. and Burton, N.H.K. 2014. The avoidance rates of collision between birds and offshore turbines. BTO Research Report No. 656. British Trust for Ornithology, Thetford, 273pp.

Cook, A.S.C.P., Johnstone, A., Wright, L.J. and Burton, N.H.K. 2012. A review of flight heights and avoidance rates of birds in relation to offshore wind farms. Strategic Ornithological Support Services. Project SOSS-02. BTO Report 618 for The Crown Estate.

Coull, K.A., Johnstone, R., & Rogers, S.I., 1998. Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.

COWI. 2015. Vesterhav Syd Offshore Wind Farm. Sediments, water quality and hydrography. Background report for EIA-study. COWI A/S.

Daan, R., Mulder, M. Bergman, M.J.N. 2009. Impact of windfarm OWEZ on the local macrobenthos community Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ) Report number: OWEZ R 261 T1.

Danish Energy Agency, 2013. Danish Offshore Wind. Key Environmental Issues – a Follow-up. The Environmental Group: The Danish Energy Agency, The Danish Nature Agency, DONG Energy and Vattenfall.

Desholm, M. 2005. TADS investigations of avian collision risk at Nysted offshore wind farm, autumn 2004. National Environmental Research Institute. Ministry of Environment.

Diederichs, A., Pehlke, H., Nehls, G., Bellmann, M., Gerke, P., Oldeland, J., Grunau, C., Witte, S., Rose, A. 2014. Entwicklung und Erprobung des Großen Blasenschleiers zur Minderung der Hydroschallemissionen bei Offshore-Rammarbeiten, BMU Förderkennzeichen 0325309A/B/C. BioConsult SH, Husum.

Dierschke, V., Furness, R.W. & Garthe, S. 2016. Seabirds and offshore wind farms in European waters: Avoidance and attraction. Biological Conservation 202: 59-68.

Dorsch, M., Girardello, M., Weiß, F., Laczny, M., Nehls, G. 2014. Horns Rev 3 Offshore Wind Farm. Resting birds. Orbicon A/S.

Dunlop, R.A., Noad, M.J., McCauley, R.D., Kniest, E., Slade, R., Paton, D., Cato, D.H. 2018. A behavioural dose-response model for migrating humpback whales and seismic air gun noise. Marine Pollution Bulletin 133, 506-516.

EC. 2000. Managing Natura 2000 sites. The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC. European Communities.East Anglia One. 2016. East Anglia One Offshore Wind Farm – Non-material change.

Ellis, J.R., Dulvy, N.K., Jennings, S., Parker-Humphreys, M. & Rogers, S.I. 2005. Assessing the status of demersal elasmobranchs in UK waters: a review. Journal of the Marine Biological Association of the United Kingdom 85: 1025-1047.

Ellis, J.R., Milligan, S., Readdy, L., South, A., Taylor,N. & Brown, M. 2010. Mapping spawning and nursery areas of species to be considered in Marine Protected Areas (Marine Conservation Zones). Report No 1: Final Report on development of derived data layers for 40 mobile species considered to be of conservation importance. CEFAS Project Code: MB5301.

EMU. 2011. Dogger Bank Zonal Characterisation. 2nd Edition – December 2011. Report commissioned by Forewind. 11/J/1/06/1761/1218. EMU.

EnergiNet 2017. Analysis of constraints in Dogger Bank. Preliminary assessment of geology and ecology for the NSWPH-project in Danish EEZ. EnergiNet.

Enger, P.S. 1967. Hearing in herring. Comp. Biochem. Physiol., 22:527-538.

Engineering Statistics Handbook. 2018. Percentiles https://www.itl.nist.gov/div898/handbook/prc/section2/prc262.htm.

ERM & East Anglia Offshore Wind Ltd. 2012a. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 2. Offshore. Chapter 8 – Underwater Noise and Vibration and Electromagnetic Fields. East Anglia Offshore Wind Ltd.

ERM & East Anglia Offshore Wind Ltd. 2012b. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 2. Offshore. Chapter 9 – Benthic and Epibenthic Environment (including Shellfish). East Anglia Offshore Wind Ltd.

ERM & East Anglia Offshore Wind Ltd. 2012c. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 2. Offshore. Chapter 10 – Fish Ecology. East Anglia Offshore Wind Ltd.

ERM & East Anglia Offshore Wind Ltd. 2012d. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 2. Offshore. Chapter 11 – Marine Mammals. East Anglia Offshore Wind Ltd.

ERM & East Anglia Offshore Wind Ltd. 2012e. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 2. Offshore. Chapter 12 – Ornithology – Marine and Coastal. East Anglia Offshore Wind Ltd.

ERM & East Anglia Offshore Wind Ltd. 2012f. East Anglia ONE Offshore Windfarm. Environmental Statement. Volume 3. Chapter 24 – Ecology and Ornithology. East Anglia Offshore Wind Ltd.

Everaert, J. 2014. Collision risk and micro avoidance rates of birds with wind turbines in Flanders. Bird Study, 61: 220-230.

Fay, R.R., Popper, A.N. 1974. Acoustic stimulation of ear of goldfish (*Carrassius auratus*). Journal of Experimental Biology 61: 243-260.

FEBI. 2013. Fehmarnbelt Fixed Link EIA. Fauna and Flora – Birds. Birds of the Fehmarnbelt Area – Impact Assessment. Report No. E3TR0015. Report to Femern A/S.

FeBEC 2013. Fehmarnbelt Fixed Link Fish and Fisheries Services. Fish Ecology in Fehmarnbelt. Impact Assessment. Report to Femern A/S.

FEMA-FEHY. 2013. Fehmarnbelt Fixed Link EIA. Marine Water & Fauna & Flora – Impact Assessment. Water Quality and Plankton of the Fehmarnbelt Area. Report No. E2TR0020 - Volume IV.

FEMM. 2013. Fehmarnbelt Fixed Link EIA. Marine Mammals – Impact assessment. Report no. E5TR0021. Report to Femern A/S.

Geelhoed et al. 2015. Gemini T-0: passive acoustic monitoring and aerial surveys of harbour porpoises. Imares.

Gemini Offshore Wind Project. 2011. GEM-TM-PRM-053-English Summary EIA Gemini windfarms-V01.0. Gemini.

Gill, A.B., Kimber, J.A., 2005. 'The potential for cooperative management of elasmobranchs and offshore renewable energy development in UK waters'. J. Mar. Biol. Ass. UK, 85, 1075-1081.

Gilles, A., S. Viquerat, E. A. Becker, K. A. Forney, S. C. V. Geelhoed, J. Haelters, J. Nabe-Nielsen, M. Scheidat, U. Siebert, S. Sveegaard, F. M. van Beest, R. van Bemmelen, & G. Aarts. 2016. Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. Ecosphere 7(6):e01367. 10.1002/ecs2.1367

Global Wind Energy Council [GWEC]. 2017. Global Wind Report. Annual market update 2016. Available at: http://www.gwec.net/global-figures/wind-energy-global-status/.

Grift, R.E., Tulp, I., Ybema, M.S., Couperus, A.S. 2004. Base line studies North Sea wind farms: Final report pelagic fish. RIVO report number: C047/04.

Gutow *et al*. 2014. Rapid increase of benthic structural and functional diversity at the alpha ventus offshore test site. P. 67-80 in: Federal Maritime and Hydrographic Agency Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Eds). Ecological Research at the Offshore Windfarm alpha ventus. Springer.

Hawkins, A.D., Roberts, L., Cheesman, S. 2014. Responses of free-living coastal pelagic fish to impulsive sounds. J. Acoust. Soc. Am. 135(5): 3101-3116.

Heinänen, S. and Skov, H. 2015. The identification of discrete and persistent areas of relatively high harbour porpoise density in the wider UK marine area. JNCC Report No.544 JNCC, Peterborough.

Heinis, F and de Jong, C. 2015. Framework for Assessing Ecological and Cumulative Effects of Offshore Wind Farms; Cumulative Effects of Impulsive Underwater Sounds on Marine Mammals. Report by TNO.

ICES. International Council for the Exploration of the Sea (ICES). 2007. Report of the Working Group Elasmobranch Fishes (WGEF), 22–28 June 2007, Galway, Ireland. ICES CM 2007/ACFM: 27. 318 pp.

Jarvis et al. 2004. North Sea Wind Farms: NSW Lot 1 Benthic Fauna. Final Report. Institute of Estuarine and Coastal Studies, University of Hull.

Jensen, F., Laczny, M., Piper, W., Coppack, T. 2014. Horns Rev 3 Offshore Wind Farm. Migratory birds (with an annex on migrating bats). Orbicon A/S.

JNCC. 2017. A potential approach to assessing the significance of disturbance against conservation objectives of the harbour porpoise cSACs. Version 3.0 Discussion document 14/02/2017. Workshop Noise management in harbour porpoise cSACs. The Dome Room, New Register House, 3 West Register Street, Edinburgh, Scotland EH1 3YT. 27th February 2017.

Kastelein, R. A., Gransier, R., Hoek, L. and Olthuis, J. (2012). Temporary threshold shifts and recovery in a harbor porpoise (*Phocoena phocoena*) after octave-band noise at 4 kHz. Journal of the Acoustical Society of America. 132(5): 3525–3537.

Kalmijn, A.J. 1989. Hydodynamic and acoustic field detection. In: Sensory biology of aquatic animals, J. Atema, R. Fay, A. Popper, W. Tavolga (eds.). Springer-Verlag, New York p 83-131.

Karlsen, H.E., Piddington, R.W., Enger, P.S., Sand, A. 2004. Infrasound initiates directional fast-start escape responses in juvenile roach *Rutilus rutilus*. Journal of Experimental Biology. 207: 4185-4193.

Krijgsveld, K.L., Fijn, R., Japink, M., Van Horssen, P., Heunks, C., Collier, M., Poot, M.J.M., Beuker, D., Dirksen, S. 2011. Effect studies offshore wind farm Egmond aan Zee. Final Report on fluxes, flight altitudes and behaviour of flying birds. Bureau Waardenburg bv. Nordzee Wind. 330pp

Krijgsveld, K.L. 2014. Avoidance behaviour of birds around offshore wind farms. Overview of knowledge.

Leewis, L., Klink, A.D., Verduin, E.C. 2018. Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017). Eurofins Omegam B.V.

Leonhard, S. 2006. EIA Report. Benthic communities. Horns Rev 2 Offshore Wind Farm. Bio/consult, CarlBro & DHI.

Leonhard, S.B. & Pedersen, J. 2006. Benthic communities at Horns Rev before, during and after Construction of Horns Rev Offshore Wind Farm Vattenfall Report number: Final Report/Annual report 2005.

Leonhard, S.B., Stenberg, C. & Støttrup, J. (Eds.) 2011. Effect of the Horns Rev 1 Off-shore Wind Farm on Fish Communities. Follow-up Seven Years after Construction. DTU Aqua, Orbicon, DHI, NaturFocus. Report commissioned by The Environmental Group through contract with Vattenfall Vindkraft A/S.

Leopold et al. 2004. Baseline studies North Sea Wind Farms: Lot 5 Marine Birds in and around the future site Nearshore Windfarm (NSW). Alterra.

Leopold, M.F., van Bemmelen, R.S.A. & Zuur, A.F. 2013. Responses of Local Birds to the Offshore Windfarms PAWP and OWEZ off the Dutch mainland coast. Report number C151/12. Imares Report.

Lewis, J. 2014. Dogger Bank Teesside A & B Draft Environmental Statement Chapter 12 Marine and Intertidal Ecology. F-OFL-CH-012. Forewind Application Reference 6.12

Lindeboom et al. 2011. Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. Environmental Research Letters 6: 1-13.

Lowe, A. & Henderson, R. 2014. Dogger Bank Teesside A & B Environmental Statement Chapter 33. Cumulative Impact Assessment. F-OFL-CH-033. Forewind Application Reference 6.33

Lucke, K., Siebert, U., Lepper, P. a, and Blanchet, M.-A. 2009. Temporary shift in masked hearing thresholds in a 26arbour porpoise (Phocoena phocoena) after exposure to seismic airgun stimuli. The Journal of the Acoustical Society of America, 125(6), 4060-70.

Mackey, B. 2013. Dogger Bank Creyke Beck Environmental Statement - Chapter 14. Marine Mammals. F-OFC-CH-014. Forewind Application Reference 6.14.

Mackey, B & Keenan, G. 2014. Dogger Bank Teesside A & B Environmental Statement. Chapter 14 Marine Mammals. F-OFC-CH-014. Forewind Application Reference 6.14.

Macnaughton, M., Nielsen, B., Nejrup, L.B. Pedersen, J. 2014. Horns Rev 3 Offshore Wind Farm. Technical report no. 4. Benthic habitats and communities. Orbicon A/S.

Madsen, P. T., Wahlberg, M., Tougaard, J., Lucke, K., & Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecolology Progress Series 309: 279-295.

Mason, T, Barham, R.J. 2013. Horns Rev 3 Offshore Wind Farm. Underwater noise modelling. Orbicon A/S.

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

Medwin, H., Clay, C.S. 1998. Fundamentals of Acoustical Oceanography. Academic Press, 711p.

Milner-Gulland, E.J. & Akçakaya, H.R. 2001. Sustainability indices for exploited populations under uncertainty. Trends in Ecology and Evolution 16: 686-692.

Munk, P., Wright, P.J. & Pihl, N.J. 2002. Distribution of the early larval stages of cod, plaice and lesser sandeel across haline fronts in the North Sea. Estuarine, Coastal and Shelf Science, 55: 139–149.

Myrberg, A.A., Gordon, C.R., Klimley, A.P. 1978. Rapid withdrawal from a sound source by open-ocean sharks. J. Acoust. Soc. Am. 64(5):1289-1297.

Nehls et al. 2014. Horns Rev 3 Offshore Wind Farm. Marine Mammals. Orbicon A/S.

NIRAS. 2015. Vesterhav Syd Offshore Wind Farm. EIA – background report. Migrating birds and bats. NIRAS.

NMFS. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-55, 178 p. National Marine Fisheries Service.

Noer, H., Christensen, T.K., Clausager, I. & Petersen, I.K. 2000. Effects on birds of an offshore wind park at Horns Rev: Environmental impact assessment. National Environmental Research Institute.

Petersen, I.K., Nielsen, R.D. & Mackenzie, M.L. 2014. Post-construction evaluation of bird abundances and distributions in the Horns Rev 2 offshore wind farm area, 2011 and 2012. Report commissioned by DONG Energy. Aarhus University, DCE – Danish Centre for Environment and Energy. 51 pp.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.B., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, D.G., Tavolga, W.N. 2014. Sound exposure guidelines for fishes and sea turtles: a technical report prepared by ANSI Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/ SC1.4 TR-2014. Springer and ASA Press, Cham, Switzerland.

Redding T. 2014. Dogger Bank Teesside A & B Environmental Statement - Chapter 32. Transboundary Effects. F-OFC-CH-032. Forewind Application Reference 6.32.

Royal Haskoning DHV. 2013. Dogger Bank Creyke Beck - Ornithology Addendum relating to the cumulative and in-combination assessment. F-OFC-HRA-007. Forewind Application Reference 6.14.

Russell, D.J.F., Hastie, G.D., Thompson, D., Janik, V.M., Hammond, P.S., Scott-Hayward, L.A.S., Matthiopoulos, J., Jones, E.L., McConnell, B.J.J. 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. Appl Ecol. doi:10.1111/1365-2664.12678.

Sand, O. & Enger, P.S. 1973. Evidence for an auditory function of swimbladder in cod. Journal of Experimental Biology, 59, 405-414.

Sand, O., Karlsen, H.E. 2000. Detection of infrasound and linear acceleration in fishes. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences. 355: 1295-1298.

Scheidat et al. 2009. Assessment of the Effects of the Offshore Wind Farm Egmond aan Zee (OWEZ) for Harbour Porpoise (comparison T0 and T1). Final Report. Imares.

Skjellerup, P., Maxon, C.M., Tarpgaard, E., Thomsen, F., Schack, H.B., Tougaard, J., Teilmann, J., Madsen, K.N., Mikaelsen, M.A., Heilskov, N.F. 2015. Marine mammals and underwater noise in relation to pile driving - Report of working group. Energinet.dk, pp. 1-20.

Skov, H. & Thomsen, F. 2006. EIA Report. Marine Mammals. Horns Rev 2 Offshore Wind Farm. Bio/consult, Carl Bro & DHI.

Skov, H. & S. Heinänen. 2017. Determining habitat impacts on seabirds in a dynamic marine environment – lessons from a model-based post-construction monitoring program in the Netherlands. Proceedings from BSH Marine Environment Symposium 2017. BSH.

Skov, H., Heinänen, S., Norman, T., Ward, R.M., Méndez-Roldán, S. & Ellis, I. 2018. ORJIP Bird Collision and Avoidance Study. Final report – April 2018. The Carbon Trust. United Kingdom. 247 pp.

SMartWind 2013a. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 2 – Offshore. Chapter 2. Benthic Subtidal and Intertidal Ecology. SMartWind.

SMartWind 2013b. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 6. Annex 6.8.1 - Construction Noise Model. SMartWind.

SMartWind 2013c. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 6. Annex 6.8.4 – Cumulative Noise Assessment. SMartWind.

SMartWind 2013d. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 4. Annex 4.5.1: Cumulative, Transboundary and Inter-relationships Document SMartWind.

SMartWind 2013e. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 2 – Offshore. Chapter 4 - Marine Mammals SMartWind.

SMartWind 2013f. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 2 – Offshore. Chapter 5 – Ornithology. SMartWind.

SMartWind 2013g. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 2 – Offshore. Chapter 6 – Nature Conservation. SMartWind.

SMartWind 2013h. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 3. Chapter 3 - Ecology and Nature Conservation SMartWind.

SMartWind 2013i. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 5. Annex 5.3.1 – Fish and Shellfish Ecology Technical Report. SMartWind.

SMartWind 2013j. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 5. Annex 5.4.1 – Marine Mammal Technical Report SMartWind.

SMartWind 2013k. Hornsea Offshore Wind Farm - Project One. Environmental Statement. Volume 6. Annex 6.3.9 – Wintering and Migratory Birds Survey. SMartWind.

SNH. 2010. Use of Avoidance Rates in the SNH Wind Farm Collision Risk Model. SNH Avoidance Rate information and Guidance Note. Available at: http://www.snh.gov.uk/planning-and-development/renewable-energy/onshore-wind/bird-collision-risks-guidance/

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R.J., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals, 33, 411-521.

Taylor, B.L., Wade, P.R., DeMaster, D.P., and Barlow, J. 2000. Incorporating uncertainty into management models for marine mammals. Conservation Biology, 14, 1243–1252.

Tien, N., Tulp, I. Grift, R. 2004. Baseline studies wind farm for demersal fish. Haskoning Nederland BV.

Thomsen, F., Lüdemann, K., Kafemann, R. & Piper, W. 2006. Effects of offshore wind farm noise on marine mammals and fish, biola, Hamburg, Germany on behalf of COWRIE Ltd.

Thornton, P. 2013. Dogger Bank Creyke Beck Environmental Statement Chapter 11 - Marine and Coastal Ornithology. F-OFC-CH-011. Forewind Application Reference 6.11.

Thornton, P. 2014. Dogger Bank Teesside A & B Environmental Statement Chapter 11 - Marine and Coastal Ornithology. F-OFL-CH-011. Forewind Application Reference 6.11.

Triton Knoll Offshore Wind Farm Ltd. 2012a. Triton Knoll Offshore Wind Farm. Environmental Statement. Volume 2: Chapter 3 – Benthic Ecology.

Triton Knoll Offshore Wind Farm Ltd. 2012b. Triton Knoll Offshore Wind Farm. Environmental Statement. Volume 2: Chapter 4 – Fish & Shellfish Resources.

Triton Knoll Offshore Wind Farm Ltd. 2012c. Triton Knoll Offshore Wind Farm. Environmental Statement. Volume 2: Chapter 5 – Marine Mammals.

Triton Knoll Offshore Wind Farm Ltd. 2012c. Triton Knoll Offshore Wind Farm. Environmental Statement. Volume 2: Chapter 6 – Bird Ecology.

Triton Knoll Offshore Wind Farm Ltd. 2012d. Triton Knoll Offshore Wind Farm. Environmental Statement. Volume 2: Chapter 7 – Conservation.

van Bemmelen, R.S.A., Geelhoed, S.C.V., Leopold, M.F. 2015. Gemini T-0: local seabirds. Imares.

van Beest, F.M, Nabe-Nielsen, J., Carstensen, J., Teilmann, J. & Tougaard, J. 2015. Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS): Status report on model development. Aarhus University, DCE – Danish Centre for Environment and Energy, 43 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 140.

Verfuss, T. 2014. Noise mitigation systems and low-noise installation technologies. Page 181-190 in: Federal Maritime and Hydrographic Agency Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Eds). Ecological Research at the Offshore Windfarm *alpha ventus*. Springer.

Volckaert et al. 2011. Environmental impact assessment - Offshore North Sea Power wind farm. Arcadis.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science, 14: 1–37.

Wahlberg, M., Larsen, O.N. 2017. Propagation of sound. In: C.H. Brown, T. Riede (Eds.) Comparative Bioacoustics Method eBook. Bentham Science Publishers, Oak Park, IL, pp. 62-119.

Welcker, J. & Nehls, G. 2016. Displacement of seabirds by an offshore wind farm in the North Sea. Marine Ecology Progress Series, 554: 173-182.

Winter, H.V., Aarts, G. Van Keeken, O.A. 2010. Residence time and behaviour of sole and cod in the OffshoreWind farm Egmond aan Zee (OWEZ) IMARES, Wageningen YR Report number: C038/10, p 50