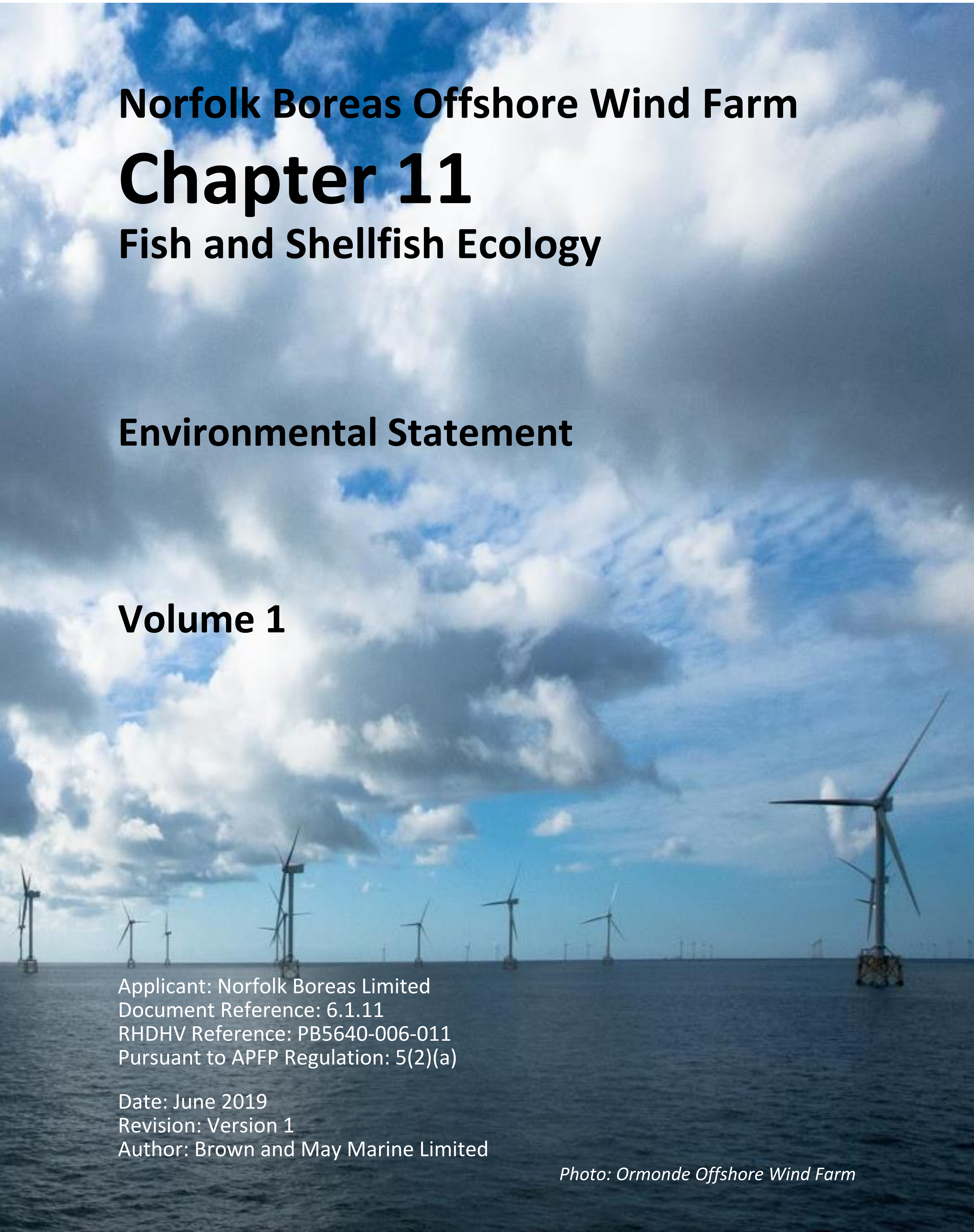
Norfolk Boreas Offshore Wind Farm

Chapter 11

Fish and Shellfish Ecology

Environmental Statement

Volume 1



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Glossary of Acronyms

AC	Alternating current
B	Magnetic field
BAP	Biodiversity Action Plan
Cefas	Centre for Environment, Fisheries and Aquaculture Science
cm	centimetres
COWRIE	Collaborative Wind Research into the Environment
dB	Decibel
CHARM	Channel Habitat Atlas for Marine Resource Management
COWRIE	Collaborative Offshore Wind Research into the Environment
CPA	Coast Protection Act
CPUE	Catch Per Unit Effort
DC	Direct current
DEFRA	Department of Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
E	Electric field
EIA	Environmental Impact Assessment
EIFCA	Eastern Inshore Fisheries and Conservation Authority
EMF	Electromagnetic field
EPP	Evidence Plan Process
ETG	Expert Topic Group
FEPA	Food and Environment Protection Act
HRA	Habitat Regulations Assessment
HVAC	High voltage alternating current
HVDC	High voltage direct current
Hz	Hertz
IBTS	International Bottom Trawl Survey
ICES	International Council for the Exploration of the Sea
IUCN	International Union for the Conservation of Nature
IMARES	Institute of Marine Resources and Ecosystem Studies, the Netherlands
IPMP	In Principle Monitoring Plan
kJ	Kilojoule
km	Kilometre
km^2	Kilometre squared
kV	Kilovolt
m	Metre
m^2	Metre squared
m^3	Metre cubed
MarLIN	Marine Life Information Network
MCEU	Marine Consents and Environment Unit
mg/l	Milligram per litre
MMO	Marine Management Organisation

MW	Megawatt
µT	Microtesla
NPS	National Policy Statement
O&M	Operation and Maintenance
OSPAR	Oslo Paris Convention
PEIR	Preliminary Environmental Information Report
PSA	Particle Size Analysis
SPA	Special Protection Area
SEL_{cum}	Cumulative Sound Exposure Level
SPL_{peak}	Peak Sound Pressure Level
SSC	Suspended Sediment Concentration
TAC	Total Allowable Catch
TTS	Temporary Threshold Shift

Glossary of Terminology

Array cables	Cables which link the wind turbine to wind turbine and wind turbine to offshore electrical platforms.
Beam trawl	A trawl net whose lateral spread during trawling is maintained by a beam across its mouth.
Benthic	Relating to, or occurring at the sea bottom.
Bioelectric	Relating to electricity or electrical phenomena produced within living organisms.
Bony fish	Any of a major taxon (class Osteichthyes or superclass Teleostomi) comprising fishes with a bony rather than a cartilaginous skeleton.
Clupeid	Any of various fishes of the family Clupeidae, which includes the herrings, sprats, sardines and shads.
Crustacean	An arthropod of the large, mainly aquatic group Crustacea, such as a crab, lobster, shrimp, or barnacle.
Demersal	Living on or near the seabed.
Diadromous	Migrating between fresh and salt water.
Elasmobranch	Any cartilaginous fish of the subclass Elasmobranchii which includes the sharks, rays and skates.
Electro-receptive	Ability to perceive electrical stimuli.
Epibenthic	Relative to the flora and fauna living on the surface of the sea bottom.
Evidence Plan Process	A voluntary consultation process with specialist stakeholders to agree the approach to the EIA and information to support HRA.
Gadoid	A bony fish of an order (Gadiformes) that comprises the cods, hakes, and their relatives.
Geomagnetic field	The Earth's magnetic field.
Gravid	Carrying eggs or young
Interconnector cables	Offshore cables which link offshore electrical platforms within the Norfolk Bores site
Offshore cable corridor	The corridor of seabed from the Norfolk Boreas site to the landfall site within which the offshore export cables will be located.
Offshore export cables	The cables which transmit power from the offshore electrical platform to the landfall.

Offshore electrical platform	A fixed structure located within the Norfolk Boreas site, containing electrical equipment to aggregate the power from the wind turbines and convert it into a suitable form for export to shore.
Offshore project area	The area including the Norfolk Boreas site, project interconnector search area and offshore cable corridor.
Offshore service platform	A platform to house workers offshore and/or provide helicopter refuelling facilities. An accommodation vessel may be used as an alternative for housing workers.
Otter trawl	A trawl net fitted with two 'otter' boards which maintain the horizontal opening of the net.
Ovigerous	Carrying or bearing eggs.
Pelagic	Living in the water column.
Piscivorous	Feeding on fish.
Project interconnector cable	Offshore cables which would link either turbines or an offshore electrical platform in the Norfolk Boreas site with an offshore electrical platform in one of the Norfolk Vanguard sites
Project interconnector search area	The area within which project interconnector cables would be installed.
Scour protection	Protective materials to avoid sediment being eroded away from the base of the foundations as a result of the flow of water.
Swim bladder	A gas-filled sac present in the body of many bony fish, used to maintain and control buoyancy.
The Applicant	Norfolk Boreas Limited
The Norfolk Vanguard OWF sites	Term used exclusively to refer to the two distinct offshore wind farm areas, Norfolk Vanguard East and Norfolk Vanguard West (also termed NV East and NV West) which will contain the Norfolk Vanguard arrays.
The project	Norfolk Boreas Wind Farm including the onshore and offshore infrastructure.

11 FISH AND SHELLFISH ECOLOGY

11.1 Introduction

1. This chapter of the Environmental Statement (ES) describes the ecology of fish and shellfish species in areas relevant to Norfolk Boreas ("the project") and provides an assessment of the potential impacts of the project on fish and shellfish receptors.

2. The areas of the project relevant to this assessment are the Norfolk Boreas site, the offshore cable corridor and the project interconnector search area. Collectively these areas are referred to as 'the offshore project area'.

3. Vattenfall Wind Power Limited (VWPL) (the parent company of Norfolk Boreas Limited) is also developing Norfolk Vanguard, a ‘sister project’ to Norfolk Boreas. Norfolk Vanguard’s development schedule is approximately one year ahead of Norfolk Boreas and as such the Development Consent Order (DCO) application was submitted in June 2018.

4. Norfolk Vanguard may undertake some enabling works for Norfolk Boreas, but these are only relevant to the assessment of impacts onshore. This assessment does however assume a worst case which includes interconnector cables between the Norfolk Boreas and Norfolk Vanguard projects (herein, ’the project interconnector’). If Norfolk Vanguard does not proceed then the project interconnector cable would not be required.

5. This chapter of the ES has been written by Brown and May Marine Limited (BMM) and incorporates results from fish and epibenthic surveys carried out in the former East Anglia Zone, the former East Anglia FOUR and in East Anglia THREE.

6. This chapter is supported by the following Appendices:

- Appendix 11.1: Fish and Shellfish Ecology Technical Report;
- Appendix 11.2: Fish and Shellfish Ecology Consultation Responses;
- Appendix 5.4: Underwater Noise Assessment; and
- Appendix 5.5: Underwater Noise of UXO at the Norfolk Boreas site.

7. Other chapters that are linked with fish and shellfish ecology, or that cover impacts that may be related to those in this chapters include:

- Chapter 8 Marine Geology, Oceanography and Physical Processes;
- Chapter 10 Benthic and Intertidal Ecology;
- Chapter 12 Marine Mammals;
- Chapter 13 Offshore Ornithology; and
- Chapter 14 Commercial Fisheries.

8. All figures referred to in this chapter are provided in Volume 2 of the ES.

11.2 Legislation, Guidance and Policy

9. The characterisation of the existing baseline and the assessment of potential impacts on fish and shellfish ecology provided in this chapter has been made with specific reference to relevant National Policy Statements (NPS):

- Overarching NPS for Energy (EN-1) (Department of Energy and Climate Change (DECC, 2011); and
- NPS for Renewable Energy Infrastructure (EN-3), July 2011.

10. The Overarching NPS for Energy (EN-1) sets out the Government's policy for delivery of major energy infrastructure, with generic considerations which are further considered in the technology-specific NPSs such as the NPS for Renewable Energy Infrastructure (EN-3). Table 11.1 summarises guidance relevant to the ES in respect of fish and shellfish ecology from EN-3 as well as providing the sections in this chapter where each is addressed.

Table 11.1 National Policy Statement (NPS) (EN-3) assessment guidance

Consultee	Comment	Response / where addressed in the ES
Effects of offshore wind farms can include temporary disturbance during the construction phase (including underwater noise) and ongoing disturbance during the operational phase and direct loss of habitat. Adverse effects can be on spawning, overwintering, nursery and feeding grounds and migratory pathways in the marine area. However, the presence of wind turbines can also have positive benefits to ecology and biodiversity.	Section 2.6.63	Section 11.7.
Assessment of offshore ecology and biodiversity should be undertaken by the applicant for all stages of the lifespan of the proposed offshore wind farm and in accordance with the appropriate policy for offshore wind farm EIAs (EN-3; Paragraph 2.6.64).	Section 2.6.64	Section 11.7
Consultation on the assessment methodologies should be undertaken at early stages with the statutory consultees as appropriate	Section 2.6.65	Section 11.3
Any relevant data that has been collected as part of post-construction ecological monitoring from existing, operational offshore wind farms should be referred to where appropriate	Section 2.6.66	Section 11.7.5
There is the potential for the construction and decommissioning phases, including activities occurring both above and below the seabed, to interact with seabed sediments and therefore have the potential to impact fish communities, migration routes, spawning activities and nursery areas of particular species. In addition, there are potential noise impacts, which could affect fish during construction and decommissioning and to a lesser extent during operation.	Section 2.6.73	Section 11.7

Consultee	Comment	Response / where addressed in the ES
The applicant should identify fish species that are the most likely receptors of impacts with respect to: • spawning grounds; • nursery grounds; • feeding grounds; • over-wintering areas for crustaceans; and • migration routes.	Section 2.6.74	Section 11.6.7 and Table 11.10
Where it is proposed that mitigation measures of the type set out in paragraph 2.6.76 below are applied to offshore export cables to reduce electromagnetic fields (EMF) the residual effects of EMF on sensitive species from cable infrastructure during operation are not likely to be significant. Once installed, operational EMF impacts are unlikely to be of sufficient range or strength to create a barrier to fish movement	Section 2.6.75	Section 11.7.5.4
EMF during operation may be mitigated by use of armoured cable for interarray and export cables that should be buried at a sufficient depth. Some research has shown that where cables are buried at depths greater than 1.5m below the seabed impacts are likely to be negligible. However, sufficient depth to mitigate impacts will depend on the geology of the seabed.	Section 2.6.76	Section 11.7.5.4
During construction, 24 hour working practices may be employed so that the overall construction programme and the potential for impacts to fish communities is reduced in overall time.	Section 2.6.77	Section 11.7.1
The construction and operation of offshore wind farms can have both positive and negative effects on fish and shellfish stocks.	Section 2.6.122	Section 11.4.1.

11. In addition to NPS guidance, the following documents have been used to inform the fish and shellfish ecology assessment:

- Centre for Environment Fisheries and Aquaculture Science (Cefas), Marine Consents and Environment Unit (MCEU), Department for Environment, Food and Rural Affairs (DEFRA) and Department of Trade and Industry (DTI) (2004) Offshore Wind Farms - Guidance note for Environmental Impact Assessment In respect of the Food and Environment Protection Act (FEPA) and CPA requirements, Version 2;
- Cefas (2012) Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. Contract report: ME5403, May 2012;
- Guidelines for ecological impact assessment in Britain and Ireland: Marine and Coastal. IEEM (2010);
- Sound Exposure Guidelines for Fishes and Sea Turtles Monitoring (Popper et al., 2014);
- Renewable UK (2013) Cumulative Impact Assessment Guidelines Guiding Principles for Cumulative Impacts Assessment in Offshore Wind Farms;

- Marine Licensing requirements (replacing Section 5 Part II of the FEPA 1985 and Section 34 of the Coast Protection Act (CPA) 1949); and
- Strategic Review of Offshore Windfarm Monitoring Data Associated with FEPA Licence Conditions (Cefas, 2010).

11.3 Consultation

12. Consultation is a key part of the DCO application process. To date, consultation regarding fish and shellfish ecology has been conducted through the Norfolk Boreas Scoping Report and Preliminary Environmental Information Report (PEIR) (Royal HaskoningDHV, 2017a; 2018).

13. In addition, consultation has been undertaken as part of the Evidence Plan Process (EPP) with the Fish and Shellfish Ecology Expert Topic Group (ETG) which includes: the Marine Management Organisation (MMO), the Eastern Inshore Fisheries and Conservation Authority (IFCA), Natural England and the Environment Agency. This included the submission to the ETG of a method statement in February 2018, detailing the assessment methodology proposed to assess the potential effects of Norfolk Boreas on fish and shellfish ecology and a meeting in February 2019 to discuss the feedback from the members of the ETG to the PEIR.

14. Feedback received on the Method Statement has been recorded in an agreement log which is provided as part of the Norfolk Boreas DCO application (Document 5.1). No further feedback was received from the ETG following the meeting in February 2019. The responses received from stakeholders to the Scoping Report, PEIR as well as feedback to date from the Fish and Shellfish Ecology ETG, are summarised in Appendix 11.2, including details of how these have been taken account of within this chapter.

15. As Norfolk Boreas and Norfolk Vanguard windfarm site are collocated and they share an offshore cable corridor, the pre-application consultation undertaken as part of Norfolk Vanguard has been used to inform the approach to the Norfolk Boreas fish ecology assessment. Furthermore, information submitted as part of the Norfolk Vanguard examination, has also been incorporated. However, in order that the programmed submission of the Norfolk Boreas DCO has not been impacted it has been necessary to use a cut-off point of the 20th March (which coincided with Norfolk Vanguard Examination Deadline 5) after which information provided at the Vanguard examination as well as any wider information has not been included in this assessment unless it could be done without impacting the programme for submission. The information from Norfolk Vanguard which has been used to inform this assessment is also presented in Appendix 11.2. These have also been taken into account in the production of this chapter.

11.4 Assessment Methodology

11.4.1 Impact Assessment Methodology

16. As specified in the Cefas and MCEU (2004) guidelines for offshore wind developments, the potential impacts of the project on fish and shellfish ecology have been assessed in relation to the following ecological aspects:

- Spawning grounds;
- Nursery grounds;
- Feeding grounds;
- Overwintering areas for crustaceans (e.g. lobster and crab);
- Migration routes;
- Conservation importance;
- Importance in the food web; and
- Commercial importance.

17. The assessment of impacts has been undertaken separately for the construction, operation and maintenance (O&M) and decommissioning phases.

18. Cumulative impacts relevant to fish and shellfish ecology arising from other marine developments have also been assessed. Similarly, consideration has been given to the potential for transboundary impacts to occur as a result of the project. The approach to the cumulative and transboundary impact assessment is described in section 11.4.2 and section 11.4.3 respectively.

19. As described above, (paragraph 3) VWPL (the parent company of Norfolk Boreas Limited) is also developing Norfolk Vanguard, a ‘sister project’ to Norfolk Boreas. Norfolk Vanguard’s development schedule is approximately one year ahead of Norfolk Boreas and as such the DCO application was submitted in June 2018.

20. Norfolk Vanguard may undertake some enabling works for Norfolk Boreas, but these are only relevant to the assessment of impacts onshore. This assessment does however assume a worst case which includes interconnector cables between the Norfolk Boreas and Norfolk Vanguard projects. If Norfolk Vanguard does not proceed then the project interconnector cables would not be required.

11.4.1.1 Sensitivity

21. Receptor sensitivity has been assigned on the basis of species specific adaptability, tolerance, and recoverability, when exposed to a potential impact. The following parameters have also been taken into account:

- Timing of the impact: whether impacts overlap with critical life-stages or seasons (i.e. spawning, migration); and
- Probability of the receptor-effect interaction occurring (e.g. vulnerability).

22. Definitions of receptor sensitivity are provided in Table 11.2.

Table 11.2 Definitions of Sensitivity Levels for Fish and Shellfish Ecology Receptors

Sensitivity	Definition
High	Individual receptor (species or stock) has very limited or no capacity to avoid, adapt to, accommodate or recover from the anticipated impact.
Medium	Individual receptor (species or stock) has limited capacity to avoid, adapt to, accommodate or recover from the anticipated impact
Low	Individual receptor (species or stock) has some tolerance to accommodate, adapt or recover from the anticipated impact.
Negligible	Individual receptor (species or stock) is generally tolerant to and can accommodate or recover from the anticipated impact.

11.4.1.2 Value

23. Where appropriate, the ecological value of the receptor may be taken into account within the framework of the assessment. In these instances, 'value' refers to the importance of the receptor with respect to conservation status, role in the ecosystem, and geographic frame of reference.

24. Note that for stocks of species which support significant fisheries, commercial value is also taken into consideration. Generic definitions of ecological value levels are provided in Table 11.3.

Table 11.3 Definitions of Value Levels for Fish and Shellfish Ecology Receptors

Value	Definition
High	Internationally or nationally important
Medium	Regionally important or internationally rare
Low	Locally important / rare
Negligible	Not considered to be particularly important / rare

11.4.1.3 Magnitude

25. The magnitude of an effect is considered for each potential impact on a given receptor and is defined geographically, temporally and in terms of the likelihood of occurrence. The definitions of terms relating to the magnitude of a potential impact on fish and shellfish ecology are provided in Table 11.4.

26. With respect to duration of potential impacts, those associated with construction are considered to be short term, occurring over the indicative overall construction window of approximately 3 years.

27. Impacts associated with O&M are longer term, occurring over the design lifetime of the project (expected to be 30 years).

Table 11.4 Definitions of Magnitude Levels for fish and shellfish ecology receptors

Magnitude	Definition
High	Fundamental, permanent / irreversible changes, over the whole receptor, and / or fundamental alteration to key characteristics or features of the particular receptors character or distinctiveness.
Medium	Considerable, permanent / irreversible changes, over the majority of the receptor, and / or discernible alteration to key characteristics or features of the particular receptors character or distinctiveness.
Low	Discernible, temporary (throughout project duration) change, over a minority of the receptor, and / or limited but discernible alteration to key characteristics or features of the particular receptors character or distinctiveness.
Negligible	Discernible, temporary (for part of the project duration) change, or barely discernible change for any length of time, over a small area of the receptor, and/or slight alteration to key characteristics or features of the particular receptors character or distinctiveness.

11.4.1.4 Impact significance

28. Taking account of the magnitude of the effect and sensitivity of the receptors, impact significance is determined using the impact significance matrix shown in Table 11.5.

29. The impact significance matrix provides a framework to aid understanding of how a judgement has been reached from the narrative of each impact assessment and it is not a prescriptive formulaic method. Therefore defining impact significance is to some extent qualitative and reliant on professional experience, interpretation and judgement.

30. The impact significance categories are divided as shown in Table 11.6. Those impacts which are of moderate or major significance are considered significant in Environmental Impact Assessment (EIA) terms.

Table 11.5 Impact Significance Matrix

		Negative Magnitude				Beneficial Magnitude			
		High	Medium	Low	Negligible	Negligible	Low	Medium	High
Sensitivity	High	*Major*	*Major*	*Moderate*	*Minor*	*Minor*	*Moderate*	*Major*	*Major*
	Medium	*Major*	*Moderate*	*Minor*	*Minor*	*Minor*	*Minor*	*Moderate*	*Major*
	Low	*Moderate*	*Minor*	*Minor*	*Negligible*	*Negligible*	*Minor*	*Minor*	*Moderate*
	Negligible	*Minor*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Minor*

Table 11.6 Impact Significance Definitions

Impact Significance	Definition
Major	Very large or large change in receptor condition, both adverse or beneficial, which are likely to be important considerations at a regional or district level because they contribute to achieving national, regional or local objectives, or, could result in exceedance of statutory objectives and / or breaches of legislation.
Moderate	Intermediate change in receptor condition, which are likely to be important considerations at a local level.
Minor	Small change in receptor condition, which may be raised as local issues but are unlikely to be important in the decision making process.
Negligible	No discernible change in receptor condition.
No change	No impact, therefore no change in receptor condition.

11.4.2 Cumulative Impact Assessment

31. The developments, activities and measures taken forward for cumulative assessment have been selected on the basis of the availability of information, probability and spatial overlap where relevant. Already installed infrastructure has been assumed to constitute part of the existing environment to which receptors have adapted. Further details on the approach to the cumulative assessment in relation to fish and shellfish ecology are provided within section 11.8.

11.4.3 Transboundary Impact Assessment

32. The distribution of fish and shellfish species is independent of national geographical boundaries. The impact assessment has therefore been undertaken taking account of the distribution of fish stocks and populations irrespective of political limits. As a result, it is considered that a specific assessment of transboundary effects is unnecessary.

11.5 Scope

11.5.1 Study Area

33. The study area in respect of fish and shellfish ecology is shown in Figure 11.1. This has been defined with reference to the International Council for the Exploration of the Sea (ICES) statistical rectangles where the offshore project area is located. These are as follows:

- ICES rectangle 35F3 – where the north east section of the Norfolk Boreas site is located;
- ICES rectangle 35F2 – where the north west section of the Norfolk Boreas site is located;
- ICES rectangle 34F3 – where the south east corner of the Norfolk Boreas site is located;
- ICES rectangles 34F2 – where the south west section of the Norfolk Boreas site, the project interconnector search area and the offshore section of the offshore cable corridor are located; and
- ICES rectangle 34F1 – where the inshore section of the offshore cable corridor is located.

34. Where appropriate, broader geographic study areas have been used for the purposes of describing the fish and shellfish existing environment and impact assessment. This has particular relevance to life history aspects such as the distribution of spawning and nursery grounds and migratory routes.

11.5.2 Data Sources

35. The principal datasets used to inform the fish and shellfish ecology baseline characterisation are outlined in Table 11.7.

Table 11.7 Data Sources

Data	Year	Coverage	Notes
Results of adult and juvenile fish site specific characterisation surveys for East Anglia THREE and the former East Anglia FOUR	2013	ICES Rectangles 34F2 and 34F3	Fish and shellfish characterisation surveys using otter and beam trawls were undertaken within East Anglia THREE and the former East Anglia FOUR to provide information on fish and shellfish assemblages. The methodologies of these surveys were designed and agreed in consultation with Cefas.
Results of the site specific benthic characterisation surveys (Fugro/ EMU 2013) for East Anglia	2013	East Anglia THREE and the former	Epibenthic surveys carried out to characterise the epibenthic community, including fish species, within East Anglia THREE and the former East Anglia FOUR. These were carried out using a 2m scientific beam trawl.

Data	Year	Coverage	Notes
THREE and the former East Anglia FOUR		East Anglia FOUR sites (ICES Rectangles 33F2 and 34F2)	
Results of the zonal epibenthic characterisation surceys (MESl, 2010) carried out across the former East Anglia Zone	2010	Former East Anglia Zone	Epibenthic surveys carried out to characterise the epibenthic community, including fish species, across the former East Anglia Zone. These were carried out using a 2m scientific beam trawl.
UK landings weights data by species (MMO, 2017)	2012-2016	ICES Rectangles 34F1, 34F2, 34F3, 35F2, 35F3	Provides an indication of the principal species targeted within a given area. Not suitable for assessments of abundance and distribution of species.
Dutch landings weights data by species (Netherlands Institute of Marine Research (IMARES, 2018)	2013-2017	ICES Rectangles 34F1, 34F2, 34F3, 35F2, 35F3	Provides an indication of the principal species targeted within a given area. Not suitable for assessments of abundance and distribution of species.
Belgian landings weights data by species (Belgian Institute for Agriculture, Fisheries and Food (ILVO, 2016)	2010-2014	ICES Rectangles 34F1, 34F2, 34F3, 35F2, 35F3	Provides an indication of the principal species targeted within a given area. Not suitable for assessments of abundance and distribution of species.
Danish satellite tracking (VMS) data for sandeel trawlers (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2017)	2011-2015	North Sea	VMS data for sandeel trawlers in the North Sea by Danish vessels. The data is filtered by speed. VMS is provided by effort (days) and by gear type.
International Bottom Trawl Survey (IBTS) data	2008-2017	ICES Rectangles 34F1, 34F2, 34F3, 35F2, 35F3	IBTS data has been accessed via the ICES Data Portal (DATRAS, the Database of Trawl Surveys: http://datras.ices.dk). Data presented refers to the average number of fish caught per hour (in those ICES rectangles corresponding to the defined study area) by IBTS North Sea surveys conducted between 2008 and 2017.

Data	Year	Coverage	Notes
ICES International Herring Larvae Survey (IHLS) data	2007-2017	Eastern and northern North Sea	IHLS data has been accessed via the ICES Data Portal (http://eggsandlarvae.ices.dk). The IHLS surveys routinely collect information on the size, abundance and distribution of herring eggs and larvae (and other species) in the North Sea.
North Sea cod and plaice egg Survey (CP-EGGS) data	2003, 2004, 2008, 2009	ICES Rectangles 34F1, 34F2, 34F3, 35F2, 35F3	CP-EGGS data has been accessed via the ICES Data Portal (http://eggsandlarvae.ices.dk). The survey characterised fish egg and larval distributions in the winter in the North Sea. Target species are cod and plaice. Surveys data is available for the years 2003, 2004, 2008 and 2009.
Channel Habitat Atlas for Marine Resource Management (CHARM) (Carpentier et al., 2009)	2003-2008	The eastern English Channel	CHARM is a collaborative Franco-British project (Interreg IIIA) initiated to support decision-making for the management of essential fish habitats. The Atlas relates fish geographic distribution and environmental factors in order to delineate the optimum habitat for a number of species. The Atlas is based on data obtained from IFREMER's Channel Ground Fish Surveys (CGFS), including species abundance and environmental data, and fish eggs data collected using Continuous Underway Fish Egg Sampler (CUFES) during the French part of the IBTS (2006-2010). Habitat suitability models (HIS) are used to produce GIS outputs of optimum habitats, spawning grounds, nursery areas and presence probability.
Distribution of Spawning and Nursery Grounds as defined in Coull et al. (1998) (Fisheries Sensitivity Maps in British Waters) and in Ellis et al. (2010, 2012) (mapping spawning and nursery areas of species to be considered in Marine Protected Areas (Marine Conservation Zones).	Coull et al.: 1991 – 1996 Ellis et al.: Varies by species but generally between 1983 and 2008.	UK territorial waters and the remainder of the North sea.	Coull et al. (1998) and Ellis et al. (2010, 2012) are the standard references that provide broad scale overviews of the potential spatial extent of nursery grounds, spawning grounds and the relative intensity and duration of spawning. Both Coull et al. (1998) and Ellis et al. (2010, 2012) are based on a compilation of a variety of data sources.
Marine Life Information Network (MarLIN)	n/a	UK	MarLIN website (https://www.marlin.ac.uk/) provides comprehensive information on the biology of species and the ecology of habitats found around the coasts of the British Isles. The information available from MarLIN's website includes Marine Evidence based Sensitivity Assessments (MarESA) for a range of pressures on various marine species and habitats.

Data	Year	Coverage	Notes
			MarESAs are subject to a number of limitations and assumptions and therefore should be interpreted with caution. These are detailed in https://www.marlin.ac.uk/sensitivity/sensitivity_rationale

36. In addition to the datasets described above, the following resources have been accessed to inform the assessment:

- Eastern IFCA publications;
- Cefas publications;
- Joint Nature Conservation Committee (JNCC) publications;
- Institute for Marine Resources and Ecosystem Studies (IMARES) publications;
- ICES stock assessments and publications; and
- Other relevant peer-review publications.

11.5.3 Assumptions and Limitations

37. The characterisation of the existing environment in respect of fish and shellfish receptors has been undertaken using the data sources listed above. These data sources, including their sensitivities and limitations, are described in further detail in Appendix 11.1.

38. Where possible, an overview of the confidence of the data and information underpinning the assessment has been presented. Confidence is classed as High, Medium or Low depending on the type of data (quantitative, qualitative or lacking) as well as the source of information (e.g. peer reviewed publications, grey literature) and its applicability to the assessment.

11.6 Existing Environment

39. This section provides a summary of the fish and shellfish ecology baseline relevant to the project and identifies key fish and shellfish receptors requiring assessment. Further detailed information on the fish and shellfish ecology baseline is provided in Appendix 11.1.

40. Receptors have been identified based on their presence/abundance in the study area, conservation importance, location of spawning and nursery grounds, commercial importance and role within the North Sea food web. In addition, in order to identify key receptors requiring assessment, consideration has been given to the feedback received from consultees during consultation for Norfolk Boreas and Norfolk Vanguard (see Appendix 11.2).

11.6.1 Surveys undertaken in the former East Anglia Zone

41. Fish and shellfish characterisation surveys were undertaken in February and May 2013 in the area of the former East Anglia FOUR and in East Anglia THREE. These included otter trawl and 4m beam trawl sampling at various locations. Given the location of East Anglia THREE and the former East Anglia FOUR, the findings of these surveys are highly relevant to the study area in respect of the project. Data from these surveys, together with other publicly available data for the area (i.e. IBTS data) are therefore considered appropriate to inform the fish and shellfish ecology baseline. This approach was agreed with the MMO, Eastern IFCA and Natural England during consultation on the Fish and Shellfish Ecology Method Statement as part of the EPP for the projects.

42. Further to the fish and shellfish surveys mentioned above, epibenthic surveys by means of 2m scientific beam trawl sampling were carried out in May 2013 in East Anglia THREE and in the area of the former East Anglia FOUR (Appendix 11.1). In addition, epibenthic surveys were undertaken in areas relevant to the project during zonal surveys undertaken in the former East Anglia Zone in 2010. The aim of this type of survey is to characterise the epibenthic assemblage, including fish species. As such, the results of the epibenthic surveys conducted in East Anglia THREE, the former East Anglia FOUR and the former East Anglia Zone are also relevant and have been used to inform this chapter.

43. A summary of the findings of these surveys, including sampling locations, frequency, duration and methodology is provided within Appendix 11.1.

44. The principal species recorded during these surveys are dab *Limanda limanda* and plaice *Pleuronectes platessa*. Other species frequently found in these surveys include whiting *Merlangius merlangus*, solenette *Buglossidium luteum*, sand goby *Pomatoschistus minutus*, lesser spotted dogfish/small spotted catshark *Scyliorhinus canicula*, lesser weever *Echiichthys vipera*, grey gurnard *Eutrigla gurnardus,* and common dragonet *Callionymus lyra*.

45. It should be noted that the surveys carried out primarily provide information on the distribution and abundance of demersal fish species, due to the specific gear types used (otter trawl, 4m beam trawl and 2m scientific beam trawl). The presence and abundance of some species/species groups may therefore be underrepresented in the survey results (i.e. shellfish species, clupeids and diadromous migratory fish).

11.6.2 International Bottom Trawl Surveys (IBTS)

46. IBTS data recorded in the study area (ICES rectangles 35F3, 35F2, 34F3, 34F2 and 34F1) have been analysed and used to further characterise the fish and shellfish community in the offshore project area.

47. Full survey results are provided in Appendix 11.1 including average relative abundance of the 50 most abundant species found in the IBTS expressed as Catch Per Unit Effort (CPUE) for the period 2008 to 2017.

48. The principal species/species groups recorded by the IBTS in the study area include whiting, dab , sandeels (*Hyperoplus lanceolatus, Ammmodytes tobianus and A. marinus*), herring *Clupea harengus*, sprat *Sprattus sprattus*, horse mackerel *Trachurus trachurus*, mackerel *Scomber scombrus*, plaice, weevers and solenette (Appendix 11.1).

11.6.3 Species commercially targeted in the study area

49. The principal commercial fish and shellfish species targeted in areas relevant to the offshore project area have been identified based on landings statistics (landings weights) in the ICES rectangles within the study area (35F3, 35F2, 34F3, 34F2 and 34F1) from the UK and other countries known to fish in the study area, particularly the Netherlands and Belgium (see Chapter 14 Commercial Fisheries).

50. In rectangles 34F2, 34F3, 35F2 and 35F3, where the Norfolk Boreas site, the offshore section of the offshore cable corridor and the project interconnector search area are located, plaice and sole *Solea solea* are the main species targeted. Other fish species are landed from this area however at lower levels. These species include turbot *Scophthalmus maximus*, cod *Gadus morhua*, sprat, brill *Scophthalmus rhombus*, skates and rays, amongst others.

51. In rectangle 34F1, where the inshore section of the cable corridor is located, commercial landings by weight are dominated by shellfish species, particularly, edible crab *Cancer pagurus*, whelks *Buccinum undatum* and lobster *Hommarus gammarus*. Fish species are also landed from the inshore area however at much lower levels, with species such as herring, cod, sole and sea bass *Dicentrarchus labrax* being targeted by some local fishermen (Appendix 11.1 and Appendix 14.1).

52. Further detailed information on landings statistics is provided in Appendix 11.1 and in Chapter 14 Commercial Fisheries.

53. Those species noted above are the main species targeted by commercial fisheries in the study area as reported from landings data. It is recognised, however, that a number of species which may not be subject to directed fisheries in the offshore project area may be of importance to commercial fisheries in the wider Southern North Sea (lemon sole *Microstomus kitt*, whiting, mackerel, etc).

11.6.4 Spawning and Nursery Grounds

54. The distribution of known spawning and nursery grounds in relation to the location of the Norfolk Boreas site, the project interconnector search area and the offshore

cable corridor is discussed in this section. This has been primarily informed by data provided in Coull et al. (1998) and Ellis et al. (2010; 2012). As outlined in Appendix 11.1, these papers are based on a review of published data and provide broad scale descriptions of the spatial and temporal extent of spawning grounds and spawning duration.

55. Species for which spawning or nursery grounds have been defined in areas that overlap with the Norfolk Boreas site, the project interconnector search area and/or the offshore cable corridor are listed in Table 11.8 and illustrated in Figure 11.2 to Figure 11.11. This includes information on key spawning periods and spawning/nursery intensity, where known.

56. Note that both spawning and nursery grounds generally cover wide sea areas with the level of overlap between the offshore project area representing a small proportion of the overall grounds used by each species (Figure 11.2 to Figure 11.11).

57. Spawning grounds for sole, plaice, cod, whiting, lemon sole, mackerel, sprat and sandeel (Ammodytidae) have all been defined within the offshore project area.

58. Nursery grounds for all of the above species with the addition of herring, thornback ray *Raja clavata* and tope *Galeorhinus galeus* have been defined within the offshore project area. Note that in the case of thornback ray and tope, there is currently insufficient data on the occurrence of egg-cases or egg-bearing females in the spawning season with which to define spawning grounds. In the case of thornback ray, it is considered that these are likely to broadly overlap with nursery grounds (Ellis et al*.,* 2012).

59. Most of the species listed in Table 11.8 are pelagic spawners, which release their eggs in the water column. Exceptions to this are herring and sandeel (Ammodytidae) which are substrate-specific demersal spawners. Thornback ray also lay eggs on benthic substrates although they are not known to have the same degree of substrate-specific spawning requirements as herring and sandeels.

60. Further detailed information on the distribution of spawning and nursery grounds of the species described above, together with information relating to their ecology is provided in Appendix 11.1.

Table 11.8 Species with spawning and/or nursery grounds in the Norfolk Boreas Site, the Project interconnector search area and the offshore cable corridor (Coull et al. (1998), Ellis et al. (2010; 2012)

Species	Spawning season												Spawning Intensity			Nursery Intensity		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Norfolk Boreas Site	Project interconnector search area	Offshore cable corridor	Norfolk Boreas Site	Project interconnector search area	Offshore cable corridor
Dover sole				●									n/a			n/a	n/a	
Plaice	●	●														n/a	n/a	
Cod		●	●															
Whiting																		
Lemon sole													n/a			n/a		
Herring													n/a	n/a	n/a			
Mackerel					●	●	●											
Sprat					●	●											n/a	n/a
Sandeel																		
Thornback ray				●	●	●	●	●					n/a			n/a	n/a	
Tope	Gravid females present year round												n/a					

(Spawning times and intensity colour key: yellow= high intensity spawning/nursery grounds, green= low intensity spawning/nursery grounds, blue= spawning/nursery intensity not defined, grey= spawning period, ● = peak spawning, n/a= no overlap with spawning/nursery grounds)

11.6.5 Species of Conservation Importance

61. Fish and shellfish species of conservation importance which have the potential to be found in the study area are outlined in the following sections including:

- Diadromous migratory species;
- Elasmobranchs; and
- Other species with designated conservation status.

62. Detailed information on the ecology, conservation status and the use that these species may make of the offshore project area or areas in its proximity is provided within Appendix 11.1.

63. It should be note that the offshore cable corridor overlaps with the Haisborough, Hammond and Winterton Special Area of Conservation (SAC). Qualifying features of this site include Sandbanks which are slightly covered by sea water at all times and *Sabellaria spinulosa* reefs.

64. In addition, the offshore cable corridor overlaps with the Greater Wash Special Protection Area (SPA) and the offshore project area overlaps with the Southern North Sea SAC both of which are designated for bird and marine mammal features respectively (Appendix 11.1).

65. The assessment of impacts on seabed and benthic features is detailed within Chapter 8 Marine Geology, Oceanography and Physical Processes and Chapter 10 Benthic and Intertidal Ecology. The assessment on marine mammals is presented in Chapter 12 Marine Mammal Ecology and the assessment on ornithology receptors in Chapter 13 Offshore Ornithology. The Information to Support Habitat Regulations Assessment (HRA) is provided in document 5.3 of this application.

66. No fish or shellfish species are listed as qualifying features for any of these designated sites. However, in the case of the Haisborough, Hammond and Winterton SAC, the importance of the site in terms of provision of habitat to fish and shellfish species is recognised. In the case of the Greater Wash SPA and Southern North Sea SAC, the importance of some fish species as prey for marine mammals and birds, including Annex II species should also be acknowledged.

11.6.5.1 Diadromous Species

67. There is potential for a number of diadromous species to transit the offshore project area and/or its vicinity during the marine phase of their life cycle. These include:

- European eel *Anguilla anguilla*;
- Allis shad *Alosa alosa*;
- Twaite shad *Alosa fallax*;

- Sea lamprey *Petromyzon marinus*;
- River lamprey *Lampreta fluviatilis*;
- Atlantic salmon *Salmo salar*;
- Sea trout *Salmo trutta*; and
- Smelt *Osmerus esperlanus*.

68. The occurrence of species such as sea trout, European eel, smelt and lampreys is well documented off the Norfolk coast (Potter and Dare, 2003; Colclough and Coates, 2013). These and the remaining species listed above are also occasionally recorded in IBTS samples and MMO commercial landings statistics.

69. None of these species has been recorded during fish and shellfish surveys carried out in the former East Anglia FOUR and in East Anglia THREE (Appendix 11.1). For the most part these species, if present in the area, would be expected in coastal areas (i.e. in inshore areas possibly in the proximity of the export cable corridor) rather than in the Norfolk Boreas site or the project interconnector search area.

11.6.5.2 Elasmobranchs

70. Elasmobranchs (sharks and rays) have slow growth rates and low reproductive output compared to other species groups (Camhi et al*.,* 1998). Their resilience to fishing mortality is therefore low (Smith et al*.,* 1998) and recovery rates tend to be slow where fisheries have depleted abundance (Holden, 1974; Musick, 2005). As a result, a wide range of elasmobranchs have conservation status and /or declining stocks. Those potentially present in the study area are listed in Table 11.9.

71. Note that of these, only thornback ray, spotted ray *Raja montagui* and starry smoothhound *Mustelus asterias* were recorded in surveys carried out in the former East Anglia FOUR and in East Anglia THREE (Appendix 11.1).

Table 11.9 Elasmobranch species of conservation interest

	Common name	Scientific name
Sharks	Basking shark	*Cetorhinus maximus*
	Starry smoothhound	*Mustelus asterias*
	Smoothhound	*M. mustelus*
	Spurdog	*Squalus acanthias*
	Thresher shark	*Alopias vulpinus*
	Tope	*Galeorhinus galeus*
Skates and Rays	Blonde ray	*Raja brachyura*
	Cuckoo ray	*Leucoraja naevus*
	Common Skate Complex	*Dipturus intermedia/Dipturus flossada*

	Common name	Scientific name
	Spotted ray	*Raja montagui*
	Thornback ray	*Raja clavata*
	Undulate ray	*Raja undulata*
	White skate	*Rostroraja alba*

11.6.5.3 Other Species of Conservation Interest

72. In addition to diadromous species and elasmobranchs, a number of species found in the study area are of conservation interest, being listed as a species of Principal Importance under the UK Post-2010 Biodiversity Framework and Section 41 of the Natural Environment and Rural Communities (NERC) Act. These are described in Appendix 11.1, along with other relevant conservation designations (e.g. OSPAR and IUCN listings). It should be noted that some of these species are commercially exploited in the area either directly (i.e. sole, plaice, cod), or indirectly as by-catch and have been recorded during surveys carried out in the former East Anglia FOUR and in East Anglia THREE (Appendix 11.1).

11.6.6 Prey Species and Foodweb Linkages

73. Abundant species with high biomass such as sandeels (Ammodytidae) and clupeids (e.g. herring and sprat) play an important functional role in North Sea food web dynamics. Such species represent an important food web link because they occupy intermediate trophic levels, are significant predators of zooplankton and represent a key dietary component for a variety of predators. As described in Appendix.11.1 both landings data and the results of the IBTS indicate that these species groups are present in the study area. Species from both families were present in surveys carried out in East Anglia THREE and in the former East Anglia FOUR, albeit in relatively low abundances (Appendix 11.1).

74. Ammodytidae and clupeid species are important prey for piscivorous fish such as elasmobranchs, gadoids, sea bass, mackerel, and sea trout, amongst others (ICES, 2005a; ICES, 2005b: ICES, 2006; ICES, 2008; ICES, 2009). The demersal egg mats of herring are also known to aggregate fish predators (Richardson et al., 2011). The diets of marine mammals, including Annex II species such as grey seal *Halichoerus grypus*, harbour seal *Phoca vitulina* and harbour porpoise *Phocoena phocoena* are also subsidised by sandeels and clupeids to varying degrees (Santos and Pierce, 2003; Santos and Pierce, 2004). Both species groups are also an important resource for seabirds; this is especially true of sandeels which are important prey for kittiwakes, razorbills, puffins and terns, particularly during the breeding season (Wright and Bailey, 1996; Furness, 1990; Wanless et al., 1998; Wanless et al., 2005).

75. The ecology of these prey species is described in further detail within Appendix 11.1.

11.6.7 Key Fish and Shellfish Species

76. In order to define the scope of the fish and shellfish ecology assessment, including receptors requiring consideration, due regard has been given to the Scoping Opinion, PEIR responses and the feedback received during consultation with the Fish and Shellfish Ecology ETG carried out as part of the EPP (Appendix 11.2). In addition, consideration has been given to stakeholder responses obtained as part of the EPP, Scoping and PEIR consultation process for Norfolk Vanguard where relevant (Appendix 11.2).

77. The key species identified, and the rationale for their inclusion within the assessment is provided in Table 11.10. This includes considerations such as commercial importance, distribution of spawning and nursery grounds and conservation status.

78. Detailed information regarding the ecology of these species and the use that they may make of the study area is provided in Appendix 11.1

Table 11.10 Key Fish and Shellfish Species taken forward for Assessment of Potential Impacts

Relevant Fish and Shellfish Species	Rationale
Principal demersal fish species	
Dover sole	• Abundant throughout the study area • Species of principal importance • Commercially important in the study area • Low intensity spawning area overlaps with the offshore cable corridor and the project interconnector search area • Low intensity nursery area overlaps with the inshore section of the offshore cable corridor
Plaice	• Abundant throughout the study area • Species of principal importance • Commercially important species in the study area • High intensity spawning area overlaps the Norfolk Boreas site, the project interconnector search area and the offshore section of the offshore cable corridor • Low intensity nursery area overlaps with the inshore section of the export cable corridor
Cod	• Species of principal importance and OSPAR listed species and 'vulnerable' on the IUCN Red List • Commercially important in the study area • Low intensity spawning area overlaps with the offshore project area • Low intensity nursery area overlaps with the offshore project area
Whiting	• Abundant throughout the study area • Species of principal importance • Of commercial importance in the Southern North Sea

Relevant Fish and Shellfish Species	Rationale
	• Low intensity spawning and nursery areas overlap with the offshore project area
Sea bass	• Commercially important to local fisheries, and relatively abundant, particularly in areas in the proximity of the export cable corridor • Subject to fisheries controls due to conservation concerns
Lemon sole	• Present throughout the study area • Spawning and nursery grounds overlap with the offshore cable corridor and the project interconnector search area
Turbot and Brill	• Present throughout the study area • Commercially important in the study area
Other species: Gurnards, lesser weever, dab solenette and small demersal species (Gobiidae spp.)	• Other species characteristic of the Southern North Sea fish assemblage • Present/abundant throughout the study area • Possible prey items for fish, bird and marine mammal species
Ammodytidae (Sandeels)	
Greater sandeel Lesser sandeel Smooth sandeel Small sandeel	• Species of principal importance • Key prey species for fish, birds and marine mammals, including Annex II species • Demersal spawning species • Low intensity spawning and nursery areas overlap with the Norfolk Boreas site, offshore cable corridor and project interconnector search area
Principal pelagic fish species	
Herring	• Present in the study area • Species of principal importance • Low intensity nursery area overlaps with the offshore project area • No spawning grounds in the offshore project area. Closest spawning areas are located to the south of the Boreas site (Downs herring) and in a discrete inshore area off Great Yarmouth, to the south of the offshore cable corridor. • Targeted in inshore areas by local fishermen in the study area • Key prey species for fish, birds and marine mammals • Demersal spawner
Sprat	• Abundant in the study area • Of commercial importance in the study area • Important prey species for fish, birds and marine mammal species • Spawning area (undefined intensity) overlaps with the offshore project area • Nursery areas (undefined intensity) overlaps with the Norfolk Boreas site
Mackerel	• Relatively abundant in the study area • Of commercial importance in the North Sea • Spawning area (undefined intensity) overlaps with the Norfolk Boreas site and project interconnector search area • Nursery grounds (low intensity) overlap with the offshore cable corridor, project interconnector search area and the south west corner of the Norfolk Boreas site • Species of principal importance
Elasmobranchs	
Rays, Skates and Sharks	• Present in study area • Some species are of principal importance or OSPAR listed and several are

Relevant Fish and Shellfish Species	Rationale
	classified on the IUCN Red-List with landings restricted or prohibited • Some species are of commercial importance in the study area • Low intensity nursery area for thornback ray overlaps with the offshore cable corridor (potential for these areas to also be used for spawning) • Low intensity nursery area for tope overlaps with the Norfolk Boreas site, offshore cable corridor and project interconnector search area
Diadromous fish species	
Sea trout	• Present in some East Anglian rivers • Species of principal importance • Feeding grounds located in the vicinity of the offshore project area, particularly in areas relevant to the export cable corridor off the Norfolk coast • May transit/feed in the study area during marine migration
Atlantic salmon	• Species of principal importance • May occasionally transit/feed in the study area during marine migration
European eel	• Present in almost all East Anglian rivers • Species of principal importance and listed as 'critically endangered' on the IUCN Red List • May transit/feed in the study area during marine migration
European smelt	• Species of principal importance • Spawning populations present in some East Anglian rivers • May transit/feed in vicinity of the inshore section of offshore cable corridor
River lamprey Sea lamprey	• Present in some East Anglian Rivers • Species of principal importance and sea lamprey listed by OSPAR as declining and/or threatened. • May transit/feed in vicinity of the study area during marine migration, more likely in areas relevant to the inshore offshore cable corridor (particularly in the case of river lamprey)
Twaite shad Allis shad	• Species of principal importance • Potential to (rarely) transit/feed in vicinity of the study area during marine phase. If present at times this would most likely be in areas relevant to the inshore section of the offshore cable corridor
Shellfish species	
Brown (edible) crab	• Present in the study area, particularly in areas relevant to the offshore cable corridor • Commercially important species • May overwinter within the study area and the wider area
Lobster	• Present in the study area, particularly in areas relevant to the inshore section of the offshore export cable corridor • Commercially important species
Brown and pink shrimp	• Present in the study area, particularly in areas relevant to the inshore section of the offshore cable corridor • Important prey species for fish • Commercially important
Whelk	• Becoming a commercially important species in the study area, particularly in areas relevant to the inshore section of the offshore cable corridor

11.6.8 Anticipated Trends in Baseline Condition

79. The existing baseline conditions within the study area described above are considered to be relatively stable in terms of fish and shellfish receptors. The fish and shellfish baseline environment of the Southern North Sea is however influenced by environmental factors and commercial fishing activity and therefore subject to change.

80. The baseline will continue to evolve as a result of global trends which include the effects of climate change as well as trends at the European level such as changes in fisheries regulations and policies.

11.7 Potential Impacts

81. An assessment of the potential impacts of the project on fish and shellfish receptors is given in the following sections.

82. The potential impacts taken forward for assessment including detailed information on the worst case scenarios assessed are outlined in Table 11.13. Both potential impacts and worst case scenarios have been defined in consultation with stakeholders through the Fish and Shellfish Ecology Method Statement submitted as part of EPP for the project. In addition, for definition of potential impacts and worst case scenarios, consideration has been given to the Scoping Opinion of Norfolk Boreas (Royal HaskoningDHV, 2017) and to the feedback received during consultation carried out for Norfolk Vanguard (Norfolk Vanguard Limited, 2018).

11.7.1 Embedded Mitigation

83. A number of mitigation measures have been incorporated as part of the project design process in order to minimise the potential impacts of Norfolk Boreas on various receptors. Those that are relevant to fish and shellfish ecology are outlined below:

84. Following Scoping, Norfolk Boreas Limited has committed to using HVDC technology. This reduces the number of export cables required and therefore the area of both temporary disturbance and permanent habitat loss compared with a HVAC solution. Furthermore, the volume of cable protection is greatly reduced as a result of committing to the HVDC solution.

85. Following the submission of the PEIR, Norfolk Boreas Limited has refined the design envelope, removing the 9MW, so that the 10MW is now the smallest turbine under consideration. This has reduced the maximum number of turbines from 200 to 180, while maintaining the maximum capacity of 1,800MW. This results in a smaller number of foundations potentially requiring piling and shorter duration for turbine foundation installation, therefore reducing the overall potential underwater noise

impacts on fish and shellfish receptors. In addition, the reduction in the maximum number of turbines would also reduce the physical footprint and associated potential loss of habitat and disturbance to fish and shellfish species.

- Norfolk Boreas Limited is committed to burying offshore export cables where possible to a minimum depth of 1m. This reduces the need for cable protection. Additionally this reduces potential effects associated with Electromagnetic Fields (EMFs).

86. It should be noted that a detailed export cable installation study has been undertaken (Appendix 5.2) and has confirmed that cable burial is expected to be possible throughout the offshore cable corridor, with the exception of cable and pipeline crossing locations. In order to provide a conservative and future-proof impact assessment, a contingency estimate has however been included in the assessment, should cable burial not be possible due to hard substrate (see Table 11.13);

- During construction, overnight working practices would be employed so that construction activities would be 24 hours where possible, thus reducing the overall period for potential impacts; and

87. A soft start and ramp-up protocol will be used for pile driving. This would enable mobile species to move away from the area of highest noise impact during installation of foundations.

11.7.2 Monitoring

88. An In Principle Monitoring Plan (IPMP) has been submitted with the DCO application (document reference 8.12). In line with good practice, monitoring must have a clear purpose in order to provide answers to specific questions where significant environmental impacts have been identified. Any monitoring that Norfolk Boreas undertake will be targeted to address significant evidence gaps or uncertainty, which are relevant to the project and can be realistically filled. In this instance it is proposed that no further monitoring or independent surveys are required.

11.7.3 Worst Case

89. The offshore project area consists of:

- The offshore cable corridor with landfall at Happisburgh South;
- The project interconnector search area; and
- The Norfolk Boreas site.

90. The detailed design of Norfolk Boreas (including numbers of wind turbines, layout configuration, requirement for scour protection, etc.) will not be finalised until

after the DCO has been determined. Therefore, realistic worst case scenarios in relation to impacts on fish and shellfish ecology are adopted which have been informed by the information on project design provided in Chapter 5 Project Description and taking account of the embedded mitigation outlined in section 11.7.181. These are described in Table 11.13.

11.7.3.1 Foundations

91. Within Norfolk Boreas, several different sizes of wind turbine are being considered in the range of 10MW and 20MW. In order to achieve the maximum 1,800MW capacity, there would be between 90 and 180 wind turbines.

92. In addition, up to two offshore electrical platforms, one service platform, two meteorological masts, two LiDAR platforms and two wave buoys, plus offshore cables are considered as part of the worst-case scenario.

93. A range of foundation options are currently being considered, these include:

- Wind turbines - jacket, gravity base structure (GBS), suction caisson, monopile and TetraBase;
- Offshore electrical platform – Jackets with pin-pile or suction caissons, or multi-legged gravity base;
- Service platform – Jackets with pin-pile or suction caissons, or multi-legged gravity base;
- Met masts - GBS, monopile or Jacket with pin-pile;
- Lidar - floating with anchors or monopile; and
- Wave buoys – floating with anchors.

11.7.3.1 Cables

94. There would be four main types of cable used in the offshore project area. These are as follows:

- Array cables – cables that connect wind turbine to wind turbine and connect wind turbine to offshore electrical platform;
- Interconnector cables – offshore cables which link offshore electrical platforms within the Norfolk Bores site;
- Project interconnector cables – offshore cables which would link an offshore electrical platform or wind turbines within the Norfolk Boreas site with an offshore electrical platform within one of the Norfolk Vanguard OWF sites. These would be located within the project interconnector search area (Figure 11.1); and
- Export cables – cables that connect an offshore project substation within the Norfolk Boreas site with the landfall.

95. There would be a requirement for either the interconnector cables or the project interconnector cables, never both. Detailed information on the electrical solutions is provided in Chapter 5 Project Description.

11.7.3.2 Phasing

96. Norfolk Boreas Limited is currently considering constructing the project in one of the following phase options.

- A single phase of up to 1,800MW capacity; or
- Two phases of up to a combined 1,800MW capacity.

97. Phasing is only applicable to the assessment of construction and decommissioning impacts and not the assessment of impacts during the O&M phase. The infrastructure would be the same for each phasing scenario. The duration of construction works for individual project components would be the same whether a single phase or a two phase approach is taken. The overall construction window under the two phase approach would however be slightly longer (39 months compared to 36 months for the single phase approach) (Table 11.11 and Table 11.12). As the two phase scenario would result in an overall longer duration of disturbance to fish and shellfish receptors, it is considered to represent the worst case scenario and has been used for assessment of potential impacts in this chapter.

98. Impacts associated with a single phase scenario would not be of greater significance than those identified under the two phase approach.

11.7.3.3 Programme

99. The full construction window is expected to be up to three years for the full 1,800MW capacity. Table 11.11 and Table 11.12 provide indicative construction programmes for the single phase and two phase options, respectively. If Norfolk Vanguard did not proceed to construction progressed the construction phase for Norfolk Boreas could be bought forward by up to one year.

Table 11.11 Indicative Norfolk Boreas construction programme – single phase where Norfolk Vanguard is built

		2024				2025				2026				2027				2028			
Indicative Programme	**Approximate duration**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pre-construction survey	9 months				■	■	■														
UXO survey and licensing	9 months				■	■	■														
UXO clearance following licencing	9 months							■	■	■											
Foundation seabed preparation	3 months									■											
Foundation installation	18 months										■	■	■	■	■	■					
Scour protection installation	12 months									■	■	■	■								
Offshore Electrical Platform Installation Works	12 months										■	■	■	■							
Array & interconnector (or project interconnector) cable seabed preparation	6 months									■	■										
Array & interconnector (or project interconnector) cable installation	18 months										■	■	■	■	■	■					
Export cable installation seabed preparation	6 months								■	■											
Export cable installation	18 months									■	■	■	■	■	■						
Cable protection installation	18 months										■	■	■	■	■	■					
Wind turbine installation	18 months														■	■	■	■	■	■	
Total construction works	36 months								■	■	■	■	■	■	■	■	■	■	■	■	

Table 11.12 Indicative Norfolk Boreas construction programme – two phases where Norfolk Vanguard is built

		2024				2025				2026				2027				2028			
Indicative Programme	**Approximate duration**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pre-construction survey	9 months				■	■	■														
UXO survey and licensing	9 months				■	■	■														
UXO clearance following licencing	9 months							■	■	■											
Foundation seabed preparation	3 months									■											
Foundation installation	2 x 9 months										■	■	■		■	■	■				
Scour protection installation	2 x 6 months									■	■			■	■						
Offshore Electrical Platform Installation Works	2 x 6 months										■	■			■	■					
Array & interconnector (or project interconnector) cable seabed preparation	2 x 3 months									■				■							
Array & interconnector (or project interconnector) cable installation	2 x 9 months										■	■	■		■	■	■				
Export cable installation seabed preparation	2 x 3 months								■				■								
Export cable installation	2 x 9 months									■	■	■		■	■	■					
Cable protection installation	2 x 9 months										■	■	■		■	■	■				
Wind turbine installation	2 x 9 months														■	■	■		■	■	■
Total construction works	39 months								■	■	■	■	■	■	■	■	■	■	■	■	■

Table 11.13 Worst Case Assumptions

Impact	Parameter	Worst Case	Rationale
Construction			
Impact 1: Physical disturbance and temporary loss of seabed habitat	Disturbance footprints in the Norfolk Boreas site due to cable laying operations, jack-up operations and seabed preparation works for turbine foundations	Worst-case scenario for a single wind turbine foundation would be a GBS foundation for a 20MW turbine due to this having the largest single footprint. Seabed preparation may be required up to a sediment depth of 5m. The preparation volume for a single 20MW GBS foundation is 2,827m^3 (based on a 60m diameter preparation area). The worst case scenario for the site as a whole would be 180 x GBS foundations for the 10MW turbines. **The maximum total turbine seabed preparation area would be:** • 180 of the foundations (requiring preparation for a circular area with diameter of 50m) = 353,429m^2. • Two offshore electrical platforms, seabed preparation = 15,000m^2 (75m x 100m per platform) • One offshore service platform seabed preparation = 7,500m^2 (75m x 100m) • Two met masts based on a circular footprint 40m in diameter seabed preparation = 2,827m^2 (40m diameter per mast) • Array cable trench – 600km length with average 20m pre-sweeping width = 12,000,000m^2 • Interconnector or project interconnector cable trench within the wind farm site 60km with 20m pre-sweeping width = 1,200,000m^2 • Export cable trench within the wind farm site 50km with 30m pre-sweeping width = 1,500,000m^2 • Jack up vessel footprints assuming 2 vessel movements per turbine = 285,120m^2 (based on 180 turbines x 2 movements x vessel footprint of 792m^2) • Vessel anchor footprints (one vessel anchoring per turbine) = 27,000m^2 • Jack up vessel footprints assuming 2 vessel movements per offshore platform and met mast = 7,920m^2 • Boulder clearance – 105 boulders of up to 5m diameter being lifted and then placed back on the seabed = 4,1243m^2 Worst case scenario total disturbance footprint = **15.40km^2** Any other works associated with cable installation would be encompassed by the	The temporary disturbance relates to seabed preparation and cable installation. The footprint of infrastructure is assessed as a long term or permanent impact in O&M Impact 1. It should be noted that the seabed preparation area for foundations is less than the footprint of the foundation scour protection. The maximum potential interconnector length is greater than the amount of project interconnector which would be located within the site, therefore the interconnector represents the worst case scenario.

Impact	Parameter	Worst Case	Rationale
		footprints outlined above.	
	Disturbance footprints in the offshore cable corridor due to cable laying operations	• Boulder clearance = 22 boulders of up to 5m diameter being lifted and then placed back on the seabed = 864m^2 • Pre-sweeping area which could be outside the ploughing area – 72,000m^2 (based on minimum overlap of pre-sweeping area and ploughing footprint, as described in 11.7.3.1) • Maximum temporary disturbance for cable installation by ploughing = 6,000,000m^2 ○ Maximum total export cable trench length of 200km. ○ Maximum width of temporary disturbance is approximately 30m, based on the disturbance impact for ploughing of a 10m wide trench with approximately 10m of spoil either side of the cable trenches. • Anchor placement – 600m^2 (based on four cable joints, two per cable pair with a footprint of 150m^2 each, assuming up to 6 anchors per vessel) Worst case scenario total disturbance footprint = **6.07km^2.** •	As above, temporary disturbance relates to seabed preparation and cable installation. The permanent footprints associated with cable protection are considered in O&M Impact 1.
	Disturbance footprints in the project interconnector search area	• Project Interconnector cable trench 92km with 20m pre-sweeping width = 1,840,000m^2 • Anchor placement (based on four cable joints two per cable pair) = 300m^2 • Boulder clearance – 28 boulders of up to 5m diameter being lifted and then placed back on the seabed = 1,100m^2 Worst case scenario total disturbance footprint = **1.84km^2.**	
Impact 2: Increased suspended sediment concentrations (SSCs) and sediment re-deposition (for further detail on worst case parameters see	Suspended sediment concentrations and associated sediment deposition from cable and foundation installation and seabed preparation in the Norfolk Boreas site	The worst case suspended sediment and deposition is described in the assessments in Chapter 8 Marine Geology, Oceanography and Physical Processes based on the following volumes: **Drill arisings** • Wind turbine foundations based on worst case volume associated with 20MW monopile (45 turbines (50%) x 30m depth x 10m diameter) = 397,608m^3 • Meteorological masts - 2 x pin-pile quadropod = 1,131m^3 • Service platform - 1 x six legged pin-pile = 848m^3 • Offshore electrical platforms - 2 x six legged 18 pin-piles = 14,137m^3 • Lidar - 2 x monopiles = 189m^3	This would result in the highest potential levels of SSCs and subsequent sediment re-deposition. Seabed preparation (dredging using a trailer suction hopper dredger and installation of a bedding and levelling layer) may be required up to a sediment depth of 5m. The worst case

Impact	Parameter	Worst Case	Rationale
Chapter 8, Marine Geology, Oceanography and Physical Processes)		Worst case scenario total = 413,913m^3 **Seabed preparation/ disposal** • 180 x GBS foundations for 10MW turbines (based on area described in Impact 1 and levelling depth of up to 5m) = 1,767,146m^3. • Two offshore electrical platforms based on area described in Impact 1 and 5m depth = 75,000m^3 • One service platform based on area described in Impact 1 and 5m depth = 37,500m^3 • Two met masts based on area described in Impact 1 and 5m depth = 12,566m^3 • Array cable trench – 600km length with average 20m pre-sweeping width and 3m depth = 36,000,000m^3 • Interconnector cable trench - 60km of trench with average 20m pre-sweeping width and 3m depth = 3,600,000m^3 (connecting platforms within the Norfolk Boreas site) • Export cable trench within the Norfolk Boreas site 50km with average 30m pre-sweeping width and 3m depth = 4,500,000m^3 Worst case scenario total disturbed sediment = **45,992,212m^3** It should be noted that seabed preparation is less likely to be required for piled foundations and, if required, would be significantly less than described above. Therefore, the volume of drill arisings and seabed preparation outlined above are not cumulative.	scenario considers the maximum volumes for the project. **NB** if piled foundations with drilling are used, the level of seabed preparation described above for gravity anchors would not be required
	Suspended sediment concentrations and associated sediment deposition from cable installation in the offshore cable corridor	The worst case suspended sediment and deposition is described in the assessments in Chapter 8 Marine Geology, Oceanography and Physical Processes based on the following volumes: The sediment disposed of as a result of the pre-sweeping activity for the offshore export cables within the offshore cable corridor would equate to about 600,000m^3 of sediment. Approximately 500,000m^3 would be within the Haisborough, Hammond and Winterton SAC (excluding the nearshore (10m water depth contour) where no pre-sweeping is proposed). Following pre-sweeping, the sediment released due to trenching for the offshore export cables would equate to approximately **3,000,000m^3** of sediment, based on a maximum	This would result in the highest potential levels of SSCs and subsequent sediment re-deposition.

Impact	Parameter	Worst Case	Rationale
		average depth of approximately 3m and a trench width of 10m with a V shaped profile. This would be back filled naturally or manually. WCS for total temporary increase in SSC due to pre-sweeping and trenching = **3,600,000m^3**	
	Suspended sediment concentrations and associated sediment deposition from project interconnector cable installation	The sediment released due to trenching and / or pre-sweeping in the project interconnector search area would equate to approximately **5,520,000m^3** of sediment, based on 92km of trench with a maximum average depth of approximately 3m and an average trench width of 20m. This would be back filled naturally or manually.	This would result in the highest potential levels of SSCs and subsequent sediment re-deposition.
Impact 3: Underwater noise from piling	Underwater noise and vibration associated with piling for foundation installation	Spatial worst case based on piling using the greatest hammer energy: • 90 x Largest turbines on monopile foundations (maximum hammer energy of 5,000kJ) • 2 x offshore electrical platforms on six legged jacket foundations (up to 18 pin-piles each) (max. hammer energy of 2,700kJ) • 1 x service platform on six legged jacket foundation (six pin-piles) (maximum hammer energy of 2,700kJ) • 2 x met masts on monopile foundations (maximum hammer energy of 5,000kJ) • 2 x LiDAR on monopile foundations (maximum hammer energy of 5,000kJ) • Up to two simultaneous piling events within the Norfolk Boreas site. Temporal worst case based on the installation of the maximum number of piles (maximum piling time providing allowance for soft-start, ramp up and issues such as low blow rate, refusal). • 180 x smallest turbines on quadrapods (720 pin piles x 1.5 hour piling each) = 1,080 hours • 2 x offshore electrical platforms with 18 pin piles (36 pin piles x 1.5 hours piling each)= 54 hours • 1x service platform with 6 pin piles (6 pin piles x 1.5 hours piling each)= 9 hours • 2x met masts on quadrapods (8 pin piles x 1.5 hours) = 12 hours • 2x LiDAR on monopile (2 monopiles x 6 hours each) = 12 hours	The spatial worst case is a result of installation of piling using the maximum hammer energies and the potential for simultaneous piling to occur at two locations within the Norfolk Boreas site. This would result in largest spatial noise impact at any given time and hence maximum impact on fish and shellfish receptors. Consideration has also been given to the worst case scenario in terms of piling duration. This would be associated with the installation of the maximum number of piles.

Impact	Parameter	Worst Case	Rationale
		• Piling occurring in only one location at a given time within the Norfolk Boreas site. Total: 772 piles – maximum of 1,167 hours (approx. 49 days) of piling.	
Impact 4: Underwater noise from other construction activities	Underwater noise and vibration associated with seabed preparation, rock dumping , cable installation and construction vessels	Construction activities other than piling noise which would generate underwater noise during the construction phase, including: • Dredging; • Drilling; • Cable laying; • Rock placement; • Trenching; and • Vessel noise. Maximum number of vessels on site at any one time: 57 Maximum number of vessel transits during construction: 1,180	This would result in the greatest noise impacts as a result of project construction activities other than piling for foundation installation.
Impact 5: Underwater noise from UXO	Underwater noise associated with UXO clearance	Assumes UXO will be identified and it will not be possible to be avoided or removed from the seabed and disposed of onshore in a designated area. Worst case number of UXO: • Up to 30 UXO in the Norfolk Boreas site • Up to 28 in the offshore cable corridor • Up to 22 in the project interconnector search area • Total: up to 80 The numbers above are based on initial geophysical data (Fugro, 2016;2017). Actual UXO numbers would be determined by a pre-construction UXO survey.	This would result in a controlled detonation of up to 80 UXO being required and therefore in potential for associated noise impacts.
Operation			
Impact 6: Permanent loss of seabed area	In the Norfolk Boreas site through the presence of wind turbine and platform foundations, scour protection, array	<u>Turbines</u> Total worst case scenario for turbine foundation footprints with scour protection across the Norfolk Boreas site is 180 GBS foundations with a footprint (foundation and scour) of a circular area 200m in diameter. For the site this equates to an area of 5,654,867m^2. <u>Array cable protection</u> Up to 60km of cable protection may be required in the unlikely event that array cables	This would result in the maximum area of seabed habitat loss for fish and shellfish ecology receptors in respect of infrastructure within the Norfolk Boreas

Impact	Parameter	Worst Case	Rationale
	cables, interconnector cables, and cable protection	cannot be buried (based on 10% of the length) resulting in a footprint of 300,000m^2 (based on protection width of 5m). Array cable protection at turbines 100m cable length x 5m width x 180 turbines = 90,000m^2 Array cable crossings protection 10 crossings x 100m x 10m = 10,000m^2 <u>Export cable protection</u> Up to 5km of cable protection may be required in the unlikely event that export cables within the Norfolk Boreas site cannot be buried (based on 10% of the length) resulting in a footprint of 25,000m^2 (based on protection width of 5m). Export cable protection at platforms 50m cable length x 5m width x two cables = 500m^2 <u>Interconnector cable protection</u> Interconnector cable protection approaching platforms 100m cable length x 5m width x 2 platforms = 1,000m^2 Surface laid interconnector cable protection 5m width x 6,000m (10% of the length) = 30,000m^2 Interconnector cable crossings protection crossings – captured within array cable crossing total <u>Platforms and other infrastructure</u> Two offshore electrical platforms with scour protection 35,000m^2 One service platform with scour protection 17,500m^2 Two met masts with scour protection 15,708m^2 Two wave buoys 300m^2 Two LiDAR monopiles with scour protection 157m^2 Overall worst case scenario total footprint within the Norfolk Boreas site is **= 6.18km^2**	site.
	In the offshore cable corridor due to cable protection	Cable protection would be required at locations where the export cables cross other cables or pipelines; at the landfall HDD exit points; in the unlikely event that cable burial is not possible; and/or during the operation and maintenance phase should cables become unburied.	This would result in the maximum area of seabed habitat loss for fish and shellfish ecology receptors in

Impact	Parameter	Worst Case	Rationale
		Export cables • Crossings A total of thirteen crossings (eleven cables and two pipelines) are required for each cable pair (i.e. up to 26 crossings in total) resulting in a total footprint of 26,000m² (based on a width of 10m and length of 100m of cable protection per crossing). • Nearshore (within 10m depth contour) Cable protection may be required at each of the landfall HDD exit points. This would entail one mattress (6m length x 3m width x 0.3m height) plus rock dumping (5m length x 5m width x 0.5m height) at each exit point (up to two cable pairs) resulting in a footprint of 86m² • Unburied cables In the unlikely event that cable burial is not possible due to hard substrate being encountered, up to 16km per cable pair outside the SAC and 4km inside the SAC per cable pair (20km in total) could require additional protection resulting in a footprint of 100,000m² (based on protection width of 5m). Worst case scenario total footprint within the offshore cable corridor is **= 0.13km²**	respect of export cables.
	In the project interconnector search area due to cable protection	Cable protection would be required at crossing points and where cable burial is not possible • Unburied cables Surface laid project interconnector cable protection 5m width x 92,000m (10% of the length) = 46,000m² • Cable crossings A total of maximum of 10 crossings (all the BBL pipeline) are required for each cable or pair of cables (i.e. up to 10 crossings in total) resulting in a total footprint of 10,000m² (based on a width of 10m and length of 100m of cable protection per crossing). • Approach to electrical platform A total of 10 cables on approaching to platform 100m cable length x 5m width = 5,000m² Worst case scenario total footprint within the project interconnector cable search area is = **0.061km²**	This would result in the maximum area of seabed habitat loss for fish and shellfish ecology receptors in respect of infrastructure within the project interconnector search area

Impact	Parameter	Worst Case	Rationale
Impact 7: Introduction of hard substrate	Introduction of hard substrate in the Norfolk Boreas site through presence of submerged infrastructure, scour and cable protection and in the export cable corridor and project interconnector search area due to cable protection	Based on the permanent infrastructure detailed for O&M Impact 1	This would result in the greatest introduction of hard substrate and therefore in the greatest extent of impacts on fish and shellfish receptors
Impact 8: Underwater noise during operation	Underwater noise and vibration associated with operational turbines and operation and maintenance activities	180 x smallest operational wind turbines. Up to 440 vessel movements per year by various vessels associated with O&M activities	This results in the maximum potential for noise disturbance on fish and shellfish receptors during the operation and maintenance phase.
Impact 9: Electromagnetic Fields (EMFs)	EMF from installed array, interconnector, project connector and export cables	Maximum length of cables: • Array cables: 600km • Interconnector cables/ project interconnector cables: 90km/92km • Export cables: 500km Maximum voltage of cables: • Array cables: 150kV AC • Interconnector cables/ project interconnector cables: +/- 525kV DC • Export cables: +/- 525kV	The maximum length of cables would result in the greatest potential for EMF related effects.

Impact	Parameter	Worst Case	Rationale
		Cables buried to a minimum depth of 1m where possible and protected elsewhere. Maximum length of cables that would be protected as described under Impact 6: Permanent loss of seabed area	
Impact 10: Changes in fishing activity	Changes in fish stocks of commercial importance as a result of changes in fishing activity	See Chapter 14 Commercial Fisheries	
Decommissioning			
Impact 11: Disturbance and Temporary loss of habitat	Foundations (turbines and platforms)	Removal of foundations is likely to be limited to parts that are above the seabed. Impacts would be less than during the construction phase. Scour protection would likely be left in-situ.	This would result in the maximum disturbance and temporary loss of habitat
	Array cables, interconnector/ project interconnect cables and protection	Some or all of the array cables and interconnector cables may be removed. Cable protection would likely be left *i*n-situ	
	Export cables and protection	Some or all of the offshore export cables may be removed. Cable protection would likely be left in-situ.	
Impact 12: Increased SSCs and sediment redeposition	See Chapter 8 Marine Geology, Oceanography and Physical Processes for further detail.		
Impact 13: Underwater Noise associated with foundations	Decommissioning of foundations	Cutting of up to 180 foundations - no piling required hence noise impact will be significantly smaller than during the construction phase.	This would result in the maximum potential noise impact associated with the decommissioning of

Impact	Parameter	Worst Case	Rationale
			foundations.
Impact 14: Underwater noise associated with other decommissioning activities	Decommissioning of cables and decommissioning vessels transit	Maximum number of vessels on site at a given time (assumed to be the same as for the construction phase (i.e. up to 57) Maximum number of vessel movements (assumed to be the same as for the construction phase (i.e. up to 1,180) In respect of cables, general UK practice will be followed, i.e. buried cables will simply be cut at the ends and left in-situ, with the exception of the inter-tidal zone across the beach where the cables would be at risk of being exposed over time. Excavation or jetting may be necessary to remove the cables in the inter-tidal zone.	This would result in the maximum potential disturbance associated with noise associated with decommissioning activities other than foundation decommissioning activities.

11.7.4 Potential Impacts during Construction

100. The potential impacts of the project on fish and shellfish receptors during construction are assessed below. As outlined in Table 11.13 these include the following:

- Impact 1: Physical disturbance and temporary loss of habitat;
- Impact 2: Increased SSCs and sediment re-deposition;
- Impact 3: Underwater noise from pile driving;
- Impact 4: Underwater noise from other construction activities; and
- Impact 5: Underwater noise from UXO clearance.

101. The worst case scenarios (Table 11.13) are assessed with construction carried out in a single phase or in two phases. A detailed assessment of the single phase approach is presented and then any pertinent differences associated with the two phase approach are highlighted.

102. Where relevant the magnitude of the impact is described separately for the Norfolk Boreas site, project interconnector search area, the offshore export cable and the project as a whole. Note that the assessment of significance provided is always based on the magnitude of impact defined for the project as a whole.

11.7.4.1 Impact 1: Physical disturbance and temporary loss of seabed habitat

103. During the construction phase, activities such as foundation installation (for turbines, offshore electrical platforms, the service platform and met masts) and installation of array, interconnector/project interconnector and export cables have the potential to result in physical disturbance and/or temporary loss of habitat to fish and shellfish receptors. Similarly, the presence of machinery on the seabed (i.e. jack up vessels legs, vessel anchors) could also result in physical disturbance or temporary habitat loss.

104. As outlined in Table 11.13, the total area disturbed during construction within the Norfolk Boreas site would be 15.4km^2. This would account for a very small proportion of the area of the Norfolk Boreas site (2.1%).

105. Similarly, the maximum area of disturbance associated with the installation of export cables in the offshore cable corridor and that associated with installation of project interconnector cables in the project interconnector search area would also be small (6.1km^2 and 1.8km^2, respectively).

106. Under the two phase approach the indicative overall offshore construction window would be approximately three years (39 months). Foundation installation, laying of offshore export cables and laying of array and interconnector/.project interconnector cables may last approximately 18 months (2 phases of 9 months

each) (Table 11.11). Additionally, up to three months would be required for seabed preparation for foundation installation and up to six months (two phases of three months each) for seabed preparation for installation of export and interconnector/project interconnector cables.

107. Physical disturbance/temporary loss would occur at localised discrete locations at any given time as construction progresses (i.e. in the immediate vicinity of infrastructure/machinery), and would be temporary and short term. In addition, the seabed disturbed would be expected to return to its original condition over a relatively short time frame once construction activities have ceased in a given area and no significant impacts on the benthic community are anticipated in relation to disturbance during construction (impact assessed as minor adverse in Chapter 10 Benthic and Intertidal Ecology).

108. In light of the above, the magnitude of the effect of physical disturbance and temporary loss of habitat is considered to be low. This is considered to be the case in respect of the Norfolk Boreas site, the offshore cable corridor, the project interconnector search area and the project as a whole.

109. The majority of fish species found in the study area are highly mobile and would therefore be able to make use of suitable undisturbed areas in the vicinity of works. In addition, most fish species under consideration have wide distribution ranges as adults and juveniles, in the context of the small areas where physical disturbance and temporary habitat loss as a result of the project could occur. In general terms, fish species are therefore considered receptors of low sensitivity. This, in combination with the low magnitude of the impact assessed for the project results in an impact of **minor adverse** significance.

110. It is recognised however, that species that depend on specific substrates (i.e. for burrowing or spawning) and species or life stages of reduced mobility, may be more susceptible to the impact of physical disturbance/temporary loss of habitat. In areas relevant to the project these include the following:

- Sandeels - require specific substrates on which to burrow as well as for spawning (demersal spawners);
- Herring - require specific substrates on which to lay their eggs (demersal spawners);
- Elasmobranch species with spawning grounds in the area of the offshore project area that lay egg cases on the seabed - thornback ray; and
- Shellfish species- have lower mobility in comparison to fish species and in some cases carry their eggs or lay them on the seabed.

111. A separate assessment for these species/species groups is given below.

Sandeels

112. Sandeels are dependent on the presence of adequate sandy substrate in which to burrow and are demersal spawners which lay their eggs on the seabed. Physical disturbance and temporary loss of seabed habitat associated with the construction of the project could therefore result in detrimental impacts on this species.

113. Sandeels have been recorded within the study area by the IBTS, particularly in ICES rectangles 34F3 and 35F3 within which the eastern section of the Norfolk Boreas site is located, in benthic surveys carried out within the Norfolk Boreas site (see Appendix 10.1 and Appendix 11.1) and during epibenthic surveys carried out in the former East Anglia FOUR, in East Anglia THREE and in the former East Anglia Zone (Appendix 11.1). In addition, the majority of sediment in the offshore project area is suitable as sandeel habitat (Appendix 11.1) and the offshore project area overlaps within low intensity spawning and nursery grounds defined for sandeels (Figure 11.10).

114. Analysis of IBTS data for the wider North Sea (Figure 11.12 to Figure 11.15), however, suggests that the offshore project area supports sandeels in comparatively low numbers. Data from these surveys indicate that highest sandeel CPUEs are recorded for the most part in areas north of the project (Figure 11.12 to Figure 11.5). Similarly, the distribution of sandeel fishing (as derived from VMS data for the Danish sandeel fishery) indicates that the highest fishing intensity occurs north of the offshore project area, around the Dogger Bank, coinciding with the area where high intensity sandeel spawning grounds are located (Figure 11.10 and Figure 11.16). Sandeel fishing within the offshore project area and its vicinity occurs at very low levels (Figure 11.16). In line with the above, the distribution of known sandeel grounds in the North Sea presented in Jensen et al. (2011) indicates that key areas for sandeels are for the most part located to the north and east of the project with the level of overlap between sandeel grounds and the offshore project area being very small. When compared to the total sandeel grounds within Sandeel Assessment Area 1r, the overlap is minimal in its extent (Figure 11.17).

115. Taking the above into account sandeels are considered to be receptors of medium sensitivity.

116. In light of the low magnitude of the impact and the medium sensitivity of the receptor, the impact of physical disturbance and temporary habitat loss is assessed to be of **minor adverse** significance.

Herring

117. Herring are demersal spawners which require the presence of coarse substrate on which to deposit their eggs. There could therefore be the potential for a

detrimental effect to occur on herring spawning as a result of physical disturbance and temporary habitat loss during the construction of the project.

118. It should be noted, however, that whilst this species is likely to be found in the study area at certain times (i.e. as suggested by landings data, section 11.6.3 and from IBTS data, Figure 11.18), there is no evidence to suggest that herring use areas within the offshore project area for spawning. Analysis of sediment samples across the offshore project area indicate that apart from a limited number of samples collected in the inshore section of the offshore cable corridor close to shore, the sediment across the majority of the offshore project area is unsuitable for herring spawning (Appendix 11.1). As indicated by the distribution of spawning grounds described in Coull et al*.* (1998) (Figure 11.7), the closest known discrete spawning area of herring is located to the south of the inshore section of the offshore cable corridor and the closest large-scale spawning ground (Downs herring) to the south of the project towards the English Channel. Records from the IHLS also suggest that herring spawning does not occur within or in the immediate proximity of the offshore project area (Figure 18 to Figure 11.20). Herring is therefore considered a receptor of low sensitivity.

119. Taking the low magnitude of the effect assessed for the project and the low sensitivity of the receptor the impact of physical disturbance and temporary loss of habitat is assessed to be of **minor adverse** significance.

Elasmobranchs –Thornback ray

120. Thornback rays lay eggs cases on the seabed and therefore have increased sensitivity to the effect of physical disturbance. However, spawning grounds for this species (as derived from the distribution of low intensity nursery grounds) only overlap with the inshore section of the export cable corridor. Considering this and recognising the overall extent of their spawning grounds (Figure 11.11), thornback ray is considered a receptor of low sensitivity.

121. This combined with the low magnitude of the effect assessed for the project results in an impact of **minor adverse** significance.

Shellfish

122. Shellfish species such as edible crab and lobster have adopted a reproductive strategy of high egg production to compensate for losses during egg extrusion and the extended incubation period (McQuaid et al*.,* 2009). Females are ovigerous, with the eggs remaining attached to the abdomen until hatching. In the case of edible crabs, females may remain buried in sediments when bearing eggs for periods ranging from four to nine months. Other species such as whelks lay demersal egg-cases which are often found attached to subtidal rocks, stones or shells (Ager, 2008).

123. Adult shellfish are also more limited in their mobility than fish species and may be less able to avoid areas where construction activity is occurring. In light of these considerations, both adults and egg masses (pre-hatching) could be vulnerable to physical damage. Therefore, receptor sensitivity is considered to be medium.

124. Taking the low magnitude of the impact assessed for the project and the medium sensitivity of the receptor, the impact of physical disturbance/temporary loss of habitat is assessed to be of **minor adverse** significance.

11.7.4.1.1 Confidence in the assessment

125. The confidence in the data and information used in this assessment is medium to high.

11.7.4.2 Impact 2: Increased suspended sediment concentrations (SSCs)

126. An expert-based assessment of the potential increase in SSCs and associated sediment re-deposition resulting from the construction of the project is given in detail within Chapter 8 Marine Geology, Oceanography and Physical Processes. Relevant information included in the expert-based assessment is summarised here and has been used to inform the definition of the magnitude of the impact.

127. Activities associated with the construction phase that have potential to result in increased SSCs and sediment re-deposition include the following:

- Seabed preparation and drilling for foundation installation; and
- Cable installation (export cables, array cables, interconnector cables and project interconnector cables).

128. As described in Chapter 8 Marine Geology, Oceanography and Physical Processes and summarised in Table 11.11, the majority of the sediment released during foundation installation would be medium-grained sand which would fall as a highly turbid dynamic plume upon its discharge, reaching the seabed within minutes or tens of minutes and within tens of metres along the axis of tidal flow from the point at which it was released. The resulting mound would likely be tens of centimetres to a few metres high and would remain local to the release point. The small proportion of fine sand and mud would stay in suspension for longer and form a passive plume. This plume (tens of mg/l) would be likely to exist for around half a tidal cycle (i.e. approximately 6 hours). Sediment would settle to the seabed within a few hundred metres up to approximately 1km along the axis of tidal flow from the location at which it was released. These deposits would be very thin (millimetres).

129. Similarly, during installation of array, interconnector and project interconnector cables the majority of sediment would fall as a highly turbid dynamic plume upon

its discharge, also reaching the seabed within minutes or tens of minutes and within tens of metres along the axis of the tidal flow from the point of installation along the cables. Deposition of this sediment would form a linear mound (likely to be tens of centimetres high).

130. The small proportion of fine sand and mud would stay in suspension for longer and form a passive plume. This plume would also be of modest concentration (tens of mg/l) and persist for around half a tidal cycle. Sediment would settle to the seabed in the proximity to its release point (within a few hundred metres up to around 1km along the axis of tidal flow). Due to the dispersion by tidal currents, and subsequent deposition and re-suspension, the deposits across the wider seabed would be very thin (millimetres).

131. In view of the small spatial and temporal extents of increased suspended sediments and deposition associated with construction activities in the Norfolk Boreas site and the project interconnector search area, the magnitude of the impact is considered to be low.

132. With regards to the offshore export cable installation, pre-sweep activities would result in the removal of up to 600,000m^3 of sediment. In addition, trenching activity could result in the release of up to 3,000,000m^3 of sediment. Whilst a relatively large quantity of material could be released, this would occur over a large area including up to two cable trenches and over a period of up to 18 months. It is therefore predicted that in water depths greater than 20m LAT (which are seen across the majority of the offshore cable corridor), peak suspended sediment concentrations would be typically less than 100mg/l, except in the immediate vicinity (a few tens of metres) of the release location. In shallow water nearer to shore (less than 5m LAT), the potential for dispersion is more limited and therefore the concentrations are likely to be greater, approaching 400mg/l at their peak. However, these plumes would be localised to within less than 1km of the location of installation and would persist for no longer than a few hours. Furthermore, following cessation of installation activities any plume would have been fully dispersed as a result of advection and diffusion.

133. Sediment from export cable laying activities would settle out onto the seabed. As discussed in Chapter 8 Marine Geology, Oceanography and Physical Processes, following completion of the cable installation activity theoretical bed level changes in excess of 0.2mm (and up to 0.8mm) are predicted at a distance of up to 20km from the cable trench and changes of up to 2mm within a few hundred metres of the inshore release locations. However, it is anticipated that under the prevailing hydrodynamic conditions, this material would be readily re-mobilised, especially in the shallow inshore area where waves would regularly stir the bed. Accordingly,

outside the immediate vicinity of the offshore cable trench, bed level changes and any changes to seabed character are expected to be not measurable in practice.

134. Taking account of the anticipated levels of increase in SSCs and the expected level of sediment deposition, the magnitude of the impact with regards to the installation of the offshore export cable is, as for the Norfolk Boreas site and project interconnector search area, considered to be low. Similarly the magnitude of the impact taking account of construction activities for the whole project is also considered to be low.

135. In general terms, adult and juvenile fish, being mobile, would be expected to rapidly redistribute to undisturbed areas within their habitat range, and are therefore considered receptors of low sensitivity. This, in combination with the low magnitude of the effect associated with the project, would result in an impact of **minor adverse** significance.

136. It is recognised that species and life stages of relatively low mobility and those highly dependent on the presence of specific substrates may have increased sensitivity to the impact of SSCs and sediment deposition. For instance, eggs and early larval stages may drift passively in the water column or be present on benthic substrates. This results in reduced capacity to avoid areas impacted by increased SSCs and re-deposition of sediments and an increased susceptibility to the potential negative effects of the impact. Similarly, shellfish species, having lower mobility in comparison to most fish species, may be more susceptible as they may not be able to avoid areas affected by increased SSCs and re-deposition.

137. Therefore, separate assessments are given below for species highly dependent on the characteristics of the substrate, early life stages (eggs and larvae) and shellfish, as follows:

- Sandeels (demersal spawners);
- Herring (demersal spawners);
- Other species with known spawning grounds in the offshore project area; and
- Shellfish species.

Sandeels

138. Sandeels spend a significant proportion of their life cycle buried within the seabed and are demersal spawners. Therefore, increased SSCs and sediment re-deposition associated with the project may have increased potential to adversely impact this species group.

139. Sandeels deposit eggs on the seabed in the vicinity of their burrows. Grains of sand may become attached to the adhesive egg membranes. Tidal currents can cover sandeel eggs with sand to a depth of a few centimetres, however, experiments

have shown that the eggs are capable of developing normally and hatch as soon as currents uncover them again (Winslade, 1971).

140. Research by Behrens et al. (2007) on the oxygenation in the burrows of sandeel *Ammodytes tobianus* found that the oxygen penetration depth at the sediment interface was only a few millimetres. Sandeels were typically buried in anoxic sediments at depths of 1-4cm. In order to respire, they appear to induce an advective transport through the permeable interstice to form an inverted cone of porewater with 93% oxygen saturation.

141. In addition to direct effect on adults and early life stages, increased SSCs and re-deposition associated with construction activity could also result in a change in the substrate characteristics causing a change/loss of habitat to sandeels. It should be noted, however, that for the most part any sediment re-deposited would be similar to that in the surrounding seabed and therefore no significant change in seabed sediment type is to be expected (Chapter 8 Marine Geology Oceanography and Physical Processes).

142. From the above, it is apparent that sandeel early life stages and adults are relatively tolerant to SSCs and sediment re-deposition. In addition, there is little potential for significant changes in the characteristics of the seabed sediment type to occur.

143. As described previously for assessment of impacts in respect of temporary disturbance/loss of habitat, evidence from IBTS surveys, the location of sandeel high intensity spawning grounds and the distribution of sandeel fishing activity and sandeel grounds (Figure 11.10 and Figure 11.12 to Figure 11.17), suggest that the offshore project area is of comparatively low importance to this species in the context of the Sandeel Assessment Area 1r.

144. With the above in mind but recognising their limited mobility and substrate dependence, they are considered receptors of medium sensitivity. Taking the low magnitude of effect assessed for the project and the medium sensitivity of the receptor the impact is assessed to be of **minor adverse** significance.

Herring

145. Herring are demersal spawners requiring the presence of a coarse substrate on which to lay their eggs. Therefore, increased SSCs and sediment re-deposition associated with the project may have increased potential to adversely impact this species.

146. Laboratory studies have established that herring eggs are tolerant to elevated SSCs as high as 300mg/l and can tolerate short term exposure at levels up to 500mg/l (Kiørboe et al., 1981). These studies concluded that dredging and other similar

operations are not likely to result in harmful effects to herring spawning grounds. Herring eggs have been recorded to successfully hatch at SSCs up to 7,000mg/l (Messieh et al., 1981).

147. Fine silt particles associated with increases in SSCs have the potential to adhere to the gills of larvae which could cause suffocation (De Groot, 1980). Griffin et al. (2009) suggested that larval survival rates could be reduced at SSCs as low as 250mg/l. Larvae of most fish species, including herring, are visual predators. Therefore, if visibility is reduced as a result of SSCs foraging success may be affected (Johnston and Wildish, 1981). There is evidence to suggest however that SSCs may enhance feeding rates by providing a visual contrast to prey items on the small perceptive scale used by the larvae. In addition, larvae may be subject to reduced predation from larger visual planktivores in turbid environments (Bone and Moore, 2008). A study which exposed Pacific herring *Clupea harengus pallasi* larvae to suspensions of estuarine sediment and volcanic ash at concentrations ranging from 0 to 8,000mg/l (Boehlert and Morgan, 1985) found that maximum feeding incidence and intensity occurred at levels of suspension of up to 500mg/l above which feeding activity decreased.

148. In addition to impacts on early life stages, increased SSCs and sediment re-deposition associated with the project could result in an impact on herring spawning grounds by means of changes in the characteristics of the substrate. As previously described, however, there is little potential for significant changes in the characteristics of the seabed sediment type to occur as a result of construction activities.

149. Furthermore, whilst herring is anticipated to be present in the study area at certain times (i.e. as suggested by landings data, section 11.6.3 and from IBTS data, Figure 11.18), there is no evidence to suggest that herring use areas within the offshore project area for spawning. As indicated by the distribution of spawning grounds described in Coull et al. (1998) (Figure 11.7), the closest known discrete spawning area of herring is located to the south of the inshore section of the offshore cable corridor, close to shore and the closest large-scale spawning ground (Downs herring) to the south of the project towards the English Channel. Records from the IHLS also suggest that herring spawning does not occur within or in the immediate proximity of the offshore project area (Figure 18 to Figure 11.20).

150. In light of the relative tolerance of herring eggs and larvae to increases in SSCs such as those associated with the construction of the project and the fact that the offshore project area and its vicinity is not expected to support herring during spawning, the receptor is considered to be of low sensitivity.

151. Taking the low magnitude of the effect assessed for the project and the low sensitivity of the receptor the impact of increased SSCs and sediment re-deposition is assessed to be of **minor adverse** significance.

Other species with spawning grounds in the offshore project area

152. As described in section 11.6.4, in addition to sandeels, there are a number of other fish species with defined spawning grounds located in areas relevant to the offshore project area. These include sole, plaice, cod, whiting, mackerel, sprat, lemon sole and thornback ray. Note that with the exception of thornback ray, these species are pelagic spawners and therefore do not have the same degree of spatial dependency on a specific substrate for spawning as sandeels or herring. Further, the spawning grounds of these species are extensive in the context of the localised areas where increased SSCs and re-deposition associated with the project may occur (see Figure 11.2 to Figure 11.6, Figure 11.8 and Figure 11.9,). In the particular case of thornback rays, whilst they lay egg cases on the seabed, their spawning grounds (inferred from the location of nursery areas) (Figure 11.11), only overlap with the inshore section of the export cable corridor.

153. Therefore, all these species are considered to be of low sensitivity. As discussed above, the magnitude of the effect for the project is low, giving an impact of **minor adverse** significance.

Shellfish species

154. The Marine Evidence based Sensitivity Assessment (MarESA) for edible crab (Neal and Wilson, 2008), considers this species to have a low sensitivity to increased SSCs (i.e. a change of 100mg/l for 1 month) and a high rating for recoverability. The sensitivity of edible crab to smothering is also considered to be very low. This is based on a benchmark which considers a scenario where the population of a species or an area of a biotope is smothered by sediment to a depth of 5cm for one month. This assessment is based on crabs being able to escape from under silt and migrate away from an area, and consequently, smothering is not expected to result in mortality.

155. There is no MarESA available for lobster. Lobsters do however belong to the same taxonomic family as the spiny lobster (Nephropidae) for which there is a MarESA, thus providing a relevant comparison. The MarESA concludes that spiny lobster is tolerant and not sensitive to increased SSCs and smothering. Given the physiological similarities between these species, it is reasonable to assume that the sensitivity to increased SSCs and smothering of the spiny lobster will be aligned with that for lobster. Similarly, in the case of shrimps, the MarESA for brown shrimp (Neal, 2008), suggests this species is not sensitive to increases in SSCs and of low sensitivity to smothering with very high recoverability.

156. In line with the above, in a review of the effects of elevated SSCs on biota, Wilber and Clark (2001) reported that in studies examining the tolerance of adult crustaceans, the majority of mortality was induced by concentrations exceeding 10,000mg/l (considerably higher than those generated by construction activities associated with the installation of foundations and offshore cables).

157. There is limited information on the sensitivity of the common whelk to increased SSCs and deposition. The MarESA for the dog whelk *Nucella lapillus* (which belongs to the same taxonomic order (Neogastropoda)), however, indicates that the species is not sensitive to increased SSCs and smothering, albeit the confidence/evidence in the assessment is low (Tyler-Walters, 2007).

158. Taking the relative tolerance of shellfish species to SSCs and smothering in the context of the small increases in SSCs and low level of re-deposition expected during the construction of the project, shellfish are considered receptors of low sensitivity. This, in combination with the low magnitude of the effect assessed for the project, would result in an impact of **minor adverse** significance.

11.7.4.2.1 Confidence in the assessment

159. The confidence in the data and information used in this assessment is medium to high.

11.7.4.3 Impact 3: Underwater noise from pile driving

160. During foundation installation, piles are generally expected to be driven but drilling may be required at some locations. In addition, other techniques, such as pile vibration, are also being considered (Chapter 5 Project Description). This will be confirmed post consent on receipt of more detailed geotechnical information.

161. It should be noted that both pile vibration and drilling are considered low-noise foundation installation methods in comparison to pile driving (Koschinski and Ludemann, 2013). Therefore, for the purposes of this assessment, under the worst case scenario (Table 11.13), it is assumed that all foundations will be installed using pile driving as this would result in the greatest noise impacts.

162. The assessment presented in this chapter is supported by the information provided in Appendix 5.4 (Underwater Noise Assessment). Relevant outputs have been summarised here.

11.7.4.3.1 Hearing in fish and shellfish

163. Very intense sounds may kill or injure marine animals. At lower levels, sound may impair their hearing, affect their ability to orientate, or make their vocalisations difficult to detect. Noise may induce changes in behaviour that may affect spawning migrations or disrupt foraging and feeding. It may cause chronic stress

and associated physiological responses. In some cases it may deny animals access to particular habitats, including preferred feeding grounds or spawning areas (Spiga et al., 2012).

164. The potential impact of noise on fish and shellfish may vary depending on the hearing sensitivity of each particular species. From the limited studies conducted to date on the hearing of fish, it is evident that there are potentially substantial differences in auditory capabilities between individual fish species. The preferred approach to understand their hearing has therefore been to distinguish fish groups on the basis of differences in their anatomy and what is known about hearing in other species with comparable hearing systems (Hawkins and Popper, 2016). In line with this, the following groups have been proposed (Popper et al., 2014):

- Fish species with no swim bladder or other gas chamber (e.g. dab and other flat fish species). These species are less susceptible to barotrauma and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure;
- Fish species with swim bladder in which hearing does not involve the swim bladder or other gas volume (e.g. Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure; and
- Fish species in which hearing involves a swim bladder or other gas volume (e.g. cod, herring and relatives). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

165. Hearing in shellfish species is poorly understood, however studies have shown that some species are able to detect sound. Lovell et al. (2005; 2006) reported that the prawn *Palaemon serratus* is capable of detecting low frequency sounds. Pye and Watson (2004) reported that immature lobsters of both sexes detected sounds in the range 20-1000Hz, whilst sexually mature lobsters exhibited two distinct peaks in their acoustic sensitivity at 20-300Hz and 1000-5000Hz. It has also been suggested that species that have complex statocysts, such as squid, cuttlefish and octopus may also be able to detect sounds (Budelmann, 1992).

11.7.4.3.2 Impact criteria

166. The noise impact criteria used for assessment of the impact of piling noise are shown in Table 11.14. These are based on Popper et al. (2014) which presents current best practice guidance on fish threshold criteria.

167. It is important to note that in some instances the noise levels used to define the criteria are the same for multiple effects. This is because data available to create the criteria is limited and most criteria are "greater than", (>) with a precise

threshold not identified. All ranges associated with criteria defined as ">" are therefore somewhat conservative.

168. Furthermore, it should be noted that under Popper et al. (2014) guidance, the use of a quantitative approach for assessment of behavioural impacts on fish is not recommended, as the best research available is limited to very specific studies on species under artificial conditions. Behavioural criteria are instead described on the basis of the relative risk (high, moderate, low) to the animal at various distances from the source of noise (near (N), intermediate (I), and far (F)) (Table 11.14). For the purpose of this assessment, in line with the definitions suggested in Popper et al. (2014), these distances have been considered as follows:

- Near: within tens of metres;
- Intermediate: within hundreds of metres; and
- Far: within thousands of metres.

Table 11.14 Impact criteria used in the assessment of piling noise on fish (Source: Popper et al., 2014)

Category	Mortality/Mortal Injury	Recoverable injury	Temporary Threshold Shift (TTS)	Behavioural
Fish with no swim bladder	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) High (I) Moderate (F) Low
Fish with swim bladder not involved in hearing	210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	>186 dB SEL_{cum}	(N) High (I) Moderate (F) Low
Fish with swim bladder involved in hearing	207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate
Eggs and larvae	>210 dB SEL_{cum} or >207 dB peak	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

11.7.4.3.3 Noise modelling

169. Two piling source scenarios have been modelled to include monopile and pin pile (jacket) wind turbine foundations across the Norfolk Boreas site. These are:

- Monopiles installed using a maximum hammer blow energy of 5000kJ; and
- Pin piles installed using a maximum hammer blow energy of 2700kJ.

170. For each foundation type modelling has been undertaken at two representative locations, covering the position closest to land (SW), which also represents one of

the deepest locations on the site, and the furthest position from this location (NE), which is situated in shallower water (Table 11.15).

Table 11.15 Underwater noise modelling locations

Location	South West (SW)	North East (NE)
Latitude	52.8708°N	53.2412°N
Longitude	002.7596°E	002.7596°E
Water depth (m)	38 m	28

171. For calculating cumulative SELs, the soft start and ramp up of blow energies along with total duration and strike rate of the piling were considered. These are summarised in Table 11.16 and Table 11.17. The ramp up takes place over the first half-hour of piling, starting at ten percent of maximum and gradually increasing in blow energy and strike rate until reaching the maximum energy, where it stays for the remaining time.

172. The monopile scenario contains 10,350 pile strikes over 360 minutes (6 hours, inclusive of soft start and ramp up). Two pin pile scenarios have been considered and both include four individual piles installed consecutively. One scenario assumes a total of 9,000 strikes over 6 hours (1 hour 30 minutes for each pin pile), and the other assumes a total of 19,800 strikes over 12 hours (3 hours for each pin pile). For the purposes of noise modelling, it is assumed that there is no pause between each individual pin pile, and there is continuous exposure.

Table 11.16 Ramp up scenario used for calculating SELs for monopiles

	Strike hammer energy (10%)	Ramp-up	Maximum hammer energy (100%)
Monopile hammer energy	500kJ	Gradual increase	5,000kJ
Number of strikes	150 strikes	300 strikes	9,900 strikes
Duration	10 minutes	20 minutes	330 minutes

Table 11.17 Ramp up scenarios for calculating SELs for pin piles

	Strike hammer energy (10%)	Ramp-up	Maximum hammer energy (100%)
Pin-pile hammer energy	270kJ	Gradual increase	2,700kJ
Number of strikes (6h)	150 strikes	300 strikes	1,800 strikes
Duration (6h)	10 minutes	20 minutes	60 minutes
Number of strikes (12h)	150 strikes	300 strikes	4,500 strikes
Duration (12h)	10 minutes	20 minutes	150 minutes

173. For the SEL_{cum} criteria, a fleeing animal speed of $1.5ms^{-1}$ has been used (Hirata, 1999). All the impact thresholds from the Popper et al. (2014) guidance are unweighted.

174. The results of the modelling using a fleeing animal approach in terms of maximum, minimum and mean impact ranges for fish in respect of mortality and potential mortal injury, recoverable injury and Temporary Threshold Shift (TTS) are given in Table 11.18 to Table 11.23.

175. Results are presented for installation of monopiles using the maximum blow energy (5,000kJ) and for installation of pin-piles using a maximum energy of 2,700kJ. As shown, installation of monopiles results in the greatest spatial impact ranges for fish.

176. The results show that fish with swim bladders involved in hearing are the most sensitive to the impact of piling noise with ranges of up to few hundred meters for the SPL_{peak} injury criteria and ranges up to 6.5km for TTS (SEL_{cum}).

Table 11.18 Impact ranges for fish (no swim bladder) for installation of a monopile with a maximum blow energy of 5,000kJ

Popper et al. (2014) - Fish (no swim bladder)				Monopile (5000 kJ)		
				Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 213 dB	70m	70m	70m
		Recoverable injury	> 213 dB	70m	70m	70m
	SELcum	Mortality and potential mortal injury	> 219 dB	< 100m	< 100m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100m	< 100m
		TTS	>> 186 dB	6.5km	6.2km	5.8km
NE location	SPLpeak	Mortality and potential mortal injury	> 213 dB	< 50m	< 50m	< 50m
		Recoverable injury	> 213 dB	< 50m	< 50m	< 50m
	SELcum	Mortality and potential mortal injury	> 219 dB	< 100m	< 100m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100m	< 100m
		TTS	>> 186 dB	2.0km	1.7km	1.6km

Table 11.19 Impact ranges for fish (no swim bladder) for installation of pin-piles with a maximum blow energy of 2,700kJ

Popper et al. (2014) - Fish (swim bladder not involved in hearing)				Pin Pile (2700 kJ)		
				Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 213 dB	50m	50 m	50m
		Recoverable injury	> 213 dB	50m	50 m	50m
	SELcum (6 hours)	Mortality and potential mortal injury	> 219 dB	< 100m	< 100 m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100 m	< 100m
		TTS	>> 186 dB	3.6km	3.5km	3.3km
	SELcum (12 hours)	Mortality and potential mortal injury	> 219 dB	< 100m	< 100m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100m	< 100m
		TTS	>> 186 dB	4.1km	3.9km	3.7km
NE location	SPLpeak	Mortality and potential mortal injury	> 213 dB	< 50m	< 50m	< 50m
		Recoverable injury	> 213 dB	< 50m	< 50m	< 50m
	SELcum (6 hours)	Mortality and potential mortal injury	> 219 dB	< 100m	< 100m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100m	< 100 m
		TTS	>> 186 dB	500m	390m	300 m
	SELcum (12 hours)	Mortality and potential mortal injury	> 219 dB	< 100m	< 100m	< 100m
		Recoverable injury	> 216 dB	< 100m	< 100m	< 100m
		TTS	>> 186 dB	600m	460m	300m

Table 11.20 Impact ranges for fish (swim bladder not involved in hearing) for installation of a monopile with a maximum blow energy of 5,000kJ

Popper et al. (2014) - Fish (swim bladder not involved in hearing)				Monopile (5000 kJ) Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 207 dB	170m	170m	170m
		Recoverable injury	> 207 dB	170m	170m	170m
	SELcum	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	6.5km	6.2km	5.8km
NE location	SPLpeak	Mortality and potential mortal injury	> 207 dB	90m	90m	90m
		Recoverable injury	> 207 dB	90m	90m	90m
	SELcum	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	2.0km	1.7km	1.6km

Table 11.21 Impact ranges for fish (swim bladder not involved in hearing) for installation of a monopile with a maximum blow energy of 2,700kJ

Popper et al. (2014) - Fish (swim bladder not involved in hearing)				Pin Pile (2700 kJ) Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 207 dB	120m	120m	120m
		Recoverable injury	> 207 dB	120m	120m	120m
	SELcum (6 hours)	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	3.6km	3.5km	3.3km
	SELcum (12 hours)	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	4.1km	3.9km	3.7km
NE location	SPLpeak	Mortality and potential mortal injury	> 207 dB	60m	60m	60m
		Recoverable injury	> 207 dB	60m	60m	60m
	SELcum (6 hours)	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	500m	390m	300m
	SELcum (12 hours)	Mortality and potential mortal injury	210 dB	< 100m	< 100m	< 100m
		Recoverable injury	203 dB	< 100m	< 100m	< 100m
		TTS	> 186 dB	600m	460m	300m

Table 11.22 Impact ranges for fish (swim bladder involved in hearing) for installation of a monopile with a maximum blow energy of 5,000kJ

Popper et al. (2014) - Fish (swim bladder involved in hearing)				Monopile (5000 kJ)		
				Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 207 dB	170m	170m	170m
SW location	SPLpeak	Recoverable injury	> 207 dB	170m	170m	170m
SW location	SELcum	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
SW location	SELcum	Recoverable injury	203 dB	< 100m	< 100m	< 100m
SW location	SELcum	TTS	186 dB	6.5km	6.2km	5.8km
NE location	SPLpeak	Mortality and potential mortal injury	> 207 dB	90m	90m	90m
NE location	SPLpeak	Recoverable injury	> 207 dB	90m	90m	90m
NE location	SELcum	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
NE location	SELcum	Recoverable injury	203 dB	< 100m	< 100m	< 100m
NE location	SELcum	TTS	186 dB	2.0km	1.7km	1.6km

Table 11.23 Impact ranges for fish (swim bladder involved in hearing) for installation of pin-piles with a maximum blow energy of 2,700kJ

Popper et al. (2014) - Fish (swim bladder involved in hearing)				Pin Pile (2700 kJ)		
				Maximum	Mean	Minimum
SW location	SPLpeak	Mortality and potential mortal injury	> 207 dB	120m	120m	120m
SW location	SPLpeak	Recoverable injury	> 207 dB	120m	120m	120m
SW location	SELcum (6 hours)	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
SW location	SELcum (6 hours)	Recoverable injury	203 dB	< 100m	< 100m	< 100m
SW location	SELcum (6 hours)	TTS	186 dB	3.6km	3.5km	3.3km
SW location	SELcum (12 hours)	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
SW location	SELcum (12 hours)	Recoverable injury	203 dB	< 100m	< 100m	< 100m
SW location	SELcum (12 hours)	TTS	186 dB	4.1km	3.9km	3.7km
NE location	SPLpeak	Mortality and potential mortal injury	> 207 dB	60m	60m	60m
NE location	SPLpeak	Recoverable injury	> 207 dB	60m	60m	60m
NE location	SELcum (6 hours)	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
NE location	SELcum (6 hours)	Recoverable injury	203 dB	< 100m	< 100m	< 100m
NE location	SELcum (6 hours)	TTS	186 dB	500m	390m	300m
NE location	SELcum (12 hours)	Mortality and potential mortal injury	207 dB	< 100m	< 100m	< 100m
NE location	SELcum (12 hours)	Recoverable injury	203 dB	< 100m	< 100m	< 100m
NE location	SELcum (12 hours)	TTS	186 dB	600m	460m	300m

11.7.4.3.4 Additional modelling – stationary animal model

177. Following from the underwater noise propagation modelling results presented in the main underwater noise report (Appendix 5.4) and taking account of the feedback provided by the MMO to the PEIR (see Appendix 11.2), additional modelling was carried out to explore the effects of using a stationary animal model for fish compared to the fleeing animal model assumed in the main underwater noise report (Appendix 5.4, Annex 1). The SELcum criteria were used for this modelling. Calculated SPLpeak impact ranges would remain the same as presented in the outputs of the fleeing animal model as these do not take noise exposure over time (or receptor movement) into consideration.

178. The stationary animal model assumes that when exposed to any noise from piling, the fish do not react in any way to reduce their exposure to noise, which will remain at the highest level modelled in the water column. It is considered unlikely that whether the fish reacts specifically to the noise or not, it would remain at the position of highest noise level for the hours of piling. This stationary animal assumption therefore most likely represents a highly conservative worst case with regard to noise exposure.

179. Modelling was undertaken for impact piling at the SW location of the Norfolk Boreas site (for the fish criteria given in Popper *et al*. (2014) (Table 11.14). All parameters used for modelling were the same as those presented with regards to the fleeing animal model in Appendix 5.4, with the exception of assumptions of movement of fish during piling activities.

180. Table 11.24 to Table 11.26, present the modelled impact ranges for monopiles (5,000kJ hammer energy) and pin piles (2,700kJ), showing the increase in predicted ranges when using a stationary animal model compared to the fleeing animal. Maximum ranges are predicted of 18km for stationary animals when considering the 186dB SEL_{cum} criteria for fish during installation of monopiles and pin piles over a 12-hour period. When considering ranges in relation to mortality/mortal injury and recoverable injury, under the stationary animal approach, the greatest impact ranges would be a result of installation of pin piles over a 12-hour period (219-, 203dB SELcum).

Table 11.24 Impact ranges for fish using Popper et al. (2014) criteria for installation of a monopile with a maximum blow energy of 5,000kJ at the south west location of the Norfolk Boreas site

Monopile (5000 kJ)	Stationary animal (0 m/s)			Fleeing animal (1.5 m/s)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
219 dB SELcum	500 m	450 m	400 m	< 100 m	< 100 m	< 100 m
216 dB SELcum	700 m	650 m	600 m	< 100 m	< 100 m	< 100 m
210 dB SELcum	1.5 km	1.5 km	1.4 km	< 100 m	< 100 m	< 100 m
207 dB SELcum	2.2 km	2.1 km	2.0 km	< 100 m	< 100 m	< 100 m

Monopile (5000 kJ)	Stationary animal (0 m/s)			Fleeing animal (1.5 m/s)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
203 dB SELcum	3.5 km	3.4 km	3.3 km	< 100 m	< 100 m	< 100 m
186 dB SELcum	18 km	17 km	16 km	6.5 km	6.2 km	5.8 km

Table 11.25 Impact ranges for fish using Popper et al. (2014) criteria for installation of pin piles with a maximum blow energy of 2,700kJ over a period of 6 hours

Pin Pile (2700 kJ) (6 hours)	Stationary animal (0 m/s)			Fleeing animal (1.5 m/s)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
219 dB SELcum	400 m	350 m	300 m	< 100 m	< 100 m	< 100 m
216 dB SELcum	500 m	450 m	400 m	< 100 m	< 100 m	< 100 m
210 dB SELcum	1.0 km	950 m	900 m	< 100 m	< 100 m	< 100 m
207 dB SELcum	1.4 km	1.4 km	1.3 km	< 100 m	< 100 m	< 100 m
203 dB SELcum	2.3 km	2.2 km	2.1 km	< 100 m	< 100 m	< 100 m
186 dB SELcum	13 km	13 km	13 km	3.6 km	3.5 km	3.3 km

Table 11.26 Impact ranges for fish using Popper et al. (2014) criteria for installation of pin piles with a maximum blow energy of 2,700kJ over a period of 12 hours

Pin Pile (2700 kJ) (12 hours)	Stationary animal (0 m/s)			Fleeing animal (1.5 m/s)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
219 dB SELcum	600 m	550 m	500 m	< 100 m	< 100 m	< 100 m
216 dB SELcum	800 m	750 m	700 m	< 100 m	< 100 m	< 100 m
210 dB SELcum	1.6 km	1.5 km	1.4 km	< 100 m	< 100 m	< 100 m
207 dB SELcum	2.2 km	2.2 km	2.1 km	< 100 m	< 100 m	< 100 m
203 dB SELcum	3.6 km	3.5 km	3.4 km	< 100 m	< 100 m	< 100 m
186 dB SELcum	18 km	17 km	17 km	4.1 km	3.9 km	3.7 km

11.7.4.3.5 Assessment

181. An assessment of the potential impact of underwater noise associated with piling activity is given below for fish and shellfish receptors.

182. The assessment presents the outcomes of the fleeing animal model first and then outlines whether the use a stationary model outputs would result in any changes to assessment conclusions.

183. In addition to the worst case impact in terms of spatial extent, consideration has been given within this assessment to the temporal worst case scenario. This would be a result of the installation of the maximum number of piles (772), which would result in a maximum of 1,167 hours (49 days) of piling (Table 11.13).

184. In order to facilitate the assessment, and in line with Popper et al. (2014), fish receptors have been grouped into categories depending on their hearing system (Table 11.27).

185. In the particular case of shellfish, given the lack of specific impact criteria, the assessment has been based on a review of literature on the current understanding of the potential effects of underwater noise on shellfish species.

Table 11.27 Hearing Categories of the Fish Receptors (? denotes uncertainty or lack of current knowledge with regards to the potential role of the swim bladder in hearing)

Category	Fish Receptors relevant to Norfolk Boreas
Fish with no swim bladder or other gas chamber	Sole Plaice Sandeels Lemon sole Mackerel Solenette Elasmobranchs River and sea lamprey Lesser weever Turbot and brill
Fish with swim bladder in which hearing does not involve the swim bladder or other gas volume	Atlantic salmon Sea trout Smelt (?) Seabass (?) Gurnards (?) Gobies
Fish in which hearing involves a swim bladder or other gas volume	Herring Sprat Cod Whiting European eel (?) Allis and Twaite shad

Mortality and recoverable injury

Fish with no swim bladder:

186. Under a fleeing animal scenario, there is potential for mortality/potential mortal injury and recoverable injury to occur in fish with no swim bladder at ranges up to 70m SPL_{peak} and <100m SEL_{cum} (Table 11.8 and Table 11.19). Taking the small areas potentially affected and the temporary, short term and intermittent nature of piling activity the magnitude of the impact is considered to be negligible. This would also be considered the case under a stationary animal model approach (mortality/potential mortal injury at ranges of up to 600m (219dB SELcum) and recoverable injury at ranges of 800m (216dB SELcum).

187. The majority of fish receptors included within the group "fish with no swim bladder" (Table 11.27) are mobile and would be expected to vacate the area in which the impact could occur with the onset of 'soft start' piling. They are therefore considered receptors of low sensitivity and the impact of mortality/recoverable injury is assessed to be of **negligible** significance (for both the fleeing animal and stationary animal scenarios).

188. An exception to this are sandeels, which given their burrowing behaviour and substrate dependence, may have limited capacity to flee the area compared to other fish species. They are therefore considered to be of medium sensitivity. This in combination with the negligible magnitude of the effect, results in an impact of **minor adverse** significance (for both the fleeing animal and stationary animal scenarios).

Fish with swim bladder not involved in hearing:

189. Under a fleeing animal scenario, there is potential for mortality/potential mortal injury and recoverable injury to occur on fish with swim bladders not involved in hearing at ranges up to 120m SPL_{peak} and <100m SELcum (Table 11.27). Taking the small areas potentially affected and the temporary, short term and intermittent nature of piling activity, the magnitude of the impact is considered to be negligible. Under a stationary animal model approach mortality/potential mortal injury would be expected at ranges up to a maximum of 1.6km (210dB SELcum) and recoverable injury at ranges of up to a maximum of 3.6km (203dB SELcum)). Based on these outputs the magnitude of the impact is considered to be low.

190. The majority of fish receptors included within the group "fish with swim bladders not involved in hearing" (Table 11.27) are mobile and would be expected to vacate the area in which the impact could occur with the onset of 'soft start' piling. As such, they are considered receptors of low sensitivity. Taking this into account together with the negligible (fleeing model)/low (stationary model) magnitude of effect, mortality and recoverable injury associated with piling noise would result in an impact of **negligible** (fleeing model)/**minor** (stationary model) significance.

191. Exceptions to this are gobies as they have limited mobility and therefore potentially a reduced capacity to escape the areas affected by the greatest noise levels. However, as gobies are abundant over wide areas of the North Sea any noise effects would impact only a small proportion of the population. Furthermore, given the relatively short life cycle of goby species (Teal et al*.,* 2009), the population would be expected to recover quickly if subject to localised lethal or injury impacts associated with piling. As such, they are considered to be receptors of medium sensitivity. This together with the negligible (fleeing model)/low (stationary model) magnitude of the effect, results in an impact of **minor adverse** significance (for both the fleeing animal and stationary animal scenarios).

Fish with swim bladder involved in hearing:

192. Under a fleeing animal scenario, there is potential for mortality/potential mortal injury and recoverable injury to occur on fish with swim bladders involved in hearing at ranges up to 170m SPLpeak and <100m SELcum (Table 11.22 and Table 11.23). Taking the small areas potentially affected and the temporary, short term and intermittent nature of piling activity, the magnitude of the impact is considered

to be negligible. Under a stationary animal model approach mortality/potential mortal injury at ranges would be up to a maximum of 2.2km (207dB SELcum) and recoverable injury at ranges up to a maximum of 3.6km (203dB SELcum). Based on these outputs the magnitude of the impact is considered to be low.

193. All the fish receptors included within the group "fish with swim bladders involved in hearing" (Table 11.27) are mobile and would be expected to vacate the area in which the impact could occur with the onset of 'soft start' piling. As such, they are considered receptors of low sensitivity. This, in combination with the negligible (fleeing model)/low (stationary model) magnitude of effect identified, results in an impact of **negligible** (fleeing model)/**minor** (stationary model) significance.

Eggs and larvae:

194. As shown in Table 11.14, the Popper et al. (2014) impact criteria for potential mortality/injury in eggs and larvae (>210 dB SELcum or >207 dB SPLpeak) is similar to that described for fish species with a swim bladder not involved in hearing (210 dB SELcum or >207 dB SPLpeak). Modelled impact ranges for this category have therefore been used to provide an indication of the potential impact on fish eggs and larvae. Under a fleeing animal scenario impact ranges would be up to 120m SPLpeak and <100m SELcum (Table 11.20 and Table 11.21).

195. Taking the small areas potentially affected and the temporary, short term and intermittent nature of piling activity the magnitude of the impact is considered to be negligible. Under a stationary animal model approach (mortality/potential mortal injury would be expected at ranges up to a maximum of 1.6km (210dB SELcum) the magnitude of the impact is considered to be low.

196. Eggs and larvae would not be able to flee the vicinity of the foundations during piling, however prolonged exposure could be reduced by any drift of eggs/larvae due to water currents which may reduce the risk of mortality.

197. The distribution of eggs and larvae of a given species extends over wide areas at a given time. Whilst eggs and larvae would not be able to flee the vicinity of piling, the probability and frequency of interaction with piling events is expected to be low. In this context, the small amount of egg/larval mortality associated with piling in relation to the natural mortality rates during these life stages should be noted. Taking the above into account, egg and larval stages are considered of medium sensitivity. This, in combination with the negligible (fleeing model)/low (stationary model) magnitude of effect identified, results in an impact of **minor adverse** significance (for both the fleeing and stationary models).

Shellfish:

198. There are no specific criteria currently published in respect of shellfish species, however studies on lobsters have shown no effect on mortality, appendage loss or the ability of animals to regain normal posture after exposure to very high sound levels (>220 dB) (Payne et al., 2007). Similarly, studies of marine bivalves (e.g. mussels *Mytilus edulis* and periwinkles *Littorina spp*.) exposed to a single airgun at a distance of 0.5m have shown no effects after exposure (Kosheleva, 1992).

199. The potential for piling noise to result in mortality/potential mortal injury or recoverable injury is therefore considered to be very low with the magnitude of the impact expected to be negligible. Given the relatively low mobility of shellfish species in comparison to most fish species, and therefore their reduced ability to avoid areas in the proximity of piling, they are however considered to be receptors of medium sensitivity. This, in combination with the negligible magnitude of the effect results in an impact of **minor adverse** significance.

TTS and behavioural impacts

200. The outputs of the noise modelling for the spatial worst case scenario indicate that under a fleeing animal model TTS may occur at distances of up to 6.5km for all the fish groups modelled (Table 11.18 to Table 11.23). Considering a stationary animal approach, distances at which TTS may occur would increase to up to 18km (Table 11.24 to Table 11.26). Behavioural responses would be anticipated within these ranges and potentially in wider areas depending on the hearing ability of the species under consideration.

201. As shown in Table 11.13, in terms of the temporal worst case scenario, the maximum duration of piling would be equivalent to 49 days (1,2167hours); although this would not be continuous.

202. Taking account of the spatial extent of the impact and the overall short duration of piling and its intermittent nature, together with the fact that any effect associated with TTS and behavioural impacts would be temporary, the magnitude of the impact is considered to be low. This would be the case considering the fleeing animal and the stationary animal scenario. The assessments presented in the following sections with regards to TTS/behavioural impacts are therefore applicable regardless of whether consideration is given to the outcomes of the stationary animal or the fleeing animal modelling.

203. Impacts associated with TTS could result in reduced fitness, whilst behavioural impacts could cause changes in distribution, such as moving from preferred sites for feeding and spawning, or alteration of migration patterns.

204. Impacts on feeding activity are unlikely to cause long term, larger scale effects on fish populations given the wider availability of suitable feeding grounds in the region. There is concern however that behavioural responses such as avoidance, could have an adverse impact on spawning behaviour and migration of certain species.

205. The assessment of the impact of TTS and behavioural impacts has been focused on key species, selected on the basis of the presence of known spawning and nursery grounds in the area of the project, conservation status, commercial value and specific concerns raised during consultation. On this basis, the following species have been taken forward for detailed assessment:

- Sole;
- Plaice;
- Lemon sole;
- Mackerel;
- Sandeels;
- Seabass
- Cod;
- Whiting;
- Sprat;
- Herring;
- Elasmobranchs; and
- Diadromous species.

<u>Sole, Plaice, Lemon sole and Mackerel:</u>

206. The offshore cable corridor and part of the project interconnector search area overlap with low intensity spawning and nursery grounds of sole and spawning/nursery grounds (intensity not defined) of lemon sole (Figure 11.2 and Figure 11.6). In the case of mackerel the Norfolk Boreas site, the project interconnector search area and the offshore section of the offshore cable corridor overlap with spawning grounds (intensity not defined) and the whole offshore project area with low intensity nursery grounds (Figure 11.8). In the case of plaice, the offshore section of the offshore cable corridor, project interconnector search area and Norfolk Boreas site overlap with the wide high intensity spawning grounds defined for this species in the North Sea and the inshore section of the export cable corridor overlaps with low intensity nursery grounds for the (Figure 11.3).

207. It should be noted, however, that the degree of overlap between the spawning/nursery grounds of these four species and the area impacted by TTS would be very small relative to the total spawning/nursery areas available to these species (see Figure 11.21, Figure 11.22, Figure 11.23 and 11.24). Furthermore,

these four species are pelagic spawners and therefore not dependent on discrete spawning grounds with particular substrate characteristics.

208. All four species lack a swim bladder and according to the criteria for behavioural impacts proposed in Popper et al. (2014) would be at high risk of behavioural impacts near the piling operation, at moderate risk at intermediate distances and at low risk when located far from the piling operation (Table 11.14).

209. Taking the wide distribution ranges of these species, including areas used as spawning/nursery grounds, in the context of the potential zones where TTS and behavioural impacts could occur, they are considered to be receptors of low sensitivity. In combination with the low magnitude of the effect this results in an impact of **minor adverse** significance.

Sandeel:

210. Monitoring of lesser sandeels *A. marinus* during seismic surveys has shown some behavioural reactions to source levels equivalent to 210dB at 1mPa with no increase in mortality or injurious effects. After the seismic shooting had ceased, normal behaviour resumed (Hassel et al*.,* 2004). The results of this study indicate that effects of such noise levels on sandeel are likely to be short term, localised and constrained to behavioural level effects, with no longer term effects likely.

211. The offshore project area overlaps with low intensity spawning and nursery grounds for sandeels (Figure 11.10) and the eastern section of the Norfolk Boreas site overlaps with a discrete, small area of sandeels grounds within Sandeel Assessment Unit 1r (Jensen et al., 2011; Figure 11.17). It should be noted, however, that the degree of overlap between sandeel spawning/nursery grounds and sandeel habitat impacted by TTS would be minimal relative to the total suitable habitat over which these species are distributed (Figure 11.25).

212. Sandeels lack a swim bladder and according to the criteria for behavioural impacts proposed in Popper et al. (2014) would be at high risk of behavioural impacts close to piling operations, at moderate risk at intermediate distances and at low risk when located far from the piling operation (Table 11.14).

213. Taking the above into account together with their seabed habitat specificity, sandeels are considered to be receptors of medium sensitivity. This, in combination with the low magnitude of effect results in an impact of **minor adverse** significance.

Sea bass:

214. Sea bass is a species commercially important to local fisheries and relatively abundant in the offshore project area, particularly in areas in the proximity of the export cable corridor. The species is currently subject to fisheries controls due to conservation concerns (Appendix 11.1).

215. Sea bass falls within the category of fish with a swim bladder which is not involved in hearing. Following Popper et al*.* (2014) criteria for behavioural impacts for this category (Table 11.14), seabass would be at high risk of behavioural impacts near the piling operation, at moderate risk at intermediate distances and at low risk when far from the piling activity.

216. A range of studies have been carried out on the potential behavioural impact of underwater noise on seabass with increases in motility and changes in swimming performance reported in response to impulsive sounds (Neo et al*.,* 2015). Changes in responsiveness to visual stimulus have also been reported in seabass exposed to playback piling noise (Everley et al*.,* 2015) and startle responses as a result of exposure to low frequency sounds (Kastelien et al*.,* 2008).

217. As mentioned above, however, sea bass is expected to be more commonly found in areas relevant to the offshore cable corridor than in the Norfolk Boreas site (where piling activity would take place). With the above considerations in mind and taking account of the relatively small areas where TTS and behavioural impacts may occur in the context of the wide distribution range of this species, a low sensitivity is assigned. This, in combination with the low magnitude of the effect results in an impact of **minor adverse** significance.

<u>Cod, whiting and sprat:</u>

218. The offshore project area overlaps with low intensity spawning/nursery grounds of cod and whiting and with spawning grounds (intensity not defined) of sprat (Figure 11.4, Figure 11.5 and Figure 11.9). In addition the eastern edge of the Norfolk Boreas site overlaps with sprat nursery grounds (Figure 11.9). It should be noted, however, that the degree of overlap between the spawning grounds of these three species and the area impacted by TTS would be very small relative to the total area that the species use for spawning/nursery (Figure 11.26, Figure 11.27 and Figure 11.28). Furthermore, these species are pelagic spawners and therefore are not dependent on discrete spawning grounds with particular substrate characteristics.

219. These three species have a swim bladder which is involved in hearing and according to the criteria for behavioural impacts proposed in Popper et al*.* (2014) would be at high risk of behavioural impacts near and at intermediate distances and at low risk when located far from the piling operation (Table 11.14). Taking the potential zones where TTS and behavioural impacts could occur, in the context of the wide distribution ranges of these species (including spawning/nursery areas), they are considered receptors of low sensitivity. This, in combination with the low magnitude of the effect, results in an impact of **minor adverse** significance.

Herring:

220. Blaxter and Hoss (1981) found startle responses in herring at received levels between 122–138dB re 1µPa and observed that the response depended on the size of the herring. A seismic study on adult herring involving sound exposure levels (SEL) ranging from 125 to 155 dB re 1 µPa2 (Peña et al., 2013) found that no changes were observed in swimming speed, swimming direction, or school size. The lack of a response to the seismic survey was interpreted as a combination of a strong motivation to spawn, and a progressively increased level of tolerance over time.

221. Herring generally adopt low-risk behavioural strategies (Fernö et al., 1998; Axelsen et al., 2000), but at times predator avoidance must be balanced with other activities that affect vigilance. During the feeding season, the reaction towards vessels has been found to be low compared with the wintering period (Misund, 1994) and the act of reproduction during the spawning season takes precedence over avoidance reactions that are evident at other times of the year (Nøttestad et al., 1996; Skaret et al., 2003). Mohr (1971) observed that gravid herring swimming close to the seabed showed no avoidance reactions to a moving trawl, consistent with high reaction thresholds during spawning.

222. Herring have a swim bladder which is involved in hearing and according to the criteria for behavioural impacts proposed in Popper et al. (2014) would be at high risk of behavioural impacts near and at intermediate distances from the piling operation and at moderate risk when located far from the piling operation (Table 11.14).

223. The offshore project area does not overlap with herring spawning grounds, however, it overlaps with low intensity nursery grounds defined for this species (Figure 11.7, Figure 11.18, Figure 11.19 and Figure 11.20).

224. Given the location of herring spawning grounds in respect of the Norfolk Boreas site, and the ranges at which TTS and behavioural impacts are expected from the project, the potential for spawning herring to be affected would be minimal (Figure 11.29). Similarly, in respect of nursery grounds, given the small areas where potential TTS and behavioural impacts could occur in the context of the wide distribution of the nursery grounds available to this species, the potential for juvenile herring to be significantly affected would also be minimal (Figure 11.19).

225. Considering the above but recognising the hearing ability of herring and its substrate specific spawning behaviour, herring is considered a receptor of medium sensitivity. This in combination with the low magnitude of effect, results in an impact of **minor adverse** significance.

Elasmobranchs:

226. Elasmobranchs are thought to be sensitive to the particle displacement component of sounds within the range of 20-1000 Hz (Casper and Mann, 2006; 2009), although laboratory studies have raised questions over sharks' capability of detecting sounds in the acoustic far field (Casper and Mann, 2006).

227. Elasmobranchs lack a swim bladder and according to the criteria for behavioural impacts proposed in Popper et al. (2014) would be at high risk of behavioural impacts near the piling operation, at moderate risk at intermediate distances and at low risk when located far from the piling operation (Table 11.14).

228. The potential areas affected by TTS and behavioural impacts are very small in the context of the wide distribution ranges of elasmobranch species, including those relating to spawning/nursery grounds for relevant species (namely thornback ray and tope) (Figure 11.30) and therefore any impacts associated with piling would be expected to be minimal.

229. Considering the above, elasmobranchs are considered to be receptors of low sensitivity. This in combination with the low magnitude of the effect results in an impact of **minor adverse** significance.

Diadromous species:

230. The diadromous species included in the assessment are river lamprey, sea lamprey, salmon, sea trout, allis shad and twaite shad, European eel and smelt (Table 11.10).

231. Potential ranges of behavioural impacts would depend on the hearing sensitivity of each species. As shown in Table 11.27, river and sea lamprey are species which lack a swim bladder; salmon, sea trout and smelt, species with a swim bladder that is not involved in hearing and European eel and allis and twaite shad species with a swim bladder that is involved in hearing. According to Popper et al. (2014) the risk of behavioural impacts on these species would be:

- For species with no swim bladder and species with swim bladder which is not involved in hearing: high near the piling operation, moderate at intermediate distances and low when located far from the piling operation; and
- For species with swim bladders involved in hearing: high near the piling operation and at intermediate distances and moderate when located far from the piling operation.

232. It should be noted, however, that diadromous species are only likely to be present occasionally in the area of the Norfolk Boreas site and therefore the potential for these species to be subject to piling noise would be very low. Furthermore, given the distance from the Norfolk Boreas site to the coast and therefore to rivers, there is no potential for piling noise to affect these species during critical periods of their

migration such as river entry and river exit. In light of the above, diadromous species are considered receptors of low sensitivity. This in combination with the low magnitude of the impact results in an impact of **minor adverse** significance.

Indirect impacts on fish species as a result of behavioural disturbance to prey species

233. Fish species such as sandeels and clupeids (herring and sprat) play an important role in the North Sea's food web as prey for birds, marine mammals and piscivorous fish. There may therefore be potential for changes in the behaviour of these prey species associated with piling noise to result in indirect impacts on the species that feed on them.

234. An assessment of the potential impact of changes in prey availability as a result of piling noise in respect of piscivorous fish is given below. Potential impacts on other receptors groups (namely marine mammals and birds) are assessed in Chapter 12 Marine Mammal Ecology and Chapter 13 Offshore Ornithology and are therefore not discussed here.

235. The outputs of the noise modelling for the spatial worst case scenario indicate that TTS may occur at distances of up to 6.5km (fleeing animal model) and 18km (stationary animal model) for all the fish groups modelled. Behavioural responses are anticipated to occur within this range and potentially in wider areas depending on the hearing ability of the species under consideration.

236. As shown in Table 11.13, under the temporal worst case scenario (maximum number of piles) the overall duration of piling would be equivalent to approximately 54 days (1,287 hours).

237. Taking account of the spatial extent of the impact and the overall short duration of piling and its intermittent nature together with the fact that any effect associated with TTS and behavioural impacts would be temporary, the magnitude of the impact is considered to be low.

238. Whilst it is recognised that changes in the distribution of key prey species to piscivorous fish may occur as a result of piling noise, as described in the assessment provided above in respect of TTS and behavioural impacts on herring, sandeels and sprat, significant impacts (i.e. above minor significance) have not been identified on any of these species. In addition, where avoidance or behavioural reactions take place, these would occur on both prey species and the fish species that feed on them. Taking this into account together with the wide distribution ranges of both, prey and piscivorous fish, the sensitivity is considered to be low. This, in combination with the low magnitude of the effect results in an impact of **minor adverse** significance.

11.7.4.3.6 Confidence in the assessment

239. The confidence in the data and information used in this assessment is medium with a precautionary approach based on maximum extent of impact and duration of piling associated with installation of each pile.

11.7.4.4 Impact 4: Underwater noise from other construction activities

240. An assessment of the potential impact on fish and shellfish receptors of underwater noise during construction, other than pile driving is given in the following section. Potential sources of underwater noise, aside from impact piling, that could be present during the construction phase of Norfolk Boreas are described in Table 11.28.

Table 11.28 Summary of possible noise generating activities during construction other than piling noise (Appendix 5.4)

Activity	Description
Dredging	Trailer suction hopper dredger may be required on site for the export cable, array cable and project interconnector/interconnector cable installation.
Drilling	Necessary in case if impact piling refusal
Cable laying	Required during the offshore cable installation.
Rock placement	Potentially required on site for installation of offshore cables and scour protection.
Trenching	Plough trenching may be required during offshore cable installation.
Vessel noise	Jack-up barges for piling, substructure and turbine installation. Other large and medium sized vessels on site to carry out other construction tasks, dive support and anchor handling.

241. In order to inform this assessment, consideration has been given to Popper et al. (2014) criteria for continuous noise sources. These are described in Table 11.29.

242. As shown, for the most part, Popper et al. (2014) criteria are qualitative being provided in terms of relative risk (high, moderate, low) to the animal at various distances from the source of noise (near (N), intermediate (I), and far (F)).

243. An exception to this is recoverable injury and TTS criteria for fish with swim bladders involved in hearing, for which specific quantitative thresholds are provided (Table 11.29). Therefore, for this, impact ranges have been modelled (Appendix 5.4). The outputs of the modelling are provided in Table 11.30 and show that for all construction activities under consideration recoverable injury and TTS would only have potential to occur in close proximity to the source of noise (<50m).

244. It should be noted that there is no direct evidence of mortality or potential mortal injury in fish as a result of continuous noise sources. As shown in Table 11.29,

Popper et al. (2014) criteria consider the risk of mortality/mortal injury associated with continuous noise sources to be low for all fish species groups regardless of distance from the source.

245. With respect of behavioural impacts, for the most part, these would also be expected to only occur near or at intermediate distances from the source of noise, with low risk of behavioural impacts at greater distances (Table 11.29).

Table 11.29 Popper et al.*(*2014) criteria for fish in respect of shipping and continuous sounds.

Category	Mortality/Mortal Injury	Recoverable injury	Temporary Threshold Shift (TTS)	Behavioural
Fish with no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
Fish with swim bladder not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
Fish with swim bladder involved in hearing	(N) Low (I) Low (F) Low	170 dB rms for 48 h	158 dB rms for 12 h	(N) High (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
(N) Near: within few tens of metres; (I) Intermediate: within hundreds of metres; and (F) Far: within thousands of metres.				

Table 11.30 Impact ranges for recoverable injury and TTS for construction activities other than piling.

Activity	Dredging	Drilling	Cable Laying	Rock Placement	Trenching	Vessels (Large)	Vessels (Small)
170 dB Unwtd RMS	<50m	<50m	<50m	<50m	<50m	<50m	<50m
158 dB Unwtd RMS	<50m	<50m	<50m	<50m	<50m	<50m	<50m

246. From the information provided above, it is apparent that some disturbance to fish and shellfish species associated with noise resulting from the construction activities outlined in Table 11.28 may occur. However, this would for the most part be limited to localised areas in the immediate proximity of construction works and/or construction vessels. Considering this and the temporary nature of construction phase (up to approximately 3 years), the magnitude of the impact is considered to be low.

247. Taking the comparatively wide distribution ranges of fish and shellfish species (including spawning and nursery grounds) in the context of the small areas potentially affected by construction noise from activities other than piling at a given time, the sensitivity of fish and shellfish is considered to be low.

248. With this in mind the resulting impact is considered to be of **minor adverse** significance.

249. In the context of this assessment it should be noted that the Norfolk Boreas site is located in the proximity of busy shipping lanes (Chapter 15 Shipping and Navigation). Fish and shellfish species would therefore be expected to have habituated to the presence of continuous noise sources to some extent.

11.7.4.4.1 Confidence in the assessment

250. The confidence in the data and information used in this assessment is medium to high.

11.7.4.5 Impact 5: Underwater noise from UXO clearance

251. Prior to construction, a detailed underwater unexploded ordnance (UXO) survey will be undertaken. Any UXO identified would preferably be avoided or removed from the seabed and disposed of onshore in a designated area. However, where it is considered unsafe to retrieve the UXO from the seafloor a controlled detonation may be required.

252. As detailed in Appendix 5.5, it is anticipated that a range of different types of UXO may be found in areas relevant to Norfolk Boreas. These are outlined in Table 11.31. The Net Explosive Quantity (NEQ) of explosive material in the device has been corrected, depending on the type of explosive material, to an equivalent quantity of TNT (Appendix 5.5).

Table 11.31 UXO devices potentially present in areas relevant to Norfolk Boreas (Source: Appendix 5.5)

UXO Item	NEQ	TNT eq.
German SC-50 bomb (amatol)	25 kg	25 kg
German SC-250 bomb (amatol)	145 kg	145 kg
250lb Allied bomb (Hexogen/TNT)	50 kg	60 kg
500lb Allied bomb (Hexogen/TNT)	126 kg	151 kg
1000lb Allied bomb (Hexogen/TNT)	260 kg	312 kg
500lb Allied mine (minol)	227 kg	340 kg
German LMB (GC) Ground Mine (Hexanite)	700 kg	770 kg

253. There are limited acoustic measurements for underwater explosions and there can be large differences in the noise levels, depending on the charge size, water depth, as well as bathymetry and seabed sediments at the site, which can influence noise propagation (von Benda-Beckmann et al., 2015).

254. In-water explosions produce a spherical shock wave that travels at speeds greater than the speed of sound in water. A large oscillating gas bubble is also produced that radiates sound (Popper et al., 2014).

255. Whilst it is well established that explosions can result in potential mortality or injury to fish species at close range, there is no data on the effects of explosions on fish hearing (e.g. TTS) or behaviour currently available. Existing information suggests that there may be temporary or partial loss of hearing at high sound levels, especially in fish where the swim bladder enhances sound pressure detection. In the case of behavioural impacts, it is considered that startle responses are likely to occur if the received signal is of sufficient magnitude. Such responses last less than a second and do not necessarily result in significant changes in subsequent behaviour (Popper et al., 2014).

256. In order to inform this assessment, estimated ranges of impact associated with UXO detonations for different charge weights have been modelled (Appendix 5.5) to provide an indication risk of mortality/potential injury to fish species. In consideration of explosives and potential mortality, all fish species groups are considered equivalent and there is no frequency weighting to account for variations in hearing sensitivity. Two thresholds are provided, 229 and 234 dB SPLpeak, which represent the range of potential impact. The ranges at which these noise levels could occur are provided in Table 11.32.

257. In the context of this assessment, it should be noted that the noise produced by the detonation of explosives is affected by a number of different elements, only one of which (the charge weight) can easily be factored into a calculation. Many other elements relating to its situation (e.g. its design, composition, age, position, orientation, whether it is covered by sediment) and exactly how they will affect the sound produced by detonation are unknown and cannot be directly considered in an assessment. This leads to a high degree of uncertainty in the estimation of the source noise level (i.e. the noise level at the position of the UXO). A worst case estimation has therefore been used for calculations, assuming that the UXO to be detonated is not buried, degraded or subject to any other significant attenuation. The consequence of this is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as they are likely to be covered by sediment and degraded (Appendix 5.5).

Table 11.32 Calculated mortal and potential injury impact ranges (m) for any fish species (Source: Appendix 5.5)

Popper et al. (2014) Unweighted SPLpeak	Charge Weight (kg) 25 kg	60 kg	145 kg	151 kg	312 kg	340 kg	770 kg
234 dB (Potential mortal injury)	170 m	230 m	310 m	320 m	410 m	420 m	550 m
229 dB (Potential mortal injury)	290 m	390 m	530 m	530 m	680 m	700 m	920 m

258. The risk of recoverable injury (including PTS), TTS and behavioural impacts are presented qualitatively in line with Popper et al. (2014) approach Table 11.33. It should be noted that the risks outlined in Table 11.33 are based on small charges, such as those used to dismantle in-water structures. A greater risk should therefore be assumed for larger charges (Appendix 5.5).

Table 11.33 Qualitative risk of recoverable injury, TTS and behavioural impact for fish species groups (Popper et al., 2014)

Fish species group	Recoverable Injury	TTS	Behaviour
Fish (no swim bladder)	(N) High (I) Low (F) Low	(N) High (I) Moderate (L) Low	(N) High (I) Moderate (F) Low
Fish (swim bladder not involved in hearing)	(N) High (I) High (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) High (F) Low
Fish (swim bladder involved in hearing)	(N) High (I) High (F) Low	(N) High (I) High (F) Low	(N) High (I) High (F) Low
Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F). (N), (I) and (F) are equivalent to tens, hundreds and thousands of metres respectively.			

259. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F). (N), (I) and (F) are equivalent to tens, hundreds and thousands of metres respectively.

260. As is apparent from the above, where the detonation of UXO within the offshore project area is required, this may result in injury and disturbance to fish species in the vicinity of the detonation. Physical injury / trauma would occur in close proximity to the detonation, with TTS and behavioural effects occurring at greater distance. Given the short and intermittent nature of this activity (limited to instances when detonation of UXO is required) and the fact that for the most part

any effects would be limited to the vicinity of the area where the detonation takes place, the magnitude of the effect is considered to be low.

261. Taking account of the severity of the impact particularly at close range, but acknowledging that impacts would occur at individual rather than at population levels, fish species are considered receptors of medium sensitivity.

262. This, in combination with the low magnitude of the effect results in an impact of **minor adverse** significance.

11.7.4.5.1 Confidence in the assessment

263. The confidence in the data and information used in this assessment is medium.

11.7.5 Potential Impacts during Operation

264. The potential impacts of the project on fish and shellfish receptors during the operational phase are described below, including:

- Impact 6: Permanent loss of habitat;
- Impact 7: Introduction of hard substrate;
- Impact 8: Operational noise;
- Impact 9: Electromagnetic Fields (EMFs); and
- Impact 10: Changes in fishing activity.

265. The assessment has been carried out taking account of the worst case parameters outlined in Table 11.13.

266. Where relevant the magnitude of the impact is described separately for the Norfolk Boreas site, the offshore cable corridor and the project interconnector search area as well as for the project as a whole. Note that the assessment of significance provided is always based on the magnitude of impact defined for the project as a whole.

11.7.5.1 Impact 6: Permanent loss of habitat

267. The worst case scenario in terms of permanent loss of habitat during the operational phase is presented in Table 11.13. This would be primarily a result of the introduction of foundations associated with turbines, offshore electrical platforms, the service platform, met masts and LIDARs and any required scour around these structures, as well as protection measures introduced for the array, interconnector/project interconnector and export cables.

268. In the Norfolk Boreas site the worst case total area of habitat loss has been estimated to be 6.2km^2 (Table 11.11). Note that this would account for a very small proportion of the area of Norfolk Boreas site (0.8%).

269. Similarly, in the case of the export cable corridor and the project interconnector search area, seabed loss would be very small (0.13km^2 and 0.061km^2, respectively), being limited to areas where cable protection measures may be required (Table 11.13).

270. Loss of habitat would be permanent throughout the expected design life of approximately 30 years. However, given the relatively small area of seabed potentially lost in the Norfolk Boreas site and the fact that this area would be scattered in smaller sections across the site (i.e. being limited to localised individual areas where project infrastructure is located) the effect is considered to be of low magnitude. In the particular case of the offshore cable corridor and project interconnector search area, given the comparatively smaller footprint of the habitat loss the magnitude of the impact is considered to be negligible. Considering the project as a whole, the magnitude of the impact would be low.

271. The fish and shellfish species likely present in areas relevant to the project use comparatively large areas for spawning, as nursery grounds and for foraging, and for the most have wide distribution ranges; all of which may be spatially and temporally variable. Further, as indicated in Chapter 10 Benthic and Intertidal Ecology, significant impacts on the benthos associated with permanent loss of habitat are not expected (impacts assessed as of minor adverse significance in Chapter 10 Benthic and Intertidal Ecology). Therefore, in general terms, impacts as a result of habitat loss are expected to be minimal and fish and shellfish species are considered receptors of low sensitivity. In combination with the low magnitude of effect assessed for the project, the impact of permanent loss of habitat is considered to be of **minor adverse** significance.

272. It is recognised, however that species which are highly dependent on the presence of specific seabed substrates during sensitive periods of their life cycle such as sandeels and herring may have increased susceptibility to the potential impact of habitat loss. Impacts on these species are therefore assessed separately below.

11.7.5.1.1 Sandeels

273. Sandeels are dependent on the presence of an adequate sandy substrate in which to burrow, have a high level of site fidelity and little ability as re-colonisers (Jensen et al., 2011). Furthermore, they are demersal spawners which lay their eggs on the seabed. Therefore, there could be potential for the permanent loss of seabed habitat associated with the project to result in a loss of habitat to sandeels, including a loss of spawning habitat.

274. It should be noted, however, that studies of fish populations in operational wind farms (i.e. Stenberg et al., 2011; Stenberg et al., 2015) have not detected significant

changes to sandeel populations. It has been suggested (Stenberg et al., 2015) that the direct loss of habitat associated with offshore wind farm infrastructure and indirect effects (i.e. changes to sediment) are too low to influence that abundance of sand-dwelling species such as sandeels. Furthermore, as described previously for assessment of impacts in respect of temporary disturbance/loss of habitat during construction (paragraph 114), sandeels are expected to be present in the offshore project area. However, evidence from IBTS surveys, the location of sandeel high intensity spawning grounds and the distribution of sandeel fishing activity and sandeel grounds (Figure 11.10 and Figure 11.12 to Figure 11.17), all suggest that the offshore project area is of comparatively low importance to this species in the context of the Sandeel Assessment Area 1r.

275. In light of the above information, sandeels are considered receptors of medium sensitivity.

276. Taking the low magnitude of the impact assessed for the project and the medium sensitivity of the receptor, the impact of permanent loss of seabed is assessed to be of **minor adverse** significance.

11.7.5.1.2 Herring

277. Herring are demersal spawners requiring the presence of a coarse substrate on which to deposit their eggs. Therefore, there could be potential for the loss of seabed habitat associated with the project to result in a loss of spawning grounds to this species.

278. It should be noted, however, that whilst this species is likely to be found in the study area at certain times (i.e. as suggested by landings data, section 11.6.3 and from IBTS data, Figure 11.18), there is no evidence to suggest that herring use areas within the offshore project area for spawning. As indicated by the distribution of spawning grounds described in Coull et al. (1998) (Figure 11.7), the closest known discrete spawning area of herring is located to the south of the inshore section of the offshore cable corridor close to shore and the closest large-scale spawning ground (Downs herring) to the south of the project towards the English Channel. Records from the IHLS also suggest that herring spawning does not occur within or in the immediate proximity of the offshore project area (Figure 11.18 to Figure 11.20). Herring is therefore considered a receptor of low sensitivity.

279. Taking the low magnitude of the effect assessed for the project and low sensitivity of the receptor the impact of permanent loss of habitat is assessed to be of **minor adverse** significance.

11.7.5.1.3 Confidence in the assessment

280. The confidence in the data and information used in this assessment is medium to high.

11.7.5.2 Impact 7: Introduction of hard substrate

281. The introduction of subsurface infrastructure associated with the project has the potential to alter the structure of benthic habitats and associated faunal assemblages. All project infrastructure that has a subsea surface element would represent a potential substrate for colonisation by marine fauna and flora, including non-native species (see Chapter 10 Benthic and Intertidal Ecology).

282. The seabed across the offshore cable corridor, the Norfolk Boreas site and the project interconnector search area is relatively homogeneous, being characterised predominantly by medium sand (Chapter 8 Marine Geology, Oceanography and Physical Processes). The introduction of hard substrate associated with the project would therefore increase habitat heterogeneity through the introduction of hard structures in an area predominantly characterised by soft substrate habitat.

283. Hard substrates introduced as part of the project would include turbines, foundations and associated scour protection as well as cable protection. In light of the 3-dimensional nature of much of these structures, the total volume of hard substrate to be introduced is not easy to predict. However, the area of introduced substrate would be proportional to the permanent loss of area estimated for the project (see section 11.7.5.1).

284. The hard substrate associated with the installation of Norfolk Boreas would occupy discrete areas only (i.e. around foundations) and would not be continuous along large lengths of offshore cables. Taking this into account and the relatively small overall area occupied by the infrastructure associated with the project, the magnitude of the effect is considered to be low in respect of the Norfolk Boreas site (where the majority of hard substrate will be introduced). In the case of the offshore cable corridor and the project interconnector search area, given the small areas where cable protection is anticipated to be used the magnitude of the impact is considered negligible, with the magnitude of the project as a whole assessed as low.

285. The potential for marine subsea structures, whether man-made or natural, to attract and concentrate fish is well documented (Sayer et al*.,* 2005; Bohnsack, 1989; Bohnsack and Sutherland, 1985; Jørgensen et al., 2002). As such, the expected increase in diversity and productivity of seabed communities may have an impact on fish, resulting in either attraction, increased productivity or changes in species composition (Hoffman et al*.,* 2000).

286. Stenberg et al. (2015) studied the long term effects of the Horns Rev 1 offshore wind farm on fish abundance, diversity and spatial distribution seven years after the wind farm was constructed. Overall fish abundance was found to increase slightly inside the offshore wind farm and declined in the control area (6km away). However, none of the key fish species or functional fish groups showed signs of negative long-term effects due to the presence of the wind farm. Overall, Stenberg et al. (2015) results indicate that the placement of the turbines gave the area a more diverse and complex habitat such that some fish species benefited for it. It was also found that the impacted area was not large enough to have adverse negative effects on species inhabiting the original sand bottom between turbines (i.e. dab and sandeels).

287. Similarly, a review of the short term ecological effects of the offshore wind farm Egmond aan Zee (OWEZ) in the Netherlands, based on two year post construction monitoring (Lindeboom et al*.,* 2011) found minor effects upon fish assemblages, especially near the monopiles. It was suggested that species such as cod may find shelter within the wind farm. A similar study conducted in the Belgian part of the North Sea (Bligh Bank wind farm; 55 monopile foundations) found that there was a decrease in overall demersal fish densities within the wind farm compared to control sites. However, for a number of commercially important species (turbot, sole and plaice), higher densities/increases in length distribution were observed (Vandendriessche et al*.,* 2012). It was not possible to determine whether this was attributable to a refuge effect (commercial fishing is excluded from Belgian wind farms), changes in epibenthic fauna (e.g. prey), substrate composition, or any combination of these variables.

288. Monitoring studies carried out at the Lillgrund wind farm in Sweden on the abundance and distribution patterns of benthic fish communities (Bergström et al*.,* 2013) found no large-scale effects on fish diversity and abundance after establishment of the wind farm when compared to the development in two reference areas. Changes in some species and in community composition were observed over time but occurred in parallel in at least one reference area, indicating that fish communities in the wind farm area were mainly driven by the same environmental factors as those in surrounding areas. Changes at smaller spatial scales were noted, particularly an increase in all studied piscivores (cod, eel, shorthorn sculpin), as well as the reef-associated goldsinny wrasse, which were all observed close to the foundations in the first years of operation.

289. Similarly, the results of pre-construction and post-construction monitoring surveys in North Hoyle and Barrow offshore wind farms in the UK suggest the abundance of commercial fish species has remained broadly comparable and in line with long term trends in the regional area (Cefas, 2010).

290. Crustaceans would be expected to exhibit the greatest affinity to scour protection material and foundation bases through the expansion of their natural habitats (Linley et al., 2007). There may be therefore potential for increases of benthic species including crabs and lobsters as a result of colonisation of subsurface structures by subtidal sessile species on which they feed (Linley et al., 2007). Post construction monitoring surveys at the Horns Rev 1 offshore wind farm noted that the hard substrates were used as a hatchery or nursery ground for several species, and was particularly successful for edible crab. They concluded that larvae and juveniles rapidly invade the hard substrates from the breeding areas (BioConsult, 2006).

291. As suggested by the results of the post construction monitoring surveys cited above, any changes in the community structure and abundance of fish and shellfish species within the project would be expected to be small and for the most limited to the immediate vicinity of the hard substrate introduced. As noted in Chapter 10 Benthic and Intertidal Ecology, there is likely to be only a small interaction between the remaining available seabed and the introduced hard substrate and any interactions would be highly localised (impact of introduction of hard substrate on benthic communities assessed as of minor adverse significance in Chapter 10 Benthic and Intertidal Ecology).

292. In light of the above, the sensitivity of fish and shellfish receptors is considered to be low. Taking the low magnitude of the effect assessed for the project and the low sensitivity of the receptors, the impact is considered to be of **minor adverse** significance.

293. The confidence in the data and information used in this assessment is medium to high.

11.7.5.3 Impact 8: Underwater noise during operation

294. As outlined in Appendix 5.4, the main source of underwater noise from operational turbines is the mechanically generated vibration from the turbines, which is transmitted into the sea through the structure of the support pile and foundations. In addition, during operation, underwater noise will be generated as a result of the presence of O&M vessels. This could result in an increase in underwater noise in respect of background levels.

295. Noise from the operation of wind turbines would be present for the design life of the project (expected to be approximately 30 years) and would contribute to the ambient noise in the region. It should be noted, however, that noise measurements made at operational wind farms, indicate that operational noise is at such low level that is it is difficult to measure it relative to background noise (Appendix 5.4).

296. In respect of noise associated with O&M vessels servicing the project, it should be noted that a maximum of 440 vessel round trips are expected to occur each year (average of 1-2/day) during the operational phase. This would be very small in the context of the current levels of vessel traffic in the area (Chapter 15 Shipping and Navigation).

297. As described in Appendix 5.4, in line with the modelling carried out in respect of construction activities, other than piling (see section 11.7.4.4), impact ranges associated with operational noise from turbines and O&M vessels would be very small (i.e. < 50m in respect of fish for recoverable injury/PTS).

298. Taking the small increase above background noise levels expected during operation and the localised nature of the potential impact, the magnitude of the effect is considered to be low.

299. As described above for assessment of introduction of hard substrate (section 11.7.5.2), monitoring at operational wind farms has not identified significant impacts on fish and shellfish communities. Considering this and the small areas potentially affected by operational noise in the context of the distribution ranges of fish and shellfish species, their sensitivity to operational noise is assessed as low.

300. This, combined with the low magnitude of the effect, results in and impact of **minor adverse** significance.

301. The confidence in the data and information used in this assessment is medium to high.

11.7.5.4 Impact 9: Electromagnetic Fields (EMFs)

302. During operation, electromagnetic fields (EMFs) produced by offshore cables may have potential to result in detrimental impacts on sensitive fish and shellfish species. Three-core AC cables transmit three current flows that fluctuate between positive and negative polarity. Therefore, the magnetic fields (B) that these cables generate are constantly changing. As a result, the motion of these B fields through the surrounding seawater continuously induces varying electric fields (iE). In the case of DC cables, the B field is static and therefore varying iE fields are not induced in the same way as AC cables. However, localised, static iE fields may be induced as seawater (tidal flow) or other conductors such as marine organisms pass through the HVDC cable’s B field (CMACS, 2012). Therefore both B and iE fields would be generated by the AC and DC offshore cables proposed for the project.

303. In addition, it should be noted that recent in-situ measurements of EMFs from HVDC cables have unexpectedly found that HVDC cables may also have an AC component to the EMF (AC B and iE fields) (Hutchison et al, 2018).

304. As stated in section 11.7.1, offshore cables (AC and DC) would be buried where possible to a minimum depth of 1m. Where substrate conditions prevent burial, and at cable or pipeline crossings, cable protection would be deployed. For the purposes of the worst case scenario in respect of EMFs, as outlined in Table 11.13, consideration has been given to the maximum length of offshore cables (array, export and interconnector /project interconnector cables) and potential maximum voltage.

305. Normandeau et al. (2011) modelled expected B fields using design characteristics taken from a range of undersea cable projects. For eight of the ten AC cables modelled it was found that the intensity of the magnetic field (B) was a function of voltage (ranging from 33kV to 345kV) although separation between the cables and burial depth also influenced field strengths. Similarly, the modelling carried out for nine DC cables also found that the B field was a function of voltage (ranging from 75 to 500kV) and cable configuration. For both AC and DC cables, the predicted B fields were strongest directly over the cables and decreased rapidly with vertical and horizontal distance from the cables (Table 11.34 and Table 11.35). Given the dependence of the iE field magnitude upon the B field magnitude, iE fields would also attenuate both horizontally and vertically with distance from the cables (CMACS, 2012).

306. The areas affected by EMFs generated by the project are therefore expected to be small, being limited to the area of the Norfolk Boreas site, the offshore cable corridor and project interconnector search area, and restricted to the immediate vicinity of the cables (i.e. within metres). In addition, EMFs are expected to attenuate rapidly in both horizontal and vertical plains with distance from the source. The magnitude of the effect is therefore considered to be low. This is considered to be the case in respect of the Norfolk Boreas site, the project interconnector search area, the offshore cable corridor and for the project as a whole.

Table 11.34 Averaged magnetic field strength values from AC cables buried 1m (Normandeau et al., 2011)

Distance (m) above seabed	Magnetic Fields Strength (μT) Horizontal distance (m) from cable		
	0m	4m	10m
0	7.85	1.47	0.22
5	0.35	0.29	0.14
10	0.13	0.12	0.08

Table 11.35 Averaged magnetic field strength values from DC cables buried 1m (Normandeau et al., 2011)

Distance (m) above seabed	Magnetic Fields Strength (µT) Horizontal distance (m) from cable		
	0m	4m	10m
0	78.27	5.97	1.02
5	2.73	1.92	0.75
10	0.83	0.74	0.46

307. With regards to receptor sensitivity, a number of organisms in the marine environment are known either to be sensitive to electromagnetic fields or have the potential to detect them (Gill and Taylor, 2001; Gill et al., 2005). These organisms can be categorised into two groups based on their mode of magnetic field detection, which may be induced electric field detection or direct magnetic field detection.

308. The first group are those species that are electro-receptive, the majority of which are elasmobranchs (sharks, skates and rays), although it also includes holocephalans (chimaeras, e.g. ratfish) and agnathans (i.e. lampreys). These can detect the presence of a magnetic field either indirectly by detection of the electrical field induced by the movement of water through a magnetic field or directly by their own movement through that field. The magnetic field could be the Earth's geomagnetic field or a magnetic field produced by a power cable. In natural scenarios, induction of the electric field usually results from organisms positioning themselves in tidal currents and animals may time activities such as foraging or migration by detecting diurnal cues resulting from varying tidal flows.

309. The second group are believed to use magnetic particles (magnetite) within their own tissues in magnetic field detection (Kirshvink, 1997). Whilst the exact mechanism is still not understood, it is generally believed that they are able to detect magnetic cues such as the Earth's geomagnetic field to orientate during migration.

310. With reference to the offshore project area is located, relevant groups are teleosts (bony fish, i.e. salmon and eel), crustaceans (lobsters, crabs, prawns and shrimps) and molluscs (snails, bivalves and cephalopods).

11.7.5.4.1 Elasmobranchs

311. Elasmobranchs are the species group considered to be the most electro sensitive. These species naturally detect bioelectric emissions from prey, conspecifics and potential predators and competitors (Gill et al., 2005). They are also known to detect magnetic fields.

312. A number of laboratory and field experiments have been carried out with elasmobranchs using cables of the type used by the offshore renewable energy industry. These suggest that that the EMFs emitted are within the range of detection by electro sensitive species such as rays and dogfish (Gill and Taylor, 2001; Gill et al., 2005; Gill et al., 2009; CMACS, 2003; COWRIE, 2009). Whilst the majority of these studies have been undertaken using AC cables, their findings are also of relevance in respect of DC cables.

313. It has been hypothesised that elasmobranchs may be confused by anthropogenic electric field sources that lie within similar ranges to natural bioelectric fields. Laboratory behavioural studies have demonstrated both AC and DC artificial electric fields stimulating feeding responses in elasmobranchs (Kalmijn 1982; Tricas & Sisneros, 2004; Kimber et al*.,* 2011). Studies with lesser spotted dogfish suggest that despite the ability to distinguish certain artificial E fields (strong versus weak; DC versus AC), sharks seemed either unable to distinguish, or showed no preference between, anthropogenic (dipole) and natural (live crab) DC E fields of similar strengths (Kimber et al*.,* 2011). Later experiments (Kimber et al., 2014), however, indicate that lesser spotted dogfish are able to learn that artificial electrical fields are not associated with food.

314. Research by Gill et al. (2009) provided the first evidence of electrically sensitive fish response to AC EMF emissions from sub-sea, electricity cables of the type used by the offshore renewable energy industry. This research found lesser spotted dogfish were more likely to be found within the zone of EMF emissions, and some thornback rays showed increased movement around the cable when the cable was switched on. Responses were unpredictable however, did not always occur, and appeared to be species dependent and individual specific.

315. Similarly, recent research carried out on the impact of HVDC cables on the little skate *Leucoraja erinacea* has found evidence of behavioural responses in elasmobranchs in the proximity of the cables (Hutchison et al., 2018). The responses identified in Hutchison et al. (2018) study included changes to the movement and distribution. These were interpreted as attraction responses, which are consistent with benthic elasmobranchs foraging behaviour. It was noted that the larger distances travelled and increased number of large turns observed, could represent an increased energetic expense. This may be of particular relevance if the EMFs emitted are not consistent spatially or temporally across a cable, as it may be more difficult for elasmobranchs to learn if an EMF represents food or not.

316. Information gathered as part of the monitoring programme at Burbo Bank offshore wind farm suggested that certain elasmobranch species feed inside the wind farm and demonstrated that they are not excluded during periods of low power generation (Cefas, 2009). Monitoring at Kentish Flats found an increase in

thornback rays, smoothhounds and other elasmobranchs during post-construction surveys in comparison to surveys before construction. There appeared to be no discernible difference however, between the data for the wind farm and reference areas in terms of changes to population structure and it was concluded that the population increase observed was unlikely to be related to the operation of the wind farm (Cefas 2009).

317. In line with the above, the following was stated in respect of EMF effects in the review of environmental data associated with post-consent monitoring of licence conditions of offshore wind farms published in 2014 (MMO, 2014):

318. "From the results of post-consent monitoring conducted to date, there is no evidence to suggest that EMFs pose a significant threat to elasmobranchs at the site or population level, and little uncertainty remains. Targeted research using high tech equipment and experimental precision has been unable to ascertain information beyond that of fish being able to detect EMFs and at what levels they become attracted or abhorrent to them. EMFs emitted from standard industry cables for offshore wind farms are unlikely to be repellent to elasmobranchs beyond a few metres from the cable if buried to sufficient depth. It is likely that the subtler effects of EMF, including attraction of elasmobranchs, inquisitiveness and feeding response to low level EMFs, may occur. The Burbo Bank offshore wind farm post-consent monitoring undertook EMF specific surveys including stomach analysis of common elasmobranch species. Fish caught at the cable site (and hence subject to EMFs) were well fed. No deleterious effects were recorded to fish populations, at least when this effect occurs in association with the probable increased feeding opportunities reported as a result of increased habitat heterogeneity".

319. Taking the above into account, it is considered that EMF-related effects could potentially, result in temporary, short term behavioural reactions rather than cause a barrier to migration or result in long term impacts upon feeding or confusion in elasmobranch species. However, recognising the potential for increasing energetic costs and acknowledging the likely presence of elasmobranch species in the Norfolk Boreas site, project interconnector search area and along the offshore cable corridor, elasmobranchs are considered receptors of medium sensitivity. In combination with the low magnitude of the effect assessed for the project the impact of EMFs on elasmobranch species is considered to be of **minor adverse** significance.

11.7.5.4.2 Lamprey

320. Lampreys, like elasmobranchs, possess electroreceptors that are sensitive to weak, low-frequency electric fields (Bodznick and Northcutt, 1981; Bodznick and Preston,

1983). Whilst responses to electric fields have been reported in these species, information on the use that they make of the electric sense is limited. It is likely however, that they use it in a similar way as elasmobranchs to detect prey, predators or conspecifics and potentially for orientation or navigation (Normadeau et al*.,* 2011). Spawning of lampreys occurs in rivers. Therefore, lampreys are only expected to be sporadically present in the vicinity of the project during the marine migration phase, primarily in areas relevant to the offshore cable corridor, and their sensitivity to EMFs is considered to be low. This combined with the low magnitude of effect assessed for the project results in an impact of **minor adverse** significance.

11.7.5.4.3 Salmon and sea trout

321. Any potential impacts on movement and behaviour in salmonids would be closely linked to the proximity of the fish to the EMF source. Gill and Bartlett (2010) suggest that any impact associated with EMFs on the migration of salmon and sea trout would be dependent on the depth of water and the proximity of home rivers to development sites. During the later stages of marine migration, salmon and sea trout rely on their olfactory system to find and identify their natal river. During these stages, they are likely to be migrating in the mid to upper layers of the water column.

322. As indicated in Table 11.10, there are no salmon rivers in the vicinity of the offshore project area and the potential interaction of salmon with the project would only be expected to occur on an occasional basis during marine migration/feeding. In the case of sea trout, there may be increased potential for the species to transit the offshore project area, particularly areas relevant to export cable corridor, as sea trout are known to feed off the Norfolk coast.

323. It should be noted, however, that Swedpower (2003) found no measurable impact when subjecting salmon and sea trout to magnetic fields twice the magnitude of the geomagnetic field. Similarly, in a recent study conducted by Marine Scotland Science (Armstrong et al*.,* 2016) where the effects on the behaviour of captive Atlantic salmon of mains frequency (50Hz) magnetic fields were studied, no evidence of unusual behaviour was found associated with magnetic fields up to 95µT. Further, Atlantic salmon migration in and out of the Baltic Sea over a number of operational subsea HVDC cables has been observed to continue apparently unaffected by the EMFs produced by the cables (Walker, 2001). Similarly, research carried out in San Francisco Bay in respect of the impact of a 200kV HVDC cable on the migration of Chinook salmon *Oncorhynchus tshawytscha*, indicate that they may be attracted to the cable after activation, however, they do not appear to be impeded from successfully migrating through the Bay (BOEM, 2016).

324. Taking the above into account, Atlantic salmon and sea trout are considered receptors of low sensitivity. This together with the low magnitude of the impact assessed for the project results in an impact of **minor adverse** significance.

11.7.5.4.4 European eel

325. As described in Table 11.10, European eel may transit the offshore project area during marine migration.

326. Various studies have been carried out in relation to the migration of eels and the potential effect of EMFs derived from offshore wind farm cables. Experiments undertaken at the operational wind farm of Nysted detected barrier effects, however correlation analysis between catch data and data on power production showed no indication that the observed effects were attributable to EMFs. Furthermore, mark and recapture experiments showed that eels did cross the offshore export cable (Hvidt et al., 2005). Similarly, a recent study carried out by Marine Scotland Science (Orpwood et al*.,* 2015) where European eels were exposed to an AC magnetic field of 9.6µT found no evidence of a difference in movement, nor observations of startle or other obvious behavioural changes associated with the magnetic fields.

327. Taking the above into account, European eel is considered a receptor of low sensitivity. This, in combination with the low magnitude of effect assessed for the project would result in an impact of **minor adverse** significance.

11.7.5.4.5 Other fish species

328. Further to the fish species mentioned above, there is some evidence of a response to EMFs in other fish species, such as cod and plaice (Gill et al*.,* 2005).

329. As suggested in the assessments of operational noise and introduction of hard substrate sections (section 11.7.5.2 and 11.7.5.3), the results of monitoring programmes carried out in operational wind farms to date do not suggest that significant changes in the fish assemblage have occurred during the operational phase. It has been suggested that the presence of the foundations and scour protection and potential changes in the fisheries related to offshore wind farm development would have the most impact upon fish species (Lindeboom et al*.,* 2011) and that noise from the wind turbines and EMFs from cabling do not seem to have a major impact on fish and other mobile organisms attracted to the hard bottom substrates for foraging, shelter and protection (Leonhard and Pedersen, 2006). In line with this, research carried out at the Nysted offshore wind farm in Denmark that focused on detecting and assessing possible impacts of EMFs on fish during power transmission (Hvidt et al*.,* 2005) found no differences in the fish community composition after the wind farm became operational. In light of the

above, other fish species for which there is some evidence of a response to EMFs are considered receptors of low sensitivity. This in combination with the low magnitude of effect assessed for the project results in an impact of **minor adverse** significance

11.7.5.4.6 Shellfish

330. Research on the ability of marine invertebrates to detect EMF has been limited to date. Although there is no direct evidence of effects to invertebrates from undersea cable EMFs (Normandeau et al., 2011), the ability to detect magnetic fields has been studied for some species and there is evidence in some of a response to magnetic fields, including molluscs and crustaceans. The role of the magnetic sense in invertebrates has been hypothesised to function in relation to orientation, navigation and homing, using geomagnetic cues (Cain et al., 2005). Research undertaken on the Caribbean spiny lobster *Panulirus argus* (Boles and Lohmann, 2003) suggests that this species derives positional information from the Earth's magnetic field that is used during long distance migration.

331. However, it is uncertain if other crustaceans including commercially important brown crab and European lobster are able to respond to magnetic fields in this way. Limited research undertaken with the European lobster found no neurological response to magnetic field strengths considerably higher than those expected directly over an average buried power cable (Normandeau et al., 2011; Ueno et al., 1986). Hutchinson et al. (2018) studied the potential impact of a HVDC cable on American lobster *Homarus americanus* and reported subtle changes in behavioural activity when they were exposed to the cable's EMFs. The results however indicate that the cable did not represent a barrier to migration.

332. Indirect evidence from post construction monitoring programmes undertaken in operational wind farms also does not suggest that crustaceans or molluscs have been affected by the presence of submarine power cables.

333. Based on the research available, the sensitivity of shellfish species to EMFs is considered to be low. Taking the low magnitude of the effect assessed for the project and the receptor sensitivity the impact is considered to be of **minor adverse** significance.

11.7.5.4.7 Confidence in the assessment

334. The confidence in the data and information used in this assessment is medium.

11.7.5.5 Impact 10: Changes in Fishing Activity

335. The presence of infrastructure associated with the project during the operation phase could result in changes to fishing activity within the Norfolk Boreas site but

also in the wider area (i.e. due to displacement of fishing activity into other areas). This could in turn result in changes in the status of commercially targeted fish stocks.

336. The principal species targeted in the Norfolk Boreas site are plaice and sole. Both species are targeted across wide areas in the Southern North Sea, with the Norfolk Boreas site accounting for a small area in the context of the overall fishing grounds for these species (see Chapter 14 Commercial Fisheries). Whilst the long term nature of the operational phase is recognised, considering the above the magnitude of the effect is assessed as low.

337. Fishing activity for these species is primarily regulated through the setting of annual total allowable catches (TACs) and limitation in fishing effort. It is therefore anticipated that the level of fishing for these species would be largely unaffected by changes in activity associated with the project, as fishing will continue until TACs or set limitations in effort are reached (i.e. through vessels fishing in the wider grounds available in the Southern North Sea).

338. Furthermore, as described in Chapter 14 Commercial Fisheries, significant impacts (i.e. exceeding minor significance) in respect of loss of fishing grounds and associated potential for displacement have not been identified for any of the fleets active in areas relevant to the project. Therefore, the sensitivity of commercially targeted fish stocks in respect of potential changes in fishing activity as a result of the project is considered to be low.

339. Taking the low receptor sensitivity and magnitude of the effect the resulting impact arising from changes in fishing activity is considered of **minor adverse** significance.

340. The confidence in the data and information used in this assessment is medium to high.

11.7.6 Potential Impacts during Decommissioning

341. The scope of the decommissioning works would most likely involve removal of the accessible installed components. This is outlined in Chapter 5 Project Description and the detail will be agreed with the relevant authorities at the time of decommissioning and be subject to separate licencing based on best available information at that time. Offshore, this is likely to include removal of all of the wind turbine components and part of the foundations (those above seabed level). Some or all of the array cables, interconnector cables, and offshore export cables may be removed. Scour and cable protection would likely be left in situ.

342. The process for removal of foundations is generally the reverse of the installation process. It should be noted, however, that foundations would be cut and therefore no piling will be required during the decommissioning phase.

343. In respect of cables, general UK practice will be followed, i.e. buried cables will simply be cut at the ends and left in-situ.

344. In light of the above, it is anticipated that types of effect on fish and shellfish receptor would be comparable to those identified for the construction phase, namely:

- Impact 11: Physical Disturbance/Temporary Loss of Habitat;
- Impact 12: Increased SSCs and Sediment Re-deposition;
- Impact 13: Underwater Noise from foundation removal; and
- Impact 14: Underwater noise from other decommissioning activities.

345. The sensitivity of receptors during decommissioning is assumed to be the same as given for the construction phase. The magnitude of effect is considered to be no greater and in all probability less than for the construction phase. Therefore, it is anticipated that any decommissioning impacts would be no greater, and probably less than those assessed for the construction phase.

346. As an alternative to decommissioning, the owners may wish to consider re-powering the wind farm. Should the owners choose to pursue this option, this would be subject to a new application for consent.

11.8 Cumulative Impacts

347. The development activities taken forward for cumulative assessment have been selected on the basis of availability and quality of information and the probability of a cumulative impact occurring, including, where relevant, spatial overlap.

348. The projects considered in the cumulative assessment are outlined in Table 11.36 and Table 11.37 including offshore wind farms and aggregate dredging. It should be noted that currently operational wind farms are not considered in this assessment as they form part of the existing environment. In the case of wind farms that are currently under construction, given the anticipated start date for offshore construction for Norfolk Boreas of 2025, there is little potential for any overlap in construction activities between Norfolk Boreas and these projects.

349. The potential impacts taken forward for cumulative assessment are as described above for assessment of the project alone and include the following:

- Construction Phase:
  - Impact 1: Physical disturbance and temporary habitat loss;

- Impact 2: Increase in SSCs and sediment re-deposition;
- Impact 3: Underwater noise associated with pile driving during construction;
- Impact 4: Noise from other construction activities; and
- Impact 5: Noise from UXO clearance.

- Operation Phase:
  - Impact 6: Permanent loss of seabed habitat;
  - Impact 7: Introduction of hard substrate;
  - Impact 8: Operation noise;
  - Impact 9: EMFs; and
  - Impact 10: Changes to fishing activity.

- Decommissioning:
  - Impact 11: Physical disturbance and temporary habitat loss;
  - Impact 12: Increase in SSCs and sediment re-deposition;
  - Impact 13: Underwater noise associated with removal of foundations; and
  - Impact 14: Noise from other decommissioning activities.

Table 11.36 Summary of Offshore Wind Farm Projects considered for the CIA in relation to the fish and shellfish receptors

Project	Distance from Norfolk Boreas site (km)	Size (MW)	Maximum number of turbines
Norfolk Boreas	**N/A**	**1,800**	**200**
Under Construction			
East Anglia ONE	62	714	102
Hornsea Project One	86	1,200	174
Hornsea Project Two	101	1,386	174
Consented			
East Anglia THREE	13	1,200	172
Doggerbank Teeside A	191	1,200	200
Sofia (previously Doggerbank Teeside B)	185	1,200	200
Doggerbank Creyke Beck A	173	1,200	200
Doggerbank Creyke Beck B	196	1,200	200
Triton Knoll	123	860	90
Application submitted but not yet determined			
Hornsea Project Three	53	2,400	342

Project	Distance from Norfolk Boreas site (km)	Size (MW)	Maximum number of turbines
Norfolk Vanguard	1	1,800	180
Thanet Extension	175	340	34
Application not yet submitted			
East Anglia ONE North	51	600-800	67
East Anglia TWO	73	400-900	75
Hornsea Project Four	120	1,200	180
Identified in strategic plans but yet in planning			
Greater Gabbard Extension	164	504	TBC
Galloper Extension	100	353	TBC
Sheringham Shoal Extension	99	317	TBC
Race Bank Extension	116	573	TBC
Dudgeon Extension	83	402	TBC

Table 11.37 Summary of aggregate dredging areas considered in the CIA in relation to fish and shellfish receptors

Name	Area	Distance from Norfolk Boreas site (km)	Name	Area	Distance from Norfolk Boreas site (km)
Colbart	530	230	North Cross Sands	494	56
Cross Sands	242/361	52	North Falls East	501	133
Goodwin Sands	521	200	North Inner Gabbard	498	107
Humber 1	514/1	172	Off Great Yarmouth	254	64
Humber 2	514/2	168	Off Great Yarmouth	228	63
Humber 3	484	65	Off Great Yarmouth Extension	240	61
Humber 3	514/3	166	Off Saltfleet	197	156
Humber 4	514/4	155	Outer Dowsing	515/1 -2	121
Humber 4 and 7	506	78	Outer OTE	528/2	154
Humber 5	483	61	Shipwash	507	121
Humber Estuary	400 & 106/1-3	154	Southwold East	430	81

Name	Area	Distance from Norfolk Boreas site (km)	Name	Area	Distance from Norfolk Boreas site (km)
Humber Overfalls	493	160	TBC	511	69
Inner Dowsing	481/1-2	140	TBC	512	65
Longsand	510/1-2	142	TBC	513/1-2	59
Longsand	509/1-2-3	142	Thames D	524	132
Longsand	508	145	Yarmouth	401/2A	52
New 495	525	49	Yarmouth	401/2B	64
Norfolk	212	57			

11.8.1 Construction Phase

11.8.1.1 Impact 1: Physical disturbance and temporary loss of area

350. There could be potential for construction works at other projects to result in additional disturbance and temporary habitat loss to fish and shellfish receptors to that identified for the project alone where construction schedules significantly overlap. Given the distances from the project to other projects and activities (Table 11.36) and considering the localised and temporary nature of impacts associated with physical disturbance and temporary loss of habitat (i.e. limited to the immediate vicinity of construction works), however, the magnitude of the cumulative impact is considered to be low.

351. The fish and shellfish species included for assessment have wide overall distribution ranges (including the extent of spawning and nursery grounds for relevant species) in the context of the discrete areas which may be affected at a given time. The sensitivity of fish and shellfish species in general is therefore considered to be low. In the case of species which depend on specific substrates and species or life stages of reduced mobility, considering the potential increased area of their habitat affected and their reduced ability to relocate to other areas, the sensitivity is considered to be medium. With the above in mind, the cumulative impact is considered to be **minor adverse** significance.

352. The confidence in the data and information used in this assessment is medium.

11.8.1.2 Impact 2: Increased SSCs and sediment re-deposition

353. There may be potential for increased SSCs and sediment re-deposition associated with other projects to cumulatively add to the impact identified for Norfolk Boreas alone, provided construction schedules coincide.

354. As discussed in Chapter 8 Marine Geology, Oceanography and Physical Processes, theoretical seabed level changes of up to 2mm are estimated as a result of

cumulative impacts of Norfolk Boreas cable installation and dredging at nearby aggregate sites. Considering the small cumulative changes in seabed level, the expected rapid dispersion of sediment plumes and the localised nature of sediment re-deposition, the magnitude of impact is considered to be low.

355. Adult and juvenile fish in general, being mobile, would be expected to redistribute to undisturbed areas within their range and are therefore considered receptors of low sensitivity. In the case of species and life stages of relatively low mobility and those highly dependent on the presence of specific substrates, considering the potential increased area of their habitat affected and their more reduced ability to relocate to other areas, their sensitivity is considered to be medium. As a result the impact of increased SSCs and sediment re-deposition is predicted to be of **minor adverse** significance.

356. The confidence in the data and information used in this assessment is medium.

11.8.1.3 Impact 3: underwater noise from pile driving

357. There is potential for noise generated during piling activity in Norfolk Boreas and other wind farm projects to result in cumulative impacts on fish species.

358. This would be a result of either increased spatial or temporal effects resulting from concurrent or sequential piling at different offshore wind farms, or a combination of both. Of particular concern in this regard is the potential for behavioural impacts to occur on species which use the area for spawning, however consideration has also been given to other fish species.

359. Species with spawning grounds in the area relevant to Norfolk Boreas include:

- Sole;
- Plaice;
- Cod;
- Sandeels
- Whiting
- Lemon sole;
- Mackerel;
- Sprat
- Thornback ray (as inferred from the location of nursery areas); and
- Herring

360. It should be noted that in the case of herring, there are no spawning grounds in the offshore project area. As discussed in section 11.7.4.3., given the location of herring spawning grounds in respect of the Norfolk Boreas site, and the ranges at which TTS and behavioural impacts are expected from the project, the potential for spawning herring to be affected would be minimal (Figure 11.29). Therefore, there

would be little potential for the project to contribute to any cumulative impact on herring spawning grounds. Similarly, in the case of sandeels, the project overlaps with low intensity spawning grounds for this species with high intensity spawning areas located to the north in the Dogger Bank area. As such, the potential for the project to significantly contribute to a cumulative impact would be limited (Figure 11.25). Recognising the increased potential areas affected by piling noise when considering other projects (particularly those south of the project and therefore closer to the spawning grounds of the Downs stock in the case of herring and those in the Dogger Bank area in the case of sandeels) and considering their seabed habitat specificity, herring and sandeels are considered of medium sensitivity.

361. The remaining species with known spawning grounds in the area have very wide spawning grounds in the context of the relatively small areas over which piling may have an effect. Further, for the most part, areas affected by noise from Norfolk Vanguard OWF sites are considered of low spawning intensity. The remaining fish species with spawning grounds in the area are therefore considered of low sensitivity.

362. With regards to other fish species present in the area, given the extent of their distribution ranges and the areas used for foraging and as nursery grounds they are also considered receptors of low sensitivity.

363. Taking account of the increased spatial effect (if construction occurs concurrently) or temporal (if construction occurs sequentially) associated with piling in other wind farm projects in addition to Norfolk Boreas, but recognising the intermittent and short term nature of piling, the magnitude of the potential impact is considered to be low.

364. In this context it is important to note that active piling will only occur over a small percentage of the overall construction period of offshore wind farm projects. Therefore it is unlikely that piling will occur concurrently at a large number of offshore wind farm projects.

365. In view of the above, the cumulative impact of construction noise from piling on fish species is considered of **minor adverse** significance.

366. The confidence in the data and information used in this assessment is medium.

11.8.1.4 Impact 4: Noise from other construction activities

367. In addition to piling noise, there may be other activities associated with construction works at other projects that could result in potential disturbance to fish and shellfish (i.e. vessel transit, cable laying, rock placement, dredging). As described in section 11.7.4.4 for the project alone, potential impacts on fish and

shellfish associated with this would however occur over very small areas (i.e. in the immediate proximity of construction works/ construction vessels).

368. Whilst the potential for additive disturbance to occur as a result of construction activities in other wind farms, either temporally (where construction is sequential) or spatially (where construction occurs concurrently) is recognised, given the small areas affected and the distance between the projects considered in the assessment and Norfolk Boreas (Table 11.36), the magnitude of the cumulative impact is considered to be low.

369. Taking account of the comparatively wide distribution ranges of fish and shellfish species in the context of the small areas potentially affected (including the extent of the spawning and nursery grounds of relevant species), the sensitivity of fish and shellfish receptors is considered to be low. This results in an impact of **minor adverse** significance.

370. The confidence in the data and information used in this assessment is medium.

11.8.1.5 Impact 5: Noise from UXO clearance

371. As described for assessment of noise from UXO removal for the project alone (section 11.7.4.5), the detonation of UXO associated with other offshore wind farm developments, would also result in injury and disturbance to fish species in the vicinity of the detonation. Physical injury / trauma would occur in close proximity to the detonation with TTS and behavioural effects occurring at greater distance.

372. Whilst it is recognised that the number of UXO detonations required will increase considering the other projects included for cumulative assessment, UXO clearance will still be an activity short term and intermittent in nature (only occurring where UXO cannot be removed by other means). Considering this together with the fact that for the most part any effects on fish and shellfish receptors would be limited to the vicinity of the area where the detonation takes place, the magnitude of the effect is considered to be low.

373. Taking account of the severity of the impact particularly at close range, but acknowledging that impacts would occur at individual rather than at population level, fish species are considered receptors of medium sensitivity.

374. This, in combination with the low magnitude of the effect results in an impact of **minor adverse** significance.

375. The confidence in the data and information used in this assessment is medium.

11.8.2 Operation Phase

11.8.2.1 Impact 6: Permanent loss of seabed habitat

376. The introduction of infrastructure associated with Norfolk Boreas together with that associated with other wind farm projects could result in cumulative impacts on fish and shellfish species in terms of loss of seabed habitat.

377. It should be noted, however, that the loss of seabed habitat would be widely dispersed between projects, and around localised areas within projects (i.e. where cables need protection and around foundations). Furthermore, studies on fish populations in operational wind farms (i.e. Stenberg et al., 2011; Stenberg et al., 2015) have not detected any changes to sandeel populations. It has been suggested (Stenberg et al., 2015) that the direct loss of habitat associated with offshore wind farm infrastructure and indirect effects (i.e. changes to sediment) are too low to influence that abundance of sand-dwelling species such as sandeels. Taking this into account together with the distance from other projects to Norfolk Boreas (Table 11.36), the magnitude of the effect is considered to be low.

378. The fish and shellfish species in the regional area use comparatively large areas for spawning, as nursery grounds and for foraging, and for the most have wide distribution ranges. Therefore, in general terms, impacts as a result of habitat loss are expected to be minimal and fish and shellfish species are considered receptors of low sensitivity. In the case of sandeels and herring given their dependence on specific substrates and therefore their more limited habitat availability they are considered of medium sensitivity.

379. With the above in mind the cumulative impact of permanent loss of habitat is considered to be of **minor adverse** significance.

380. The confidence in the data and information used in this assessment is medium.

11.8.2.2 Impact 7: Introduction of hard substrate

381. The introduction of hard substrate as part of the project together with that introduced as a result of other wind farm projects could result in cumulative impacts on fish and shellfish species in terms of changes to the species assemblage.

382. It should be noted, however, that in line with the cumulative loss of seabed habitat assessed above, the introduction of hard substrate would occur in a scattered manner, around localised sections of the projects (i.e. where cable need protection and around foundations). Taking this into account together with the distance from other project to Norfolk Boreas (Table 11.36), the magnitude of the effect is considered to be low.

383. As previously mentioned (section 11.7.5.2), the results of post construction monitoring surveys undertaken in operational wind farms to date, suggest that any changes in the community structure and abundance of fish and shellfish species associated with introduction of hard substrate would be highly localised, being for the most part limited to the immediate vicinity foundations. With this in mind, the sensitivity of fish and shellfish species is considered to be low, resulting in a cumulative impact of **minor adverse** significance.

384. The confidence in the data and information used in this assessment is medium.

11.8.2.3 Impact 8: Operational noise

385. During the operational phase there may be potential for operational noise from Norfolk Boreas to add cumulatively to operational noise from other offshore wind farm projects.

386. However, as outlined for assessment of operational noise for the project alone, the increase above background noise levels expected during operation would be very small and localised in nature. With this in mind and taking the distance between Norfolk Boreas and other projects (Table 11.36), the magnitude of the effect is considered to be low.

387. Monitoring data from operational wind farms does not suggest that operational noise has potential to result in any discernible effect on fish and shellfish species. With this in mind, fish and shellfish species are considered receptors of low sensitivity. This, combined with the low magnitude of the effect, would result in and impact of **minor adverse** significance.

388. The confidence in the data and information used in this assessment is medium.

11.8.2.4 Impact 9: EMFs

389. EMFs associated with cables at Norfolk Boreas and other offshore wind farm projects could result in a cumulative impact on sensitive fish and shellfish species (particularly elasmobranchs).

390. As described for assessment of EMFs for the project alone, however, areas affected by EMFs would be expected to be very small, being limited to the immediate vicinity of offshore cables (i.e. within metres). Taking this into account, together with the distance from other projects to Norfolk Boreas (Table 11.36), the magnitude of the effect is considered to be low.

391. Considering the wide overall extent of the distribution of the fish and shellfish species in the regional area in the context of the small areas affected by EMFs, fish and shellfish species are considered receptors of low sensitivity.

392. In the particular case of elasmboranchs, given their increased ability to detect EMFs compared to other species groups, their sensitivity is considered to be medium. It should be noted, that as described in section 11.7.5.4 for the project alone, EMFs from cables are expected to, result in temporary, short term behavioural reactions rather than cause a barrier to migration or result in long term impacts upon feeding or confusion in elasmbranchs. This would also apply in a cumulative context.

393. The sensitivities identified above (low for fish and shellfish in general and medium for elasmobranchs), in combination with the low magnitude of the effect, result in an impact of **minor adverse** significance.

394. The confidence in the data and information used in this assessment is medium.

11.8.2.5 Impact 10: Changes to fishing activity

395. The presence of infrastructure associated with offshore wind farms during the operation phase could result in changes to fishing activity within wind farm arrays but also in the wider area (i.e. due to displacement of fishing activity into other areas). This could in turn result in changes in the status of commercially targeted fish stocks.

396. As discussed for assessment of the project alone, the principal species targeted in the Norfolk Boreas site are plaice and sole. Both species are targeted across wide areas in the Southern North Sea, with the Norfolk Boreas site accounting for a small area in the context of the overall fishing grounds (see Chapter 14 Commercial Fisheries). However, recognising the increase in the area over which changes in fishing activity may occur when taking account of other projects in the Southern North Sea, the magnitude of the effect is assessed to be medium.

397. Fishing activity for these species is primarily regulated through the setting of TACs and limitations in fishing effort. It is therefore anticipated that the level of fishing would be largely unaffected by changes in fishing activity associated with the project, as fishing will continue until TACs or set limitations in effort are reached (i.e. through fishing activity of the wider grounds in the Southern North Sea).

398. With the above in mind the sensitivity of commercially targeted fish stocks in respect of potential changes in fishing activity as a result of the project is considered to be low.

399. Taking the low receptor sensitivity and medium magnitude of the effect the resulting impact arising from changes in fishing activity is considered of **minor adverse** significance.

400. The confidence in the data and information used in this assessment is medium.

11.8.3 Decommissioning

401. As outlined for the project alone (section 11.7.6), it is anticipated that the types of effect on fish and shellfish receptor during the decommissioning phase in a cumulative context would be comparable to those identified for the construction phase, namely:

- Impact 11: Physical disturbance/temporary loss of habitat;
- Impact 12: Increased SSCs and sediment re-deposition;
- Impact 13: Underwater noise from foundation removal; and
- Impact 14: Underwater noise from other decommissioning activities.

402. The sensitivity of receptors during the decommissioning is therefore assumed to be the same as given for the construction phase. The magnitude of effect is considered to be no greater and in all probability less than considered for the construction. Therefore, it is anticipated that any cumulative decommissioning impacts would be no greater, and probably less than those assessed for the construction phase.

11.9 Inter-relationships

403. The assessment of the impacts arising from construction, operation and decommissioning of the project indicates that impacts on receptors addressed in other ES chapters may potentially further contribute to the impacts assessed on fish and shellfish species and vice versa.

404. The principal linkages identified are summarised Table 11.38. No inter-relationships have been identified where an accumulation of residual impacts on fish and shellfish ecology gives rise to a need for additional mitigation.

Table 11.38 Chapter topic inter-relationships

Topic and description	Related Chapter	Where addressed in this Chapter
Benthic and Intertidal Ecology The benthic environment provides habitat and prey species for fish and shellfish receptors. Therefore impacts on benthic ecology can have subsequent impacts on fish and shellfish.	10	Section 11.7.5.1 and section 11.7.5.2
Commercial Fisheries Changes in commercial fishing activity associated with the project can have effects on fish and shellfish stocks.	14	Section 11.7.5.5
Marine Mammals Impacts on fish and shellfish ecology can have an impact on the prey resource for marine mammals.	12	Section 11.7

Topic and description	Related Chapter	Where addressed in this Chapter
Offshore Ornithology Impacts on fish and shellfish ecology can have an impact on the prey resource for bird species	13	Section 11.7

11.10 Interactions

405. The impacts identified and assessed in this chapter have the potential to interact with each other, which could give rise to synergistic impacts as a result of that interaction. The worst case impacts assessed within the chapter take these interactions into account and for the impact assessments are considered conservative and robust. For clarity the areas of interaction between impacts are presented in Table 11.39, along with an indication as to whether the interaction may give rise to synergistic impacts.

Table 11.39 Interaction between impacts

Potential interaction between impacts					
Construction					
	1 Physical disturbance and temporary loss of habitat	2 Increased suspended sediment concentrations and sediment re-deposition	3 Underwater noise from piling	4 Underwater noise from other construction activities	5. Underwater noise from UXO
1 Physical disturbance and temporary loss of habitat	-	Yes	No	No	No
2 Increased suspended sediment concentrations and sediment re-deposition	Yes	-	No	No	No
3 Underwater noise from piling	No	No	-	Yes	Yes
4 Underwater noise from other construction activities	No	No	Yes	-	Yes
5. Underwater noise from UXO	No	No	Yes	Yes	-
Operation					
	6 Permanent loss of seabed habitat	7 Introduction of hard substrate	8 Underwater noise during operation	9 EMF	10 Changes in Fishing Activity
6 Permanent loss of seabed habitat	-	Yes	No	No	No
7 Introduction of hard substrate	Yes	-	No	No	No
8 Underwater noise during	No	No	-	No	No

Potential interaction between impacts					
operation					
9 Electromagnetic Fields (EMF)	No	No	No	-	No
10 Changes in Fishing Activity	No	No	No	No	-
Decommissioning					
It is anticipated that the decommissioning impacts will be similar in nature to those of construction.					

11.11 Summary

406. A summary of the outcomes of the impact assessment on fish and shellfish receptors is given in Table 11.40. As shown, no significant impacts (above minor) have been identified

Table 11.40 Potential Impacts Identified for fish and shellfish receptors

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Construction						
Physical disturbance and temporary loss of seabed habitat	Fish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeels	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Herring	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Thornback ray	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Shellfish	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Increased SSCs and sediment re-deposition	Adult and juvenile fish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeels	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Herring	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Other species with spawning grounds in the offshore project area	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Shellfish	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Underwater noise from piling (mortality/recoverable injury) (F: Fleeing animal modelling) (S: Stationary animal modelling)	Fish with no swim bladder	Low - general	Negligible (F/S)	**Negligible (F/S)**	N/A	**Negligible (F/S)**
		Medium -sandeels		**Minor adverse (F/S)**	N/A	**Minor adverse (F/S)**
	Fish with swim bladder not involved in hearing	Low -general	Negligible (F) Low (S)	**Negligible (F) Minor adverse (S)**	N/A	**Negligible (F) Minor adverse (S)**
		Medium- Gobies		**Minor adverse (F/S)**	N/A	**Minor adverse (F/S)**

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
	Fish with swim bladder involved in hearing	Low	Negligible (F) Low (S)	**Negligible (F)** **Minor adverse (S)**	N/A	**Negligible (F)** **Minor adverse (S)**
	Eggs and larvae	Medium	Negligible (F) Low (S)	**Minor adverse (F/S)**	N/A	**Minor adverse (F/S)**
	Shellfish	Medium	Negligible	**Minor adverse**	N/A	**Minor adverse**
Underwater noise from piling (TTS and behavioural) *outcomes of the assessment apply to both a fleeing animal or stationary animal modelling scenario.	Sole, plaice, lemon sole and mackerel	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeels	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Sea bass	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Cod, whiting and sprat	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Herring	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Elasmobranchs	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Diadromous species	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Indirect impacts on fish species as a result of behavioural disturbance to prey species associated with construction noise	Piscivorous fish	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Underwater noise from other construction activities	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Noise from UXO clearance	Fish and shellfish in	Medium	Low	**Minor adverse**	N/A	**Minor adverse**

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
	general					
Operation						
Permanent loss of seabed habitat	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeels	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Herring	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Introduction of hard substrate	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Underwater noise during operation	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
EMFs	Elasmobranchs	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
	Lamprey	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Salmon and sea trout	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	European eel	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Other fish species	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Shellfish	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Changes in fishing activity	Commercially targeted stocks	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Decommissioning						
Physical disturbance and temporary loss of habitat	As above for the construction phase and likely less					
Increased SSCs and sediment	As above for the construction phase and likely less					

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
re-deposition						
Underwater noise from foundation removal	As above for the construction phase and likely less					
Underwater noise from other decommissioning activities	As above for the construction phase and likely less					
Cumulative						
Construction						
Physical disturbance and temporary loss of seabed habitat	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Species which depend on specific substrates or species/life stages of limited mobility	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Increased SSCs and sediment re-deposition	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Species which depend on specific substrates or species/life stages of limited mobility	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Underwater noise from piling (behavioural)	Fish in general (including species with spawning grounds)	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeel and herring	Medium	Low	**Minor adverse**	N/A	**Minor adverse**

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Underwater noise from other construction activities	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Noise from UXO clearance	Fish and shellfish in general	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Operation						
Permanent loss of seabed habitat during operation	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Sandeels and herring	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Introduction of hard substrate	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Underwater noise during operation	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
EMFs	Fish and shellfish in general	Low	Low	**Minor adverse**	N/A	**Minor adverse**
	Elasmobranchs	Medium	Low	**Minor adverse**	N/A	**Minor adverse**
Changes in fishing activity	Commercially targeted stocks	Low	Low	**Minor adverse**	N/A	**Minor adverse**
Decommissioning						
As above for the construction phase and likely less						
Transboundary						
N/A	N/A					

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