Dudgeon and Sheringham Shoal Offshore Wind Farm Extensions

Preliminary Environmental Information Report

Volume 1

Chapter 11 - Fish Ecology

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Appendix 11.1 Fish and Shellfish Ecology Baseline Technical Report

Glossary of Acronyms

BGS	British Geological Survey
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CIA	Cumulative Impact Assessment
COWRIE	Collaborative Offshore Wind Research into the Environment
CPUE	Catch Per Unit Effort
DCO	Development Consent Order
Defra	Department for the Environment and Rural Affairs
DEP	Dudgeon Extension Project
DTI	Department of Trade and Industry
EC	European Commission
EEA	European Economic Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIFCA	Eastern Inshore Fisheries and Conservation Authority
EMF	Electromagnetic Field
EPP	Evidence Plan Process
ES	Environmental Statement
ETG	Expert Topic Group
EU	European Union
FEPA	Food and Environmental Protection Act
IBTS	International Bottom Trawl Survey
ICES	International Council for the Exploration of the Sea
IHLS	International Herring Larvae Survey
IMARES	Institute for Marine Resources and Ecosystem Studies
IPMP	In-Principle Monitoring Plan
km	Kilometre
MarESA	Marine Evidence based Sensitivity Assessment
MarLIN	Marine Life Information Network
MCEU	Marine Consents and Environment Unit
MCZ	Marine Conservation Zone
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Management Organisation

ML	Marine Licence
MPS	Marine Policy Statement
MSFD	Marine Strategy Framework Directive
MW	Megawatts
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Project
ORJIP	Offshore Renewables Joint Industry Programme
OS	Ordnance Survey
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
PEIR	Preliminary Environmental Information Report
PTS	Permanent Threshold Shift
SAC	Special Area of Conservation
SEP	Sheringham Shoal Extension Project
SNC	South Norfolk Council
SNS	Southern North Sea
SIP	Site Integrity Plan
TAC	Total Allowable Catches
TNT	Trinitrotoluene
TTS	Temporary Threshold Shift
UK	United Kingdom
UN	United Nations
UXO	Unexploded ordnance
WFD	Water Framework Directive
WTG	Wind Turbine Generator

Glossary of Terms

The Applicant	Equinor New Energy Limited
Array cables	See infield cables
Beam Trawl	A trawl net whose lateral spread during trawling is maintained by a beam across its mouth.
Clupeid	Fish species of the family Clupeidae, which are ray-finned fishes, including herring, sprat, sardine and shad.
Crustacean	An arthropod of the large, mainly aquatic group Crustacea, such as a crab, lobster, shrimp, or barnacle.
DCO boundary	The area subject to the application for development consent, including all permanent and temporary works for DEP and SEP. The DCO boundary will be subject to an updated impact assessment and further development of mitigation proposals to inform the ES.
Demersal	Living on or near the sea bed.
Diadromous	Migrating between fresh and salt water.
Dudgeon Offshore Wind Farm Extension site	The Dudgeon Offshore Wind Farm Extension lease area.
The Dudgeon Offshore Wind Farm Extension Project (DEP)	The Dudgeon Offshore Wind Farm Extension site, as well as all onshore and offshore infrastructure.
Elasmobranch	Any cartilaginous fish of the subclass Elasmobranchii which includes sharks, rays and skates.
European site	Sites designated for nature conservation under the Habitats Directive and Birds Directive. This includes candidate Special Areas of Conservation; Sites of Community Importance; Special Areas of Conservation and Special Protection Areas, and is defined in regulation 8 of the Conservation of Habitats and Species Regulations 2017.
Evidence Plan Process (EPP)	A voluntary consultation process with specialist stakeholders to agree the approach, and information to support, the EIA and HRA for certain topics.
Gadoid	A bony fish of an order (Gadiformes) that comprises the cods, hakes, and their relatives.
Gravid	Carrying eggs or young.
Grid option	Mechanism by which DEP and SEP will connect to the existing electricity network. This may either be

	an integrated grid option providing transmission infrastructure which serves both of the wind farms, or a separated grid option, which allows DEP and SEP to transmit electricity entirely separately.
Horizontal directional drilling (HDD) zones	The areas within the onshore cable route which would house HDD entry or exit points.
ICES Rectangles	Statistical rectangles measuring 30 minutes of latitude, by 1 degree of longitude in size (approximately 30 nautical miles by 30 nautical miles). They are the smallest spatial unit for which fisheries data is collected.
Infield cables	Cables which link the wind turbine generators to the offshore substation platforms.
Interlink cables	Cables linking two separate project areas. This can be cables linking: 1. DEP South and DEP North 2. DEP South and SEP 3. DEP North and SEP 1 is relevant if DEP is constructed alone or first in a phased development. 2 and 3 are relevant in a tandem construction.
Landfall	The point on the coastline at which the offshore export cables are brought onshore and connected to the onshore export cables.
Mollusc	An invertebrate of a large phylum which includes snails, slugs, mussels, and octopuses. They have a soft unsegmented body; live in aquatic or damp habitats with, most species having an external calcareous shell.
Natura 2000 site	A site forming part of the network of sites made up of Special Areas of Conservation and Special Protection Areas designated respectively under the Habitats Directive and Birds Directive.
Offshore export cables	The cables which would bring electricity from the offshore substation platform(s) to the landfall. 220 – 230kV
Offshore substation platform	A fixed structure located within the wind farm area, containing electrical equipment to aggregate the power generated by the wind turbines and increase the voltage before transmitting the power to shore.
Otter trawl	A trawl net fitted with two 'otter' boards which maintain the horizontal opening of the net.
Ovigerous	Carrying or bearing eggs.

PEIR boundary	The area subject to survey and preliminary impact assessment to inform the PEIR, including all permanent and temporary works for DEP and SEP. The PEIR boundary will be refined down to the final DCO boundary ahead of the application for development consent.
Pelagic	Living in the water column.
Piscivorous	Feeding on fish.
Scour protection	Protective materials to avoid sediment being eroded away from the base of the foundations as a result of the flow of water.
Study area	Area where potential impacts from the project could occur, as defined for each individual EIA topic.
Sheringham Shoal Offshore Wind Farm Extension site	Sheringham Shoal Offshore Wind Farm Extension lease area.
The Sheringham Shoal Offshore Wind Farm Extension Project (SEP)	The Sheringham Shoal Offshore Wind Farm Extension site as well as all onshore and offshore infrastructure.
Species of Conservation Interest	Marine species that are particularly threatened, rare, or declining.
Swim bladder	A gas-filled sac present in the body of many bony fish, used to maintain and control buoyancy.

11 FISH AND SHELLFISH ECOLOGY

11.1 Introduction

1. This chapter of the Preliminary Environmental Information Report (PEIR) considers the potential impacts of the proposed Dudgeon Extension Offshore Wind Farm Project (DEP) and Sheringham Shoal Extension Offshore Wind Farm Project (SEP) on fish and shellfish ecology. The chapter provides an overview of the existing environment for the proposed offshore development area, followed by an assessment of the potential impacts and associated mitigation for the construction, operation and decommissioning phases of DEP and SEP.
2. This chapter has been written by Royal HaskoningDHV, with the assessment undertaken with specific reference to the relevant legislation and guidance, of which the primary source are the National Policy Statements (NPS). Details of these and the methodology used for the Environmental Impact Assessment (EIA) and Cumulative Impact Assessment (CIA) are presented in **Section 11.4**.
3. The assessment should be read in conjunction with following linked chapters:
   - **Chapter 8 Marine Geology, Oceanography and Physical Processes**;
   - **Chapter 9 Marine Water and Sediment Quality**;
   - **Chapter 10 Benthic and Intertidal Ecology**;
   - **Chapter 12 Marine Mammal Ecology**;
   - **Chapter 13 Offshore Ornithology**; and
   - **Chapter 14 Commercial Fisheries**.
4. Additional information to support the fish and shellfish ecology assessment is included in **Appendix 11.1 Fish and Shellfish Ecology Baseline Technical Report** and **Appendix 12.2 Underwater Noise Modelling Report**.

11.2 Consultation

5. Consultation with regard to fish and shellfish ecology has been undertaken in line with the general process described in **Chapter 6 EIA Methodology**. The key elements to date have included scoping and the ongoing Evidence Plan Process (EPP) via the Seabed Expert Topic Group (ETG), with meetings held in October 2019, June 2020 and February 2021. The feedback received has been considered in preparing the PEIR. **Table 11-1** provides a summary of how the consultation responses received to date have influenced the approach that has been taken for the PEIR.
6. This chapter will be updated following the consultation on the PEIR in order to produce the final assessment that will be submitted with the Development Consent Order (DCO) application. Full details of the consultation process will also be presented in the Consultation Report alongside the DCO application.

Table 11-1: Consultation responses.

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	Table 2-13 Physical disturbance and temporary loss of sea bed habitat, spawning or nursery grounds during intrusive works -operation. The Inspectorate is content that intrusive works during operation are not likely to occur on a scale that would result in significant effects and this matter can be scoped out of the assessment.	Noted
The Planning Inspectorate	November 2019 Scoping Opinion	Permanent habitat loss - construction and decommissioning. The Scoping Report proposes to assess permanent habitat loss during operation and decommissioning only. A number of construction activities have the potential to result in a degree of habitat loss during construction. The Inspectorate considers that ‘temporary habitat loss’ should be scoped in for all phases of the Proposed Development as any interaction with the sea bed may cause loss of habitat for some species. This should include as assessment of likely significant effects from cable protection. The consultation responses from the MMO) and NE support this position. The Inspectorate therefore does not agree that construction and decommissioning phase effects can be scoped out of the assessment.	These have been discussed in **Sections 11.6.2.2** and **11.6.3**.

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	Introduction of wind turbine foundations, scour protection and hard substrate – construction and decommissioning. During construction/decommissioning, turbines would be incrementally constructed/removed, with turbine foundations and scour protection also being installed/removed. As such, there is potential for effects to occur after installation of the first turbines (during construction) and until removal of the last (during decommissioning). Based on the information provided at this stage, the Inspectorate is unable to rule out a significant effect and does not agree that this matter can be scoped out of the ES. The ES should explain the assumptions that have been used to inform the assessment.	Noted. The impacts from introduction of hard substrates will start once the first piece of infrastructure is installed, as such the effects will start during construction. However, the worst case scenario regarding the impacts of introduced hard substrates is once all infrastructure is in place. This has been assessed in **Section 11.6.2.4**
The Planning Inspectorate	November 2019 Scoping Opinion	Underwater noise during foundation piling - operation and decommissioning. The Inspectorate is content that this matter is only relevant to the construction phase with no significant effects anticipated during operation and decommissioning and therefore can be scoped out of the assessment for operation and decommissioning.	Noted
The Planning Inspectorate	November 2019 Scoping Opinion	Impacts from EMF - construction and decommissioning. The Inspectorate is content that this matter is only relevant to the operational phase with no significant effects anticipated during operation and decommissioning and therefore can be scoped out of the assessment for construction and decommissioning	Noted

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	Site specific surveys. The Scoping Report concludes that the existing data described in Table 2-14 is sufficient to undertake a robust assessment and therefore the Applicant does not propose to undertake further site specific surveys. Table 2-14 refers to characterisation surveys for the existing Dudgeon and Sheringham Shoal OWF ES's (undertaken in 2008 and 2005 respectively) and post- construction surveys at Sheringham Shoal (2012 and 2013). The table also identifies numerous other sources, including MMO landings data. The Inspectorate agrees that new fish characterisation surveys are not necessary as the sources of data proposed to inform the desk-based assessment will be adequate. The Applicant must ensure that the ES presents a robust baseline upon which to base its assessment and should acknowledge any limitations associated with the data sources. The Applicant should make effort to agree the baseline used in the assessment with the relevant consultation bodies.	Noted, further details are found in **Section 11.4.2** and in **Section 11.1.2** of **Appendix 11.1.**

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	The Scoping Report identifies species of commercial importance and spawning and nursery areas. In accordance with NPS EN-3, the ES should also identify any feeding grounds, over-wintering areas for crustaceans and migration routes that could be significantly affected by the Proposed Development. The location of these areas, in relation to the Proposed Development, should be depicted in the ES using appropriate figures.	Evidence suggests that the brown crab (*Cancer pagurus*) migrate to offshore overwintering grounds where eggs are hatched, moving back to coastal areas in the spring. Mature females undertake long-distance migrations to the north (**Appendix 11.1**). Potential impacts on brown crab migrations are assessed in **Sections 11.6.1.1** and **11.6.1.2**
The Planning Inspectorate	November 2019 Scoping Opinion	Cromer Shoal MCZ is predominantly designated for subtidal chalk habitat with a thin veneer of gravelly sand on top of the bedrock. The Inspectorate recommends the Applicant makes efforts to agree necessary pre-application surveys with NE in order to provide confidence that cable installation will be feasible within the site.	Noted. The pre-application benthic characterisation survey scope was shared and agreed with Natural England and the MMO.
The Planning Inspectorate	November 2019 Scoping Opinion	The Applicant should ensure that benthic surveys are undertaken at appropriate times of year, taking into account weather conditions and the ability to collect satisfactory datasets.	Noted

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	The most recently published International Herring Larvae Survey 2019 should be used to inform the baseline. The assessment of herring potential spawning habitat should be undertaken using the method described in MarineSpace (2013) and informed by Particle Size Analysis data from the geophysical and benthic sampling surveys. Any likely significant effects on these areas should be assessed in the ES.	An assessment of potential spawning habitat based on MarineSpace et al. (2013) is included in **Appendix 10.3 DEP and SEP Habitat Mapping** and summarised in **Section 11.5.2.3.1**. **Appendix 11.1** includes 2019 International Herring Larvae Survey data and is used to inform the baseline. An assessment of likely significant effects on herring spawning grounds is provided **Sections 11.6.1.1** and Error! Reference source not found. of this chapter.
The Planning Inspectorate	November 2019 Scoping Opinion	The potential for impacts from suspended sediment during cable and foundation installation works has been scoped into the assessment. The ES should assess the likely significant smothering effects this could have on fish populations, including spawning and nursery areas, present within the zone of influence.	This is discussed in **Section 11.6.1.2**.
The Planning Inspectorate	November 2019 Scoping Opinion	Underwater noise. The Inspectorate considers that increased underwater noise during construction has the potential to result in temporary threshold shift, recoverable injury and mortality to sensitive species. Significant effects associated with these impacts should be assessed in the ES. The Applicant is encouraged to make effort to discuss and agree the approach to this assessment with relevant consultation bodies including the MMO.	This is discussed in **Sections 11.6.1.4** to **11.6.1.6**.

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	The Scoping Report proposes to assess the effects of disturbance and displacement of acoustically sensitive fish species and spawning and nursery areas from underwater noise. The effects of mortality, injury, behavioural changes and auditory masking should also be assessed, where significant effects are likely. The Scoping Report provides little information on how the assessment will be undertaken. The assessment should explain how the characteristics of the receptors have been taken into account e.g. fish species and their capability to flee from noise sources. The Applicant should make efforts to agree the approach with the MMO.	This is discussed in **Sections 11.6.1.4** to **11.6.1.6**.
The Planning Inspectorate	November 2019 Scoping Opinion	Inter-relationships –fishing pressure. Reduced fishing pressure within the array has the potential to result in positive effects to commercially targeted species. The ES should assess any benefits associated with the reduced pressure, where significant effects are likely.	This is discussed in **Sections 11.6.1.7**, **11.6.2.9** and **11.6.3**.
The Planning Inspectorate	November 2019 Scoping Opinion	The MMO notes that sandeel are of ecological importance as prey species for marine mammals and birds. It highlights that sand eel has a spatial dependency on a specific substrate and show site fidelity. The Inspectorate considers that the ES should include information to characterise the sandeel habitat in the array and export cable corridor and assess any likely significant effects to the species from the project alone and cumulatively with other plans or projects.	This is discussed in **Section 11.6** of this chapter and **Section 11.3.3.9.1** in **Appendix 11.1**.

Consultee	Date/ Document	Comment	Project Response
The Planning Inspectorate	November 2019 Scoping Opinion	The ES should assess any likely significant effects to migratory fish transiting the area e.g. to/from the Wash and River Humber.	This is discussed in **Section 11.6**.
Marine Management Organisation	November 2019 Scoping Opinion	The commercial and ecological importance of sandeel has not been discussed in any detail in the Scoping Report. The ecological and commercial importance of sandeel should be acknowledged in the ES and an appropriate species-specific impact assessment should be undertaken for sandeel.	This is discussed in **Section 11.6** and **Section 11.3.3.9** in **Appendix 11.1.**
Marine Management Organisation	November 2019 Scoping Opinion	Sandeel, as well as juvenile herring and sprat, are of ecological importance as a prey source for marine mammals and birds, some of which are protected and qualifying features of nearby Special Protection Areas (SPA) or Special Areas of Conservation (SAC) such as the Greater Wash SPA and The Wash & North Norfolk Coast SAC. Sandeel have a spatial dependency on a specific substrate and it is recognised that sandeel show site fidelity to defined areas of sea bed, and do not tend to travel to other locations to spawn.	This is discussed in **Section 11.6** and **Section 11.3.3.9** in **Appendix 11.1**.

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	Otter and beam trawls are not considered suitable survey gears to adequately sample sandeel species. Catches of sandeel (e.g. from grabs, trawls) in the area can provide information on presence, however this method does not provide information about abundance and distribution. The most accurate method for assessing the DEP and SEP areas as a sandeel habitat would be through a sandeel dredge survey. Surveys would need to be carried out either during night-time or during seasonal hibernation periods, using specific sandeel dredge gear. To provide a statistically robust study these surveys would have to be carried out over a number years pre- and post-construction. This may be disruptive for the population, and the study would be expensive, so this is not recommended by the MMO. Instead, the EIA would be expected to characterise sandeel habitat following the method described in MarineSpace (2013b) which uses broadscale sediment data and site-specific PSA data from the array and export cable corridor. As per the assessment of herring potential spawning habitat, PSA data collected during the proposed benthic sampling surveys can be used to inform the area's suitability as sandeel habitat. Any catches of sandeel observed in grabs will provide anecdotal evidence of their presence in the array and export cable route areas.	An assessment of potential sandeel habitat is included in **Appendix 10.3 DEP and SEP Habitat Mapping** based on Latto et al. (2013) after it was agreed with Cefas that this is the correct methodology to apply. An alternative method is also presented using grab samples assessed for sandeel preference based on Greenstreet et al. (2010), and mapping between samples based on recent site specific geophysical survey data. This assessment is summarised in **Section 11.5.2.3.2**.

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	Whilst there are a number of broad areas of the Southern North Sea that are considered suitable as sandeel habitat, many areas are already subjected to anthropogenic activities such as windfarm construction, trawling and aggregate dredging. Additionally, many areas may not provide suitable habitat due to physical parameters such as incompatible substrate composition or water depth. The cumulative impact assessment should consider these factors when assessing the impacts of the windfarm development on sandeel.	This is discussed in **Section 11.7.**
Marine Management Organisation	November 2019 Scoping Opinion	Migratory fish species should be included in the assessment and the various conservation statuses of these species should also be considered. Potential impacts from construction and operational activities should be adequately assessed in relation to migratory fish transiting the area e.g. to/from the Wash and River Humber. The Environment Agency carry out fisheries surveys to monitor coastal and transitional waters, including the River Humber and the Wash. Data can be downloaded via; https://data.gov.uk/dataset/41308817-191b-459d-aa39-788f74c76623/trac-fish-counts-for-all-species-for-all-estuaries-and-all-years.	Throughout the assessment in **Section 11.6** certain species or groups are assessed individually, however where receptors are not specific, they are included under “all fish species” assessments.

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	Generally, the approach to the scoping assessment is appropriate in that it sets out the proposed methods to be used to inform and undertake the EIA. However, given that the scoping report is intended to support an application for the construction of up to two nationally significant infrastructure projects (NSIPs), more detailed descriptions of the potential impacts to fisheries and fish ecology as well as more detailed explanations of how the potential impacts to key sensitive species will be assessed would have been beneficial.	Noted. Further details are included in this chapter in **Sections 11.6.1.7**, **11.6.2.9, 11.6.3** and in **Chapter 14 Commercial Fisheries**.

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	The table of data sources (Table 2-14) proposed for the characterisation of the existing environment for fish is generally appropriate. However, there are some concerns with the timeliness of data collected during the Dudgeon and Sheringham Shoal OWF EIA characterisation surveys and the Sheringham Shoal OWF Post- construction surveys for the reasons outlined below: The Environmental Statement (ES) should recognise the limitation that the data collected for EIA fish characterisation surveys for Dudgeon OWF (2008) and Sheringham Shoal OWF (2005) are now in excess of 10 years old, and that the surveys were carried out prior to the placement and operation of OWF infrastructure. Factors such as loss of habitat, introduction of hard substrates, and temporal and natural variations in fish assemblages may have changed over this period. However, the MMO advise there is no requirement for new fish characterisation surveys to be undertaken, as the various sources of data proposed to inform the desk-based assessment will be adequate to provide a general description of the fish species typically found in the DEP and SEP areas.	Limitations of data sources are discussed in **Section 11.4.2** and in **Section 11.1.2** of **Appendix 11.1.**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	Point 292 of the Scoping Report refers to the Sheringham Shoal post-cable installation elasmobranch survey which recorded a single starry smooth-hound (*Mustelus asterias*) in the export cable corridor just south of the wind farm array (Brown & May Marine, 2013). Conversely, starry smooth-hounds represented the greatest numbers caught in the pre-construction cable installation elasmobranch survey report (Brown & May Marine, 2010). The MMO recommend that if data from the Sheringham Shoal Post-cable Installation Elasmobranch Survey 2013 are to be used to inform the EIA, then so too should data from the Post-Cable Installation Elasmobranch Survey Reports from 2012 and 2015 and the Pre-construction Cable Installation Elasmobranch Survey Report (Brown & May Marine, 2010).	This has been included in **Section 11.4.2.1** and in **Section 11.2.4.4** of **Appendix 11.1**.
Marine Management Organisation	November 2019 Scoping Opinion	It should also be noted that there are no recent confirmed records of common smooth-hound (*Mustelus mustelus*) (listed in Table 2-11) being captured in UK waters. A genetic study (Farrell *et al.*, 2009) confirmed that all specimens investigated were found to be starry smooth-hounds (*Mustelus asterias*). Therefore, it may be more appropriate to refer to *Mustelus spp*. in the ES.	Noted, this is discussed further in **Section 11.2.4.4** of **Appendix 11.1**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	When using any fisheries data collected from past surveys, it is important that the data are interpreted and presented appropriately and that all survey limitations are acknowledged within the ES, as per point 1.3.9. It is recommended that any trawl or longline catch data should be presented in standardised units, for example, Catch Per Unit Effort (CPUE). The survey methods, timings and limitations of survey and gear types as well as gear selectivity should be discussed or acknowledged within the ES, especially with regard to the influence on species and life stages captured by individual gear types/sampling methods. For example, a 2m epibenthic beam trawl will not adequately target large/adult fish, or pelagic fish; otter trawls and epibenthic beam trawls will not adequately target sandeels and the season in which a survey is undertaken may influence species abundance in that particular area.	These are stated in **Table 11.1.1** in **Appendix 11.1**.
Marine Management Organisation	November 2019 Scoping Opinion	The Scoping Report has correctly identified that herring are sensitive to activities that disturb the sea bed and are sensitive to noise and vibration, making them vulnerable to the impacts of OWF (OWF) construction and operation activities. Comments and recommendations are provided below on how the assessment of impacts for this species should be carried out.	This is discussed in **Section 11.6.**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	The nearest herring spawning ground to the DEP and SEP sites, is that of the Banks/Dogger population off the coast of Flamborough Head. Some smaller, localised herring spawning grounds also exist at locations along the Norfolk and Lincolnshire coasts and outside the Wash, although due to a lack of recent larval data for these locations it is not known whether these sites are currently 'active'. The MMO recommend that an assessment of herring potential spawning habitat is undertaken to inform the EIA, using the method described in MarineSpace (2013). The assessment should be supported by 10 years of International Herring Larval Survey (IHLS) data (data up to 2018 are available). The applicant's intention to undertake a program of geophysical and benthic sampling across the proposed wind farm areas and export cable corridors in order to characterise the sea bed is noted. PSA data from these surveys can be used to inform the potential herring spawning habitat assessment.	An assessment of potential spawning habitat based on MarineSpace et al (2013) is included in **Appendix 10.3 DEP and SEP Habitat Mapping** and summarised in **Section 11.5.2.3.1**.
Marine Management Organisation	November 2019 Scoping Opinion	Little information is presented on how the assessment of impacts of noise and vibration on fish will be carried out, or what resources will be used, or the proposed methods for modelling. An accurate description of the physiological and behavioural impacts to fish caused by noise and vibration should be presented in the ES, and fish species relevant to the development should be assigned into one of the four categories described in Popper *et al.* (2014).	This is discussed in **Section 11.6.1.4**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	We recommend that fish are treated as a stationary receptor in any modelling used to make predictions for noise propagation on fish spawning and nursery grounds. The MMO does not support the use of a fleeing animal model for fish for the reasons outlined below: It is known that fish will respond to loud noise and vibration, through observed reactions including schooling more closely, moving to the bottom of the water column, swimming away and burying in the substrate (Popper *et al.* 2014). However, this is not the same as fleeing, which would require a fish to flee directly away from the source over the distance shown in the modelling. The MMO is not aware of scientific or empirical evidence to support the assumption that fish will flee in this manner.	This is discussed in **Section 11.6.1.4**
Marine Management Organisation	November 2019 Scoping Opinion	The assumption that a fish will flee from the source of noise is overly simplistic as it overlooks factors such as fish size and mobility, biological drivers and philopatric behaviour which may cause an animal to remain/return to the area of impact. This is of particular relevance to herring, as they are benthic spawners which spawn in a specific location due to its substrate composition	Noted, the assessment has used stationary response in the underwater noise modelling and is discussed further in **Section 11.6.1.4**
Marine Management Organisation	November 2019 Scoping Opinion	Eggs and larvae have little to no mobility, which makes them vulnerable to barotrauma and developmental effects. Accordingly, they should also be assessed and modelled as a stationary receptor, as per the Popper *et al.* (2014) guidelines.	This is discussed in **Section 11.6.1.4**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	The outputs of modelling should be presented in map-form depicting the predicted noise contours. 10 years of IHLS data (2008-2018) should be presented in the form of a 'heat map' which should be overlaid with the mapped noise contours. This will provide a better understanding of the likely extent of noise propagation into herring spawning grounds and allow for a more robust assessment of impacts to be made.	This is discussed in **Section 11.6.1.4.2** and presented in **Figure 11.6**
Marine Management Organisation	November 2019 Scoping Opinion	The applicant should clearly state in their ES (and PEIR if applicable) whether they propose to undertake simultaneous piling, i.e. the installation of more than one pile at a time, for the installation of WTGs or other offshore platform structures. If simultaneous piling is proposed, then underwater noise modelling for impacts to fish should be based on this scenario.	Simultaneous piling is possible should DEP and SEP both be constructed concurrently. In this scenario, as a worst case, one piling operation could occur in the SEP wind farm site at the same time as a piling operation in the DEP wind farm sites (one piling operation per project). This is discussed and assessed in **Section 11.6.1.4.2**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	The applicant should also consider the use of embedded mitigation and good practice measures to remove or reduce impacts and effects on fish. Such measures might include; The use of soft start procedures on commencement of piling. The MMO's technical advisers Cefas recommend a 20-minute soft-start in accordance with the Joint Nature Conservation Committee (JNCC) protocol for minimising the risk of injury to marine mammals and other fauna from piling noise (JNCC 2010). Should piling cease for a period greater than 10 minutes, then the soft-start procedure must be repeated. Cable burial to a minimum depth of 1.5 m (subject to local geology and obstructions) to minimise the effects of EMF, as recommended in the Department of Energy and Climate Change report (2011). The use of air bubble curtains to reduce or mitigate the impacts of noise and vibration from piling.	Mitigation is summarised in **Section 11.3.3**
Marine Management Organisation	November 2019 Scoping Opinion	Potential impacts are categorised by development phase in the report. Whilst a number of potential impacts are identified these are not associated with specific species. Further detail and clarification should be provided as the application progresses. Generally, all relevant impacts to shellfish species and shell-fishers have been scoped in.	Addressed in **Section 11.6**

Consultee	Date/ Document	Comment	Project Response
Marine Management Organisation	November 2019 Scoping Opinion	Permanent habitat loss to shellfish has been scoped in during the operation stage but scoped out for both construction and decommissioning. "Permanent habitat loss" suggests that the habitat will never recover. The MMO advise changing this to "temporary habitat loss" and scoping the impact into both the construction and decommissioning phases as any interaction with the sea bed may cause loss of habitat for some species and all phases of the project could result in temporary habitat loss for shellfish. It is notable from the report that "permanent habitat loss" is intended to complement "Physical disturbance and temporary loss of sea bed habitat, spawning or nursery grounds during intrusive works", however, the two are not similar and should not be considered so.	Noted. Temporary habitat loss has been assessed along with physical disturbance for all project phases in **Sections11.6.1.1**, **11.6.2.2** and **11.6.3**. Permanent habitat loss has been included in the assessment for infrastructure that may be decommissioned *in-situ*, in **Section** Error! Reference source not found...
Natural England	November 2019 Scoping Opinion	General. Overall the proposed approach seems appropriate. Please see the following two comments, and otherwise, Natural England defers to the expert advice at Cefas with regards to the need for surveys or additional assessment work for Fish and Shellfish.	Noted
Natural England	November 2019 Scoping Opinion	Potential impacts here should also include impacts from disposal activities, such as smothering of larvae or potential changes to habitat.	This is discussed in **Sections 11.6.1.2**, **11.6.2.5** and **11.6.3**

Consultee	Date/ Document	Comment	Project Response
Natural England	November 2019 Scoping Opinion	Data from the most recently published International Herring Larvae Survey 2019 report should also be included to confirm what spawning, if any, is occurring at the identified potential spawning area. September 2019 is the latest publication at time of writing. Table 2-14 suggests that only up to 2018 will be considered.	Most recent International Herring Larvae Survey data available has been used including from 2019. More recent data (post 2019) will be incorporated with the final ES where available.
Cefas & MMO	October 2019 ETG meeting	Cefas stated that the assessment has to acknowledge limitations of the existing data. MMO also stated that fish surveys from previous projects encountered access problems on cable routes due to fishing activity, resulting in some stations being missed. This limitation should also be acknowledged.	This is discussed in **Section 11.4.2** and in **Appendix 11.1**
Cefas & EIFCA	June 2020 ETG meeting	Cefas and EIFCA stated that there might be whelk fishery present in the area. There is anecdotal information from members of fishing community that the whelk community was affected by installation of pipelines and that organotins could be present at depth. Cefas stated that organotins should not be excluded from sediment sample chemical analysis.	A subset of sediment samples were tested for organotins. Full details are presented in **Chapter 9 Marine Water and Sediment Quality**. The impacts of any sediment bound contaminants are assessed in **Section 11.6.1.3**

Consultee	Date/ Document	Comment	Project Response
Cefas	February 2021 ETG Meeting	Cefas commented on levels of herring spawning in area and noted that the previous (Dudgeon and Sheringham Shoal) survey results should not be treated as conclusive as they were not consistent, however agreed that herring spawning is not prevalent in the areas considered for DEP and SEP. The potential relevance of the Flamborough Head grounds to this project was noted, which should be considered alongside the outputs of the UWN modelling and the available IHLS data. Assessment should acknowledge data gaps.	Limitations of the data are acknowledged in **Table 11-5** and **Appendix 11.1**. The likelihood of herring spawning in the DEP and SEP areas is discussed in **Section 11.5.2.3**. The spatial overlaps of underwater noise impact ranges and the herring spawning areas is shown in **Figure 11.42**, and the spatial overlap of underwater noise impact ranges and the IHLS Small Larvae Abundance area are shown in **Figures 11.43** to **11.46**.
Cefas	February 2021 ETG Meeting	Commercial landing results collected in the past were not always consistent and therefore feedback will be provided based on the interpretation of results within the PEIR. However, Cefas stated that they are happy with the species identified. And stressed that data used within the assessment should not normally be older than 5 years, or where it is that the limitations are noted.	Various reports and regional survey data have been included to inform the baseline and are presented in **Section 11.4.2** and **Section 11.1.2** of **Appendix 11.1**

11.3 Scope

11.3.1 Study Area

7. The DEP and SEP offshore infrastructure are located within ICES rectangles 35F1 and 34F1. These rectangles define the 'local study area' as shown in **Figure 11.1** these are the primary focus of this assessment. Further to the west, ICES rectangles 34F0 and 35F0 are also considered as part of the wider 'regional area'. As ICES rectangle boundaries are used to determine the study area, the data acquired will account for a wide variety of species in and around DEP and SEP. Species included will range from primarily permanent residents; seasonal residents that use these areas for foraging, spawning and nursery grounds; and transient (migratory) species. In describing the fish and shellfish ecology baseline, historic fish surveys at the Dudgeon and Sheringham Shoal OWF sites have been used and given prominence due to their proximity to DEP and SEP, whilst acknowledging that the data is now several years old. In addition, in certain cases a wider geographical area is used for environmental baseline descriptions and impact assessment, for example the distribution of spawning grounds in the southern North Sea.

11.3.2 Realistic Worst Case Scenario

11.3.2.1 General Approach

8. The final design of DEP and SEP will be confirmed through detailed engineering design studies that will be undertaken post-consent to enable the commencement of construction. In order to provide a precautionary, but robust impact assessment at this stage of the development process, realistic worst case scenarios have been defined in terms of the potential effects that may arise. This approach to EIA, referred to as the Rochdale Envelope, is common practice for developments of this nature, as set out in Planning Inspectorate Advice Note Nine (2018). The Rochdale Envelope for a project outlines the realistic worst case scenario for each individual impact, so that it can be safely assumed that all lesser options will have less impact. Further details are provided in **Chapter 6 EIA Methodology**.

9. The realistic worst case scenarios for the Fish and Shellfish Ecology assessment are summarised in **Table 11-2**. These are based on the project parameters described in **Chapter 5 Project Description**, which provides further details regarding specific activities and their durations.

10. In addition to the design parameters set out in **Table 11-2**, consideration is also given to how DEP and SEP will be built out as described in **Section 11.3.2.2** to **Section 11.3.2.4** below. This accounts for the fact that whilst DEP and SEP are the subject of one DCO application, it is possible that either one or both of the projects will be developed, and if both are developed, that construction may be undertaken either concurrently or sequentially.

Table 11-2: Realistic Worst Case Scenarios.

<table>
<tr><th>Impact</th><th>DEP in Isolation</th><th>SEP in Isolation</th><th>DEP & SEP Together</th><th>Notes and Rationale</th></tr>
<tr><td colspan="5">Construction</td></tr>
<tr><td rowspan="2">Impact 1: Temporary habitat loss / disturbance</td><td colspan="3">The worst case scenarios for Impact 1 are set out in Chapter 10 Benthic Ecology (Table 10.3). The following impacts are relevant to the worst case for Fish Ecology:

• Impact 1: Temporary habitat loss / physical disturbances

A summary of total disturbance footprints are set out below.

The realistic worst case scenario for seabed disturbance for DEP and SEP together is presented below. For the worst case scenario for seabed disturbance for each cable (export/interlink/infield) OSP and temporary mornings when considered in isolation see Chapter 10 Benthic Ecology Impact 1 (Table 10.2). The realistic worst case scenario is when DEP and SEP are both developed in an integrated grid option, and both DEP North and DEP South are developed.</td><td>The temporary disturbance relates to seabed preparation and cable installation.

It should be noted that the seabed preparation area for foundations is less than the footprint of the foundation scour protection.</td></tr>
<tr><td>Offshore cables: Up to 267km of cables

• Maximum area disturbed: 0.789km² (Export cable 0.186km², Infield cables 0.405km², Interlink cables 0.1980km²)</td><td>Offshore cables: Up to 130km of cables

• Maximum area disturbed: 0.390km² (Export cable 0.12km², Infield cables 0.27km²)</td><td>Offshore cables: Up to 448km of cables based on combined scenario.

• Maximum area disturbed (combined scenario): 1.35km²</td><td>Worst case scenario associated with 14MW wind turbines with GBS with scour protection. Preparation area per 14MW wind turbine = 14,314m²</td></tr>
</table>

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
			(Export cable 0.24km^2, Infield cables 0.68km^2, Interlink cables 0.43km^2)	
	Seabed preparation (0.986km^2) • Sandwave clearance maximum disturbed area: **0.93km^2** • Levelling (dredging) for GBS foundations: **0.056km^2** • Route clearance: Pre-lay grapnel run (PLGR): included in trench area • Boulder clearance: **785m^2**	**Seabed preparation (0.043km^2)** • Levelling (dredging) for GBS foundations: **0.042km^2** • Route clearance: PLGR: included in cable trench areas • Boulder clearance: **1,178m^2**	**Seabed preparation (0.86km^2)** • Sandwave clearance maximum disturbed area: **0.76km^2** • Levelling (dredging) for GBS foundations: **0.097km^2** • Route clearance: PLGR: included in the cable trench areas • Boulder clearance: **1,963m^2**	The width of seabed disturbance along the PLGR is estimated to be up to 3m, which would be encompassed by the maximum footprint of cable installation works which has already been accounted for above. Boulders that present an obstacle to installation of infrastructure will be confirmed by the pre-construction surveys. Large boulders (in the order of 5m diameter and 1m height) will be relocated by subsea grab to an adjacent area of seabed within the

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
				DEP and SEP boundaries. The footprint of the boulder placement in the new location has been counted in the 'boulder clearance' disturbance footprint.
	Vessels (0.134km²) **Jack up vessels** • 32 turbines + 1 OSP= **79,200m²** **Anchoring (77,520m²)** • Turbine installation vessel anchoring(Up to 12 lines per location) = **23,760m²** • Export cable installation vessel	**Vessels (0.078km²)** **Jack up vessels** • 24 turbines + 1 OSP= **60,000m²** **Anchoring (34,800m²)** • Turbine installation vessel anchoring (Up to 12 lines per location) = **18,000m²** • Export cable installation vessel	**Vessels (0.272km²)** **Jack up vessels** • 56 turbines + 2 OSPs= **136,800m²** **Anchoring (134,700m²)** • Turbine installation vessel anchoring: (Up to 12 lines per location) = **41,040m²** • Export cable installation vessel anchoring (7 lines)= **33,600m²**	Worst-case scenario assumed up to 2 jack-up deployment at each turbine/OSP. Jack-up barge with six legs per barge (200m² per leg) equating to a total footprint of 1,200m² per installation. Worst case scenario assumes anchors have up to 12 lines per location with anchor footprints of up to 6m width.

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
	anchoring (7 lines) = **26,040m²** • Interlink cable installation vessel anchoring (7 moorings) = **27,720m²**	anchoring (7 lines) (40km) = **16,800m²**	• Interlink cable installation vessel anchoring (7 moorings) = **60,060m²**	
	HDD Exit Point **(614m²)** • Initial trench (600m²) • Transition zone (50m²) • Jack up footprint (128m²) • Deposited material on seabed (200m²)	**HDD Exit Point** **(614m²)** • Initial trench (600m²) • Transition zone (50m²) • Jack up footprint (128m²) • Deposited material on seabed (200m²)	**HDD Exit Point** **(1,356m²)** • Initial trench (600m²) • Transition zone (100m²) • Jack up footprint (256m²) • Deposited material on seabed (400m²)	Horizontal Directional Drilling (HDD) beneath intertidal zone with offshore exit point approximately 1,000m offshore. For the DEP and SEP together scenario, the initial trench assumes both export cables are within the same initial trench, meaning the area of disturbance is the same as DEP and SEP in isolation scenarios. However, for the transition zone it assumes two trenches therefore the area of

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
				disturbance is double DEP and SEP in isolation scenarios. Jack up footprint for DEP and SEP together is includes total jack up legs footprint and jack up movements required.
	Total seabed disturbance Worst case scenario total temporary disturbance footprint = **1.93km²**.	**Total seabed disturbance** Worst case scenario total temporary disturbance footprint = **0.53km²**.	**Total seabed disturbance** Realistic worst case scenario total temporary disturbance footprint = **2.47km²**.	**Realistic worst case scenario** The realistic worst case scenario for seabed disturbance is DEP and SEP developed in an integrated grid option and both DEP North and DEP South are developed.
Impact 2: Temporary increases in suspended sediment concentrations	The worst case scenarios for Impact 2 are set out in **Chapter 8 Marine Geology, Oceanography and Physical Processes** (**Table 8.3**). The following impacts are relevant to the worst case for fish ecology: • Impact 1 (a and b): Changes in suspended sediment concentrations due to seabed preparation and foundation installation and OSPs			The worst case scenario represents the greatest potential for increased SSC across the study area as a result of

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
(SSC) and deposition	• Impact 2 (a and b): Changed in sea bed level due to seabed preparation and foundation installation and OSPs • Impact 3: Changes in suspended sediment concentrations due to export cable corridor • Impact 4: Change in seabed level due to deposition from the suspended sediment plume during export cable installation within the offshore cable corridor. • Impact 5: Changes in suspended sediment concentrations due to offshore cables installation (infield and interlink cables) • Impact 6: Change in sea bed level due to offshore cable installation (infield and interlink cables) The realistic worst case scenario for increased SSC and deposition for DEP and SEP together is presented below. For the worst case scenario for increases SSC for each cable (export/interlink/infield) OSP and temporary mornings when considered in isolation see **Chapter 10 Benthic Ecology** Impact 2 (**Table 10.2**). The realistic worst case scenario is when DEP and SEP are both developed in an integrated grid option, and both DEP North and DEP South are developed.			changes to physical processes which could result in impacts to fish and shellfish ecology.
	Total increases in SSC Worst case scenario for total temporary increases in SSC for	**Total increases in SSC** Worst case scenario for total temporary increases	**Total increases in SSC** Realistic worst case scenario for total temporary increases in SSC for DEP	The realistic worst case scenario for increased SSC is DEP and SEP developed in an integrated grid option

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
	DEP in isolation= **719,150.06 m^3**	in SSC for SEP in isolation= **431,217.77m^3**	and SEP together= **1,744,451.03m^3**	and both DEP North and DEP South are developed.
Impact 3: Re-mobilisation of contaminated sediments	The worst case scenarios for Impact 3 are set out in **Chapter 9 Marine Water and Sediment Quality** (**Table 9.2**). The following impacts are relevant to the worst case scenario for fish ecology: • Impact 5: Deterioration in water quality due to the release of contaminated sediment during construction activities			
Impact 4: Underwater noise during foundation piling	**WTG Foundations** Up to 32 turbines Foundation options: Monopile = 1 pile; 4 leg-jacket = 4 pin pile Number of piles for wind turbines (14MW) = 32 monopiles or 128 pin piles **Offshore substation foundations**	**WTG Foundations** Up to 24 turbines Foundation options: Monopile = 1 pile; 4 leg-jacket = 4 pin pile Number of piles for wind turbines (14MW) = 24 monopiles or 96 pin piles **Offshore substation foundations** 1 x Offshore Substation	**WTG Foundations** Up to 56 turbines Foundation options: Monopile = 1 pile; 4 leg-jacket = 4 pin pile Number of piles for wind turbines (14MW) = 56 monopiles or 224 pin piles **Offshore substation foundations** 2 x Offshore Substations Foundation options:	Hammer piled foundations represent the worst-case scenario for underwater noise. Assumes 100% of foundations are piled.

<table>
<tr><th>Impact</th><th>DEP in Isolation</th><th>SEP in Isolation</th><th>DEP & SEP Together</th><th>Notes and Rationale</th></tr>
<tr><td rowspan="2"></td><td>1 x Offshore Substation
Foundation options:
2 x 4 leg-jacket = 8 pin piles

Maximum number of piled foundations:
Up to 32 monopiles plus 8 pin piles or
Up to 136 pin piles</td><td>Foundation options:
2 x 4 leg-jacket = 8 pin piles

Maximum number of piled foundations:
Up to 24 monopiles plus 8 pin piles or
Up to 112 pin piles</td><td>4 x 4 leg-jacket = 16 pin piles

Maximum number of piled foundations:
Up to 56 monopiles plus 8 pin piles or
Up to 240 pin piles</td><td></td></tr>
<tr><td colspan="3">Maximum hammer energy:
• Monopiles:
  ○ Up to 5,000kJ for 14MW; and
  ○ Up to 5,500kJ for 18+MW.
• Pin piles:
  ○ Up to 3,000kJ.
Maximum active piling time (including soft-start and ramp-up and providing allowance for issues such as low blow rate, refusal, etc):
• Four hours per monopile; and
• Three hours per pin pile (12 hours per WTG (four pin piles per foundation)
Maximum pile diameters: See Chapter 12 Marine Mammal Ecology Table 12.2.</td><td>This is the worst-case scenario. The maximum hammer energy will not be required for all piles and would not be required for the entire duration to install a pile.</td></tr>
</table>

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
	Total **monopile** active piling time is up to **128 hours** (**5.3 days**) for 32 WTGs.	Total **monopile** active piling time is up to **96 hours** (**4 days**) for 24 WTGs.	Total **monopile** active piling time is up to **224 hours** (**9.3 days**) for 56 WTGs.	Assumes a wind turbine foundation installation of 12 months for DEP or SEP in isolation and 24 months for DEP and SEP together. Assumes 4 hours per WTG
	Total **pin pile** active piling time is up to **384 hours** (**16 days**) for 32 WTGs Total pin pile active piling time is up to **24 hours (1 day)** per substation (eight pin piles per foundation) **Maximum total active piling time** is up to **408 hours** (**17 days**) based on pin pile foundations for **32 WTGs** and **one substation**	Total **pin pile** active piling time is up to **288 hours** (**12 days**) for 24 WTGs Total pin pile active piling time is up to **24 hours (1 day)** per substation (eight pin piles per foundation) **Maximum total active piling time** is up to **312 hours** (**13 days**) based on pin pile foundations for **24 WTGs** and **one substation**	Total **pin pile** active piling time is up to **672 hours** (**28 days**) for 56 WTGs Total pin pile active piling time is up to **48 hours (2 days)** per substation (eight pin piles per foundation) **Maximum total active piling time** is up to **720 hours** (**30 days**) based on pin pile foundations for **56 WTGs** and **two substations**	Total piling time includes soft-start and ramp-up, and providing allowance for issues such as low blow rate, refusal, etc. More likely worst-case scenario is up to 3.2 hours per monopile, totaling 179.2 hours for 56 WTGs. Worst-case average (for all WTGs) active piling time for 13m or 16m pin-piles is 2.5 hours (150). With soft-

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
				start and ramp-up the total average piling time is 180 minutes per pin-pile, or 720 minutes per WTG.
	No concurrent piling at DEP	No concurrent piling at SEP	Potential for concurrent piling between DEP and SEP depending on build scenario	Concurrent piling between DEP and SEP is the worst-case
	Number of monopiles to be installed per 24 hour period = 1 Number of pin-piles to be installed per 24 hour period = 1	Number of monopiles to be installed per 24 hour period = 1 Number of pin-piles to be installed per 24 hour period = 1	Number of monopiles to be installed per 24 hour period = 1 Number of pin-piles to be installed per 24 hour period = 1	Note that the underwater noise modelling has applied a stationary animal approach.
Impact 5: Underwater noise from other construction activities (such as seabed preparation, cable installation	**Seabed clearance** Activities could include PLGR, boulder clearance, ploughing, pre-sweeping and dredging.			
	Cable installation The intention is to bury cables, however in areas where burial is not possible, the cable will be surface laid with cable protection. Additional methods considered include ploughing, jetting, trenching mechanical cutting			Assumed equal amounts of jetting and cutting.

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
and rock placement)	**Vessels** • Maximum number of vessels on site at any one time: up to 16 vessels • Construction vessels trips to port: 603 over 2 year construction period.	**Vessels** • Maximum number of vessels on site at any one time: up to 16 vessels • Construction vessels trips to port: 603 over 2 year construction period.	**Vessels** • Maximum number of vessels on site at any one time: 25 • Construction vessels trips to port: 1,196 over 4 year construction period if constructed sequentially.	Maximum number of construction vessels. Construction port/s will not be confirmed until nearer the start of construction.
Impact 6: Underwater noise during UXO clearance	Various possible types and sizes of UXO. Worst case identified by Sheringham Shoal OWF and Dudgeon OWF: 2,000lb German air dropped bomb (Trinitrotoluene (TNT) equivalent of 525kg). Possible number of UXO unknown.			Indicative only. A detailed UXO survey would be completed prior to construction. The exact type, size and number of possible detonations and duration of UXO clearance operations is therefore not known at this stage. N.B. Assessments for UXO clearance are for information only and are not part of the DCO application (separate (ML) application/s will

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
				be made prior to construction).
Impact 7: Impacts on commercially exploited species associated with their displacement from the area of activity/works	The worst case scenarios for Impact 7 are set out in **Chapter 14 Commercial Fisheries** (**Table 14.3**). The following impacts are relevant to the worst case for fish ecology: • Impact 1: Construction activities and physical presence of constructed wind farm infrastructure leading to reduction in access to, or exclusion from established fishing grounds. • Impact 2: Offshore cable corridor construction activities leading to reduction in access to, or exclusion from established fishing grounds • Impact 3: Displacement from the wind farm site leading to gear conflict and increased pressure on adjacent grounds • Impact 4: Displacement from cable corridor leading to gear conflict and increased pressure on adjacent grounds • Impact 6: Increased vessel traffic within fishing grounds as a result of changes to shipping routes and transiting construction vessel traffic from wind farm sites and offshore export cable corridor infrastructure leading to interference with fishing activity.			
Operation				
Impact 1: Temporary habitat loss / disturbance	• Up to 10 jack-up deployments per year. Legs / spudcans footprint	• Up to 10 jack-up deployments per year. Legs / spudcans footprint	• Up to 20 jack-up deployments per year. Legs / spudcans footprint up to **24,000m²** per year	Assuming a jack-up vessel with a seabed footprint of 1,200m^2 (up to four legs / spudcans,

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
	up to **12,000m²** per year • Cable repair, replacement and reburial footprint: **1,743m²** per year **Total Disturbance** Worst case scenario total temporary disturbance footprint for DEP in isolation per year = **13,743m²** Approximate total temporary disturbance footprint for DEP in isolation per operational lifetime (35 years) = **0.48km²**	up to **12,000m²** per year • Cable repair, replacement and reburial footprint: **1,170m²** per year **Total Disturbance** Worst case scenario total temporary disturbance footprint for SEP in isolation per year = **13,170m²** Approximate total temporary disturbance footprint for SEP in isolation per operational lifetime (35 years) = **0.46km²**	• Cable repair, replacement and reburial footprint: **4,704m²** per year **Total Disturbance** Realistic Worst case scenario total temporary disturbance footprint for DEP and SEP together per year= **28,704m²** Approximate total temporary disturbance footprint for DEP and SEP together per operational lifetime (35 years) = **1km²**	each with a footprint of up to 300m²). Disturbance is shown on average per year, however maintenance could vary across years during the operational stage. An approximate total disturbance is also shown for the operational life time, which is expected to be 35 years. The realistic worst case scenario is shown for DEP and SEP together. To see the worst case scenario for cables, OSP and anchoring in isolation see **Chapter 10 Benthic Ecology Table 10.3** Construction Impact 1. The realistic worst case scenario for temporary habitat loss is DEP and

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
				SEP developed in integrated grid option and both DEP North and DEP South are developed.
Impact 2: Long term habitat loss (in Cromer Shoal Chalk Beds MCZ)	**Cable protection ($900m^2$):** • HDD exit transition zone (100m x 3m): **$300m^2$** • External cable protection (100m x 3m): **$600m^2$**	**Cable protection ($900m^2$):** • HDD exit transition zone (100m x 3m): **$300m^2$** • External cable protection (100m x 3m): **$600m^2$**	**Cable protection ($1,800m^2$):** • HDD exit transition zone (2 cables): **$600m^2$** • External cable protection (2 cables): **$1,200m^2$**	Rock bags (designed to be removable on decommissioning) may be placed in the HDD exit transition zone and as cable protection for export cable. The impact assessment is based on removal during decommissioning.
Impact 3: Permanent habitat loss	**Wind turbine foundations:** Maximum footprint of 32 GBS foundations (14MW) including	**Wind turbine foundations:** Maximum footprint of 24 GBS foundations (14MW) including	**Wind turbine foundations:** Maximum footprint of 56 GBS foundations (14MW) including foundation scour protection: **$0.8km^2$**	Infrastructure that may not be removed during decommissioning. Footprint of cable protection does not include cable protection in the MCZ

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
	foundation scour protection: **0.46km^2** **Substation foundations:** Maximum footprint of substation foundations including scour protection (with suction cans): **1,662m^2** **Subsea cable surface protection and pipeline crossings:** Maximum footprint of cable protection (Export, interlink and infield) and cable crossing protection: **0.051km^2**	foundation scour protection: **0.34km^2** **Substation foundations:** Maximum footprint of substation foundations including scour protection (with suction cans): **1,662m^2** **Subsea cable surface protection and pipeline crossings:** Maximum footprint of cable protection (Export, interlink and infield) and cable crossing protection: **0.015km^2**	**Substation foundations:** Maximum footprint of substation foundations including scour protection (with suction cans): **3,324m^2** **Subsea cable surface protection and pipeline crossings:** Maximum footprint of cable protection (Export, interlink and infield) and cable crossing protection: **0.059km^2**	as this is covered in long term habitat loss (Impact 2) below, as this will be removed at decommissioning.
	Total permanent habitat loss: 0.51km^2	**Total permanent habitat loss:** 0.36km^2	**Total permanent habitat loss:** 0.86km^2	

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
Impact 4: Introduction of wind turbine foundations, scour protection and hard substrate	See impacts 2 and 3.			
Impact 5: Temporary increases in suspended sediment concentrations (SSC)	See Operation Impact 1: Temporary habitat loss / disturbance. Temporary increases in SSC will result from periodic jack up vessel deployment, and cable repair, replacement and reburial activities.			The volume of sediment that could be suspended has not been calculated but will be a small proportion of the quantity generated by construction and decommissioning activities.
Impact 6: Re-mobilisation of contaminated sediment	The worst case scenarios for Impact 6 are set out in **Chapter 9 Marine Water and Sediment Quality** (**Table 9.2**). The following impacts are relevant to the worst case scenario for fish ecology: • Impact 5: Deterioration in water quality due to the release of contaminated sediment during construction activities			

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
Impact 7: Underwater noise	The worst case scenarios for Impact 3 are set out in **Chapter 12 Marine Mammal Ecology** (**Table 12.2**). The following impacts are relevant to the worst case scenario for fish ecology: • Underwater noise from operational turbines • Underwater noise from maintenance activities (cable repair, replacement ad reburial and cable protection works) • Underwater noise from vessels			
Impact 8: EMF	**Offshore cables:** Up to **267km** of cables comprising: • One HVAC export cable up to **62km** in length • **135km** of infield cables (DEP North: 90km; DEP South: 45km) • Up to 3 parallel interlink cables	**Offshore cables:** Up to **130km** of cables comprising: • One HVAC export cable up to **40km** in length • **90km** of infield cables • No interlink cables • Burial depth: Same as DEP in isolation	**Offshore cables:** Up to **481km** of cables based on combined scenario[1]: • 2 HVAC export cables up to **102km** in length • Up to **225km** of infield cables • Up to 7 interlink cables from DEP North to OSP in SEP, up to **154km** total length	

[1] The individual worst case scenarios presented for export, interlink and infield cable lengths would not represent a developable scenario if taken as a total, therefore a 'realistic' worst case scenario for all cables together is presented, which does represent the worst case developable scenario.

<table>
<tr><th>Impact</th><th>DEP in Isolation</th><th>SEP in Isolation</th><th>DEP & SEP Together</th><th>Notes and Rationale</th></tr>
<tr><td rowspan="2"></td><td rowspan="2">between DEP South and OSP in DEP North: up to 66km in length (combined)
• Burial depth: 0.5 to 1.5m (excluding burial in sand waves up to 20m; export cable surface lay possible in Cromer Shoal Chalk Beds MCZ) and up to 1.0m for the export cables.</td><td rowspan="2"></td><td>• Burial depth: Same as DEP and SEP in isolation</td><td></td></tr>
<tr><td>Realistic worst case scenario for all cables
Up to 448km of cables
(Export cable: 80km, Infield cables: 225km, Interlink cables: 143km)
• Burial depth: Same as the worst case scenario for each cable individually.</td><td>Realistic worst case scenario for all cables
The realistic worst case scenario for cable lengths is DEP and SEP are developed in an integrated grid option and both DEP North and DEP South are developed.</td></tr>
<tr><td>Impact 9: Impacts on commercially exploited species associated with their displacement from the area of activity/works</td><td colspan="3">The worst case scenarios for Impact 9 are set out in Chapter 14 Commercial Fisheries (Table 14.3). The following impacts are relevant to the worst case for fish ecology:
• Impact 1: Physical presence of wind farm site infrastructure leading to reduction in access to, or exclusion from established fishing grounds
• Impact 2: Physical presence of offshore export cable and infrastructure within the DEP/SEP offshore export cable corridor leading to reduction in access to, or exclusion from established fishing grounds
• Impact 3: Displacement from the wind farm site and offshore export cable corridor leading to gear conflict and increased pressure on adjacent grounds</td><td></td></tr>
</table>

<table>
<tr><th>Impact</th><th>DEP in Isolation</th><th>SEP in Isolation</th><th>DEP & SEP Together</th><th>Notes and Rationale</th></tr>
<tr><td></td><td colspan="3">Impact 4: Physical presence of the wind farm site and offshore export cable leading to gear snagging
Impact 6: Increased vessel traffic within fishing grounds as a result of changes to shipping routes and transiting construction vessel traffic from wind farm sites and offshore export cable corridor infrastructure leading to interference with fishing activity.</td><td></td></tr>
<tr><td colspan="5">Decommissioning</td></tr>
<tr><td>Impact 1: Temporary habitat loss / physical disturbance</td><td colspan="3" rowspan="5">No final decision has yet been made regarding the final decommissioning policy for the offshore project infrastructure. It is also recognised that legislation and industry best practice change over time. However, the following infrastructure is likely be removed, reused or recycled where practicable:
Turbines including monopile, steel jacket and GBS foundations;
OSPs including topsides and steel jacket foundations;
Offshore cables may be removed or left in situ depending on available information at the time of decommissioning; and
Cable protection in the Cromer Shoal Chalk Beds MCZ.
The following infrastructure is likely to be decommissioned in situ depending on available information at the time of decommissioning:
Scour protection;
Offshore cables may be removed or left in situ; and
Crossings and cable protection outside the Cromer Shoal Chalk Beds MCZ.
The detail and scope of the decommissioning works will be determined by the relevant legislation and guidance at the time of decommissioning and will be</td><td rowspan="5">Decommissioning arrangements will be detailed in a Decommissioning Plan, which will be drawn up

and agreed with the Department for Business, Energy and Industrial Strategy (BEIS) prior to construction.</td></tr>
<tr><td>Impact 2: Permanent habitat loss</td></tr>
<tr><td>Impact 3: increased in SSC and deposition</td></tr>
<tr><td>Impact 4: Re-mobilisation of contaminated sediments</td></tr>
<tr><td>Impact 5: Underwater noise</td></tr>
</table>

Impact	DEP in Isolation	SEP in Isolation	DEP & SEP Together	Notes and Rationale
Impact 6: Impacts on commercially exploited species associated with their displacement from the area of activity/works	agreed with the regulator. For the purposes of the worst case scenario, it is anticipated that the impacts will be no greater than those identified for the construction phase.			

11.3.2.2 Construction Scenarios

11. The following principles set out the framework for how DEP and SEP may be constructed:

- DEP and SEP may be constructed at the same time, or at different times;
- If built at the same time both projects could be constructed in four years, with offshore construction being undertaken over two years (likely years three and four) of the overall construction period;
- If built at different times, either project could be built first;
- If built at different times the first project would require a four-year period of construction including a two year offshore construction period, the second project a three-year period of construction including a two year offshore construction period;
- If built at different times, the duration of the gap between start of construction of the first project, and the start of construction of the second project may vary from two to four years;
  - If the gap between the projects is less than two years, the first project would wait for the second project in order to be constructed together;
- Assuming maximum construction periods, and taking the above into account, the maximum period over which the construction of both projects could take place is seven years; and
- The earliest construction start date is 2024 and the latest is 2028.

12. In order to determine which construction scenario presents the realistic worst case for each receptor and impact, the assessment considers both maximum duration effects and maximum peak effects, in addition to each Project being developed in isolation, drawing out any differences between each of the two Projects.

13. The three construction scenarios considered by the fish and shellfish ecology assessment are therefore:

- Build DEP or build SEP in isolation;
- Build DEP and SEP concurrently – reflecting the maximum peak effects; and
- Build one project followed by the other with a gap of up to four years (sequential) – reflecting the maximum duration of effects. This would result in a maximum gap in offshore construction of one year.

14. Any differences between DEP and SEP, or differences that could result from the manner in which the first and the second Projects are built (concurrent or sequential and the length of any gap) are identified and discussed where relevant in the impact assessment section of this chapter (**Section 11.6**). For each potential impact only the worst case construction scenario for two Projects is presented, i.e. either concurrent or sequential. The justification for what constitutes the worst case is provided, where necessary, in **Section 11.6**.

11.3.2.3 Operation Scenarios

15. Operation scenarios are described in detail in **Chapter 5 Project Description**. The assessment considers the following three scenarios:
    - Only DEP in operation;
    - Only SEP in operation; and
    - The two projects operating at the same time, with a gap of up to three years between each project commencing operation.
16. The operational lifetime of each project is expected to be 35 years.

11.3.2.4 Decommissioning Scenarios

17. Decommissioning scenarios are described in detail in **Chapter 5 Project Description**. Decommissioning arrangements will be agreed through the submission of a Decommissioning Plan prior to construction, however for the purpose of this assessment it is assumed that decommissioning of DEP and SEP could be conducted separately, or at the same time.

11.3.3 Summary of Mitigation Embedded in the Design

18. This section outlines the embedded mitigation relevant to the fish and shellfish ecology assessment, which has been incorporated into the design of the Project (**Table 11-3**). Where other mitigation measures are proposed, these are detailed in the impact assessment (**Section 11.6**).
19. The Applicant has committed to a number of techniques and engineering designs / modifications inherent as part of the project, during the pre-application phase, in order to avoid a number of impacts or reduce impacts as far as possible. Embedding mitigation into the project design is a type of primary mitigation and is an inherent aspect of the EIA process.
20. A range of different information sources have been considered as part of embedding mitigation into the design of the project (for further details see **Chapter 5 Project Description**, **Chapter 4 Site Selection and Assessment of Alternatives**) including engineering requirements, ongoing discussions with stakeholders and regulators, commercial considerations and environmental best practice.
21. Where possible, the embedded mitigation has been taken into account in each relevant impact assessment when assessing the potential magnitude of effect.

Table 11-3: Embedded Mitigation Measures

Parameter	Mitigation Measures Embedded into the Design of DEP and SEP
Electromagnetic Fields	
Cable Burial	The Applicant is committed to burying offshore export cables where possible, reducing the effects of electromagnetic fields (EMF) and also reducing the need for surface cable protection which reduces the introduction of hard substrate and modification of habitat. Typical burial depth for DEP and SEP cables, excluding in areas of sand waves, is expected to be between 0.5m to 1.5m (or up to 1m for the export cables). Cable burial requirements for the purpose of

Parameter	Mitigation Measures Embedded into the Design of DEP and SEP
	the environmental assessment have been informed through the completion of a draft export cable burial risk assessment (Pace Geotechnics, 2020) which has been produced by the Applicant at an early stage to inform the design and environmental assessment processes on advice from relevant stakeholders. The burial requirements for all cables will be finalised based on an assessment of the risks posed to the project in specific areas, following the completion of detailed pre-construction geotechnical and geophysical investigations and the subsequent finalisation of the cable burial risk assessment, prior to the start of construction.
Underwater Noise	
Construction	During construction, overnight working practices would be employed offshore so that construction activities could be 24 hours, thus reducing the overall period for potential impacts to fish communities in proximity to the wind farm areas.
Soft-start and ramp-up during Piling Activities	Each piling event would commence with a soft-start at a lower hammer energy followed, by a gradual ramp-up for at least 20 minutes to the maximum hammer energy required (the maximum hammer energy is only likely to be required at a few of the piling installation locations to allow mobile species to move away from the area of highest noise impact. This commitment is presented in the draft Marine Mammal Mitigation Protocol (MMMP) and is secured under the conditions of the draft DCO.
UXO	The following measures are presented in **Chapter 12 Marine Mammal Ecology** but are also of relevance to impacts on fish and shellfish receptors: • Only one unexploded ordnance (UXO) would be detonated at a time during UXO clearance operations in the offshore development area. There would be no simultaneous UXO detonations, but potentially more than one UXO detonation could occur in a 24 hour period. • There would be no UXO detonation in the offshore development area at the same time as piling in the offshore development area during the winter period, in that although they may occur in the same day or 24 hour period, they would not occur at exactly the same time. • There would be no concurrent piling or UXO detonation between DEP and SEP if both projects are constructed at the same time. This is stated within the draft MMMP which will be submitted with the DCO application. The final MMMP for piling will be produced pre-construction and is secured through the DCO.

Parameter	Mitigation Measures Embedded into the Design of DEP and SEP
	• A MMMP and Southern North Sea Special Areas of Conservation (SAC) Site Integrity Plan (SIP) for both piling and UXO clearance will be implemented for marine mammal mitigation. Any mitigation beneficial to the marine mammals would also potentially reduce impacts on fish and shellfish receptors. Draft and in principle versions of these documents will be submitted with the DCO application.

11.4 Impact Assessment Methodology

11.4.1 Policy, Legislation and Guidance

11.4.1.1 National Policy Statements

22. The assessment of potential impacts upon fish and shellfish ecology has been made with specific reference to the relevant National Policy Statements (NPS). These are the principal decision making documents for Nationally Significant Infrastructure Projects (NSIPs). Those relevant to the Project are:

- Overarching NPS for Energy (EN-1) (Department of Energy and Climate Change (DECC) 2011a);
- NPS for Renewable Energy Infrastructure (EN-3) (DECC 2011b); and
- NPS for Electricity Networks Infrastructure (EN-5) (DECC 2011c).

23. The specific assessment requirements for fish and shellfish ecology, as detailed in the NPS, are summarised in **Table 11-4** together with an indication of the section of the PEIR chapter where each is addressed.

Table 11-4: NPS Assessment Requirements.

NPS Requirement	NPS Reference	Section Reference
EN-3 NPS for Renewable Energy Infrastructure (EN-3)		
There is the potential for the construction and decommissioning phases, including activities occurring both above and below the sea bed, to interact with sea bed 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.	EN-3 section 2.6.73	Potential impacts during construction, operation and decommissioning have been assessed in **Section 11.6**

NPS Requirement	NPS Reference	Section Reference
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.	EN-3 section 2.6.74	Fish species which may be likely receptors of impact are identified in **Section 11.5.5**
Where it is proposed that mitigation measures of the type set out in paragraph 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.	EN-3 section 2.6.75	**Section 11.6.2.8** identifies and assesses potential impacts on fish and shellfish receptors due to EMF during operation. The use of armoured cables and cable burial as mitigation is discussed in **Section 11.3.3**
EMF during operation may be mitigated by use of armoured cable for inter-array 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 sea bed impacts are likely to be negligible. However, sufficient depth to mitigate impacts will depend on the geology of the sea bed.	EN-3 section 2.6.76	
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.	EN-3 section 2.6.77	Mitigation measures embedded in the project design are outlined in **Section 11.3.3**

NPS Requirement	NPS Reference	Section Reference
The construction and operation of offshore windfarms can have both positive and negative effects on fish and shellfish stocks.	EN-3 section 2.6.122	**Sections 11.6.1** and **11.6.2**
Effects of offshore windfarms 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.	EN-3 section 2.6.63	
Assessment of offshore ecology and biodiversity should be undertaken by the applicant for all stages of the lifespan of the proposed offshore windfarm and in accordance with the appropriate policy for offshore windfarm EIAs	EN-3 section 2.6.64	**Sections 11.6.1, 11.6.2** and **11.6.3** assess the potential impacts of DEP and SEP during construction, operation and decommissioning on various fish and shellfish receptors.
Consultation on the assessment methodologies should be undertaken at early stages with the statutory consultees as appropriate.	EN-3 section 2.6.65	**Section 11.2** details consultation which has been undertaken with regard to fish and shellfish ecology, including responses to the Scoping Report and feedback provided through the ETG meetings.
Any relevant data that has been collected as part of post-construction ecological monitoring from existing, operational offshore windfarm should be referred to where appropriate.	EN-3 section 2.6.66	Such data has been referred in **Sections 11.6.1** and **11.6.2.**

NPS Requirement	NPS Reference	Section Reference
The assessment should include the potential for the scheme to have both positive and negative impacts on marine ecology and biodiversity.	EN-3 section 2.6.67	**Sections 11.6.1** and **11.6.2** assess the potential impacts (both positive and negative) of DEP and SEP during construction, operation and decommissioning on various fish and shellfish receptors
Ecological monitoring is likely to be appropriate during the construction and operational phases to identify the actual impact so that, where appropriate, adverse effects can then be mitigated and to enable further useful information to be published relevant to future projects.	EN-3 section 2.6.71	Monitoring requirements are addressed in **Section 11.11**.

11.4.1.2 Other

24. In addition to the NPS, there are a number of pieces of legislation, policy and guidance applicable to the assessment of fish and shellfish ecology.

25. The Marine Policy Statement (MPS) (HM Government, 2011) sets out the framework for environmental, social and economic considerations that need to be taken into account in marine planning, providing high-level approach to marine planning and general principles for decision making. The high level objective of ‘Living within environmental limits’ covers the points relevant to fish and shellfish ecology, this requires that:

- Biodiversity is protected, conserved and where appropriate recovered and loss has been halted;
- Healthy marine and coastal habitats occur across their natural range and can support strong, biodiverse biological communities and the functioning of healthy, resilient and adaptable marine ecosystems; and
- Our oceans support viable populations of representative, rare, vulnerable, and valued species.

26. The East Inshore and East Offshore Marine Plans (HM Government, 2014) have the following objectives that are relevant to this chapter:

- Objective 6 “To have a healthy, resilient and adaptable marine ecosystem in the East Marine Plan areas”; and

- Objective 7 "To protect, conserve and, where appropriate, recover biodiversity that is in or dependent upon the East marine plan areas".

27. These cover policies and commitments on the wider ecosystem, set out in the MPS including those relating to the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD) (see **Chapter 3 Policy and Legislative Context** and **Chapter 9 Water and Sediment Quality** for more details), as well as other environmental, social and economic considerations.

28. Several policies within the East Marine Plan (HM Government, 2014) are of particular relevance to fish and shellfish ecology and have been considered within this assessment:

- FISH 1: Within areas of fishing activity, proposals should demonstrate:
    - That they will not prevent fishing activities on, or access to, fishing grounds;
    - How, if there are adverse impacts on the ability to undertake fishing activities or access to fishing grounds, they will minimise them;
    - How, if the adverse impacts cannot be minimised, they will be mitigated; and
    - The case for proceeding with their proposal if it is not possible to minimise or mitigate the adverse impacts.
- FISH 2: Proposals should demonstrate, in order of preference:
    - That they will not have an adverse impact upon spawning and nursery areas and any associated habitat;
    - How, if there are adverse impacts upon the spawning and nursery areas and any associated habitat, they will minimise them;
    - How, if the adverse impacts cannot be minimised they will be mitigated; and
    - The case for proceeding with their proposals if it is not possible to minimise or mitigate the adverse impacts.
- ECO1: Cumulative impacts affecting the ecosystem of the East marine plans and adjacent areas (marine, terrestrial) should be addressed in decision-making and plan implementation.

29. In addition to the above the following documents have been used to inform the assessment of potential impacts of DEP and SEP on fish and shellfish ecology. These include:

- Guidance document on wind energy developments and EU nature legislation (2020);
- Energy transmission infrastructure and EU nature legislation (2018);
- Guidelines for Ecological Impact Assessment in the UK and Ireland (CIEEM, 2018);

- Centre for Environment, Fisheries and Aquaculture Science (Cefas) (2011) Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. Contract report: ME5403, September 2011;
- Sound Exposure Guidelines for Fishes and Sea Turtles Monitoring (Popper *et al.,* 2014);
- Cefas, Marine Consents and Environment Unit (MCEU), Department for Environment, Food and Rural Affairs (Defra) and Department of Trade and Industry (DTI) (2004) OWFs - Guidance note for Environmental Impact Assessment In respect of the Food and Environmental Protection Act (FEPA) and CPA requirements, Version 2;
- Strategic Review of Offshore Windfarm Monitoring Data Associated with FEPA Licence Conditions (Cefas, 2010);
- Review of post-consent OWF monitoring data associated with licence conditions (MMO, 2014);
- Renewable UK (2013) Cumulative impact assessment guidelines, guiding principles for cumulative impacts assessments in OWFs;
- Monitoring Guidance for Underwater Noise in European Seas, Part II Monitoring Guidance Specifications. JRC Scientific and Policy Report EUR 26555 EN. (Dekeling *et al*, 2014);
- Blyth-Skyrme, R.E. (2010) Options and opportunities for marine fisheries mitigation associated with wind farms. Final report for Collaborative Offshore Wind Research into the Environment contract FISHMITIG09. COWRIE Ltd, London; and
- Planning Inspectorate Scoping Opinion (Planning Inspectorate, 2019) which included scoping responses from statutory consultees.

30. Further detail is provided in **Chapter 3 Policy and Legislative Context**.

11.4.2 Data and Information Sources

31. In order to provide site specific and up to date information on which to base the impact assessment, the data sources listed in **Table 11-5** were used. As fish are highly mobile, other data sets with large-scale coverage are of more relevance for characterising the natural fish and shellfish resource. A key source of information used are fisheries landings data; these provide both large spatial coverage and effort, although the data has some limitations (i.e. they are skewed towards commercial species with many non-commercial species being discarded at sea).

32. It was agreed with stakeholders through the EPP that sufficient publicly available information is available to undertake a robust assessment (with any limitations clearly stated where relevant – see **Table 11-5** and **Section 11.4.6**) and, as a result, that site specific fish sampling surveys were not required.

Table 11-5: Data Sources

Data set	Spatial coverage	Year	Notes
MMO landings data (weight and value) by species	ICES rectangles 34F1, 35F1, 34F0 and 34F1	2009 to 2019	34F1 and 35F1 contain DEP and SEP and are the primary data source
North Sea International Bottom Trawl Survey (IBTS)	North Sea	2010 to 2020	ICES rectangles 34F1 and 35F1
Fish spawning and nursery grounds	Southern North Sea	N/A	(Coull *et al.*, 1998; Ellis *et al.*, 2012; Aires *et al.*, 2014))
ICES International Herring Larvae Survey (IHLS) data	North Sea (and other areas)	2010 to 2019	The IHLS data has not covered the area off the North Norfolk coast where the projects are located since the 1970s. More recent data (post 2019) will be incorporated with the final ES where available.
Dudgeon and Sheringham Shoal OWF site characterisation and pre-construction surveys fish and shellfish	Sheringham Shoal and Dudgeon OWFs (including export cable corridors)	2005, 2008, 2014	Beam, otter and epibenthic trawls. It is acknowledged that these surveys are several years old.
Dudgeon and Sheringham Shoal OWF herring spawning surveys (Pre- and post-construction)	Sheringham Shoal and Dudgeon OWFs (including export cable corridors and adjacent areas)	2008, 2009, 2010	There were some inconsistencies during the herring spawning campaigns as well as encountering access problems due to fishing activity resulting in stations being missed.
Sheringham Shoal OWF elasmobranch surveys (Pre- and post-cable installation)	Sheringham Shoal OWF offshore export cable route	2010, 2012 - 2015	These surveys were spatially and temporally quite limited and therefore only provide additional context to the other available sources of information.

Data set	Spatial coverage	Year	Notes
Project Benthic Characterisation Survey	DEP and SEP wind farm sites and export cable corridors	2020	All project areas surveyed except the narrow interlink cable corridor between DEP South and DEP North.
DEP and SEP aerial surveys	Area encompassing the DEP and SEP wind farm sites plus 4km buffer	2018 to 2020	19 transects, 2.5km parallel transect spacing. Survey at least monthly over a 24-month period.

11.4.2.1 Other available sources

33. Other sources that have been used to inform the assessment are listed below:

- Cefas publications;
- Institute for Marine Resources and Ecosystem Studies (IMARES) publications;
- Collaborative Offshore Wind Research into the Environment (COWRIE) reports;
- International Council for the Exploration of the Sea (ICES) publications;
- East Marine Plan documents (HM Government, 2014);
- Marine Conservation Zone (MCZ) recommendations (Natural England, 2018);
- Offshore Renewables Joint Industry Programme (ORJIP) study on impacts from piling on fish at offshore windfarm sites (Boyle and New, 2018);
- Results of monitoring programmes undertaken in operational windfarms in the UK and other European countries; and
- Other relevant peer-review publications and assessments.

11.4.3 Impact Assessment Methodology

34. **Chapter 6 EIA Methodology** provides a summary of the general impact assessment methodology applied to DEP and SEP. The following sections confirm the methodology used to assess the potential impacts on fish and shellfish ecology as agreed by statutory stakeholders through the EPP.

35. The potential impacts that are relevant to DEP and SEP on fish and shellfish are specified in the Cefas and MCEU (2004) guidelines for offshore wind developments. The following aspects are taken forward for assessment:

- Spawning grounds;
- Nursery grounds;
- Feeding grounds;
- Shellfish production areas;
- Overwintering areas for crustaceans (e.g. lobster and crab);
- Migration routes;

- Conservation importance;
- Importance in the food web; and
- Commercial importance.

36. Assessment of the impacts on the above have been separately applied to the construction, operational and decommissioning phases.

37. Cumulative impacts relevant to fish and shellfish ecology arising from other marine developments are discussed in **Section 11.7** and inter-relationships and interactions with other receptor groups are described in **Section 11.9** and **11.10** respectively.

11.4.3.1 Definitions

38. For each effect, the assessment identifies receptors sensitive to that effect and implements a systematic approach to understanding the impact pathways and the level of impacts on given receptors. The definitions of sensitivity, value and magnitude for the purpose of the fish and shellfish ecology assessment are provided in **Table 11-6, Table 11-7** and **Table 11-8**.

11.4.3.2 Sensitivity

39. 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. risk as defined by Popper *et al.,* (2014)).

40. Throughout the assessment, receptor sensitivities have been informed through review of the available peer-reviewed scientific literature, and assessments available on the Marine Life Information Network (MarLIN) database and the associated Marine Evidence based Sensitivity Assessment (MarESA) framework. It is acknowledged that the MarLIN assessments have limitations and are not available for all species. However, the MarLIN 'evidence base' remains the largest review yet undertaken on the effects of human activities and natural events on marine species and habitats, and includes evidence-based sensitivity assessments that have been used in the impact assessment. Where relevant, limitations have been taken in to account and other information and data accessed where appropriate. Definitions of receptor sensitivity are provided in **Table 11-6**.

41. With regard to noise related impacts, the criteria adopted are based on internationally accepted peer-reviewed evidence and criteria proposed by consensus of expert committees. Fish criteria were adopted from Popper *et al.* (2014) and National Marine Fisheries Service (NMFS, 2016) thresholds and criteria for the modelling of underwater noise from piling activity was also used and consideration has been given to work by Mueller-Blenkle *et al.* (2010) and Halvorsen *et al.* (2012).

Table 11-6 Definition of sensitivity for Fish and Shellfish receptor

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.

**In this case individual receptor does not refer to an individual organism but refers to the population or stock of a species*

11.4.3.3 Value

42. In some instances the ecological value of the receptor may also be taken into account within the assessment of impacts. In these instances 'value' refers to the importance of the receptor in the area in terms of conservation status, role in the ecosystem, and geographic frame of reference. Note that for stocks of species which support significant fisheries commercial value is also taken into consideration. Value definitions are provided in **Table 11-7.**

Table 11-7 Definition of value for Fish and Shellfish receptor

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

11.4.3.4 Magnitude

43. The magnitude of an effect is considered for each predicted 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 11-8**.

Table 11-8 Definition of magnitude for Fish and Shellfish receptor

Magnitude	Definition
High	Fundamental, permanent / irreversible changes, over the whole receptor, and / or fundamental alteration to key characteristics or features of the 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 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 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 receptors' character or distinctiveness.

11.4.3.5 Impact Significance

44. In basic terms, the potential significance of an impact is a function of the sensitivity of the fish and shellfish receptors and the magnitude of effect (see **Chapter 6 EIA Methodology** for further details). The determination of significance is guided by the use of an impact significance matrix, as shown in **Table 11-9**. Definitions of each level of significance are provided in **Table 11-10**.

45. Potential impacts identified within the assessment as major or moderate are regarded as significant in terms of the EIA regulations. Appropriate mitigation has been identified, where possible, in consultation with the regulatory authorities and relevant stakeholders. The aim of mitigation measures is to avoid or reduce the overall impact in order to determine a residual impact upon a given receptor.

Table 11-9 Impact significance matrix

		Adverse 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 11-10 Definition of impact significance

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.

11.4.4 Cumulative Impact Assessment Methodology

46. The CIA considers other plans, projects and activities that may impact cumulatively with DEP and SEP. As part of this process, the assessment considers which of the residual impacts assessed for DEP and/or SEP on their own have the potential to contribute to a cumulative impact, the data and information available to inform the cumulative assessment and the resulting confidence in any assessment that is undertaken. **Chapter 6 EIA Methodology** provides further details of the general framework and approach to the CIA.

47. For fish and shellfish ecology, these activities include other OWFs (tier 1 to tier 6), marine aggregate dredging projects, subsea cables and pipelines and oil and gas exploration.

11.4.5 Transboundary Impact Assessment Methodology

48. The transboundary assessment considers the potential for transboundary effects to occur on fish and shellfish ecology receptors as a result of DEP and SEP; either those that might arise within the Exclusive Economic Zone (EEZ) of European Economic Area (EEA) states or arising on the interests of EEA states e.g. a non UK fishing vessel. **Chapter 6 EIA Methodology** provides further details of the general framework and approach to the assessment of transboundary effects.

49. For fish and shellfish ecology, the distribution of fish stocks and populations of many species cross national geographic boundaries and therefore the main assessment for DEP and SEP has been undertaken irrespective of national jurisdictions. As such, potential transboundary effects are considered as an inherent aspect of the main assessment. See **Section 11.8** for further details.

11.4.6 Assumptions and Limitations

50. There are numerous datasets on fish and shellfish within the study area and from other existing OWF surrounding DEP and SEP that have been used to characterise the species assemblage. However, as fish and some shellfish are highly mobile, and are subject to a range of environmental (seasonal), biological (spawning) and anthropogenic factors, the available data has limitations. These include historic site survey data that are over 15 years old and/or where the surveys were temporally and spatially quite limited, whereby it is acknowledged that such datasets only represent a snapshot of the assemblage at the time of survey (see for **Table 11-5** further details). Similarly, UK MMO landings data provide a good indication of principal commercial species within the study area, but do not necessarily reflect accurately the community or species composition, relative abundance or biomass.

51. However, these limitations are not considered to materially affect the overall confidence in the assessment outcomes which, as set out in **Section 11.4.2**, are based on the best available data and information sources, which are also typical for informing an assessment of this nature.

52. Limitations, sensitivities and gaps of the data sources are further detailed in **Section 11.1.2** of **Appendix 11.1**.

11.5 Existing Environment

53. The characterisation of the existing environment is undertaken using data sources listed in **Table 11-5** plus other relevant literature. **Appendix 11.1** gives further detail on the species typically found within the study area.

11.5.1 Overview

54. Regional and local data sources have been used to describe the fish and shellfish ecology baseline, with a focus on the local study area defined by ICES rectangles 34F1 and 35F1. Regional data includes MMO landings, used to identify commercially important species; and the IBTS, which provides information about demersal species present locally that are effectively sampled by beam trawls, including non-commercial species. Data from historic surveys undertaken pre and post-construction of the existing Dudgeon and Sheringham Shoal OWFs have also been included in the baseline. These included several otter, beam and pelagic trawl surveys, and longline surveys for elasmobranchs (see **Table 11.1.1** in **Appendix 11.1** for details).

55. The southern North Sea (ICES Division IVc) is generally shallower than more northerly waters. The dominant fish species are those that are characteristic of inshore, coastal waters (<50m deep). Plaice (*Pleuronectes platessa)*, sole (*Solea vulgaris)*, dab (*Limanda limanda)* and whiting (*Merlangius merlangus)* are some of the dominant commercial species, along with non-commercial species such as lesser weever (*Echiichthys vipera)*, grey gurnard (*Eutrigla gurnardus)* and solenette (*Buglossidium luteum)* all forming important components of the overall fish assemblage (Teal, 2011). Species such as sandeels *(Ammodytidae*) and sand gobies (*Pomatoschistus spp.*) are also abundant and are important prey species for many species of demersal fish, birds and marine mammals (Teal, 2011).

56. There are over 23 different elasmobranch species (sharks, skates and rays) that have been recorded in the North Sea with the most common shark species, spurdog (*Squalus acanthias*), lesser spotted dogfish (*Scyliorhinus canicula*) and starry smoothhound (*Mustelus asterias*) concentrated in the western part of the North Sea (Daan, 2005). Between 1902 – 2013, larger species (thornback ray, tope, spurdog) exhibited long-term declines, and the largest (common skate complex) became locally extirpated (as did angelshark). Smaller species increased (spotted and starry ray, lesser-spotted dogfish) as did smoothhound, likely benefiting from greater resilience to fishing and/or climate change (Sguotti *et al.*, 2016).

57. There have been occasional records of diadromous fish species within the study area, suggesting that such species may transit through the DEP and SEP areas during seasonal migrations between the sea and riverine environments, potentially for spawning and nursery life-history stages.

58. Similarly, there are records of several species of conservation importance in the study area but in low abundance, including possible spawning and nursery grounds of thornback ray (*Raja clavata*), herring (*Clupea harengus*), Dover sole (*Solea solea*), plaice (*Pleuronectes platessa*), mackerel (*Scomber scombrus*), whiting (*Merlangius merlangus*) and lesser sandeel (*Ammodytes tobianus*).

59. The southern North Sea supports commercially important shellfish species such as brown crab (*Cancer pagurus)*, lobster (*Hommarus gammarus*), velvet swimming crab (*Necora puber)*, brown shrimp (*Crangon crangon)*, pink shrimp (*Pandalus montagui),* mussels (*Mytilus edulis)*, cockles (*Cerastoderma edule*) and the edible common whelk (*Buccinum undatum*). Species of lower commercial importance relevant to the DEP and SEP areas include harbour crab (*Liocarcinus depurator*), long-clawed porcelain crab (*Pisidia longicornis*), slipper shell (*Crepidula fornicata*).

11.5.2 Fish and Shellfish

11.5.2.1 Commercial Species

60. Species and associated quantities available for landings are determined through a system of Total Allowable Catches (TACs) and quotas (**Chapter 14 Commercial Fisheries**), these quotas vary between fleets and vessels. Therefore, landings do not necessarily reflect accurately the community or species composition, relative abundance or biomass. In addition, vessels target certain species and discard others. Species may be absent from statistics due to stock conservation measures and lastly the presence and distribution of fish and shellfish species are dependent on a number of biological and environmental factors, which interact in direct and indirect ways, and are subject to temporal and spatial seasonal and annual variations. It is therefore concluded that commercial landings data does not give an accurate reflection of species composition in an area, therefore, to give a more accurate presentation of the commercial species present, MMO data has been used.

11.5.2.1.1 UK MMO Landings

61. The DEP and SEP offshore infrastructure are within ICES rectangles 35F1 (offshore area) and 34F1 (inshore area). Data from 2009 to 2019 (**Table 11.2.1** in **Appendix 11.1**) from the local study area show that the key commercial fish species were herring. **Table 11.2.1** in **Appendix 11.1** also show that the key commercial species for the regional area (ICES rectangles 35F0 and 34F0) were primarily shellfish.

62. Over the decade herring from 34F1 were landed every year along with other key commercial species including cod (*Gadus morhua*), bass (*Dicentrarchus labrax*), mackerel, sprat and Dover sole (**Plate 11.2.3** in **Appendix 11.1**). Whereas key commercial fish landed from 35F1 during 2009 to 2019 vary, species also include herring, cod, bass, Dover sole, plaice, brill and whiting (**Plate 11.2.7** in **Appendix 11.1**).

63. Data from 2009 to 2019 (**Table 11.2.1** in **Appendix 11.1**) from the local study area show that the key commercial shellfish species were whelk, brown crab, lobster, mussels and cockles. **Table 11.2.1** in **Appendix 11.1** also show that the key commercial shellfish species for the regional area (ICES rectangles 35F0 and 34F0) also included whelks, cockles, mussels, brown crab and lobster with the addition of brown and pink shrimp and scallops.

64. Over the decade brown crab was landed in the greatest quantities followed by whelks, and lobster from 34F1, whereas whelk dominated the landings from 35F1, followed by brown crab and lobster.

11.5.2.2 International Bottom Trawl Survey

65. There were 81 fish and shellfish species recorded by the IBTS in the local study area as defined by ICES rectangles 34F1 and 35F1 from stations shown in **Figure 11.2** between 2010 to 2020. CPUE data for the principal species recorded is shown in **Table 11.2.2** of **Appendix 11.1**. Of the fish species, greater sandeel CPUE was the highest in ICES rectangle 35F1 with a CPUE of 444 (**Figure 11.25**). Sprat (*Sprattus sprattus*) had the highest CPUE in ICES rectangle 34F1 with a CPUE of 70 (**Figure 11.23**).

66. The CPUE of shellfish species were far less to the above fish species. Brown crab CPUE was the highest in ICES rectangle 34F1 with a CPUE of 12 (**Figure 11.3**). Veined squid had the highest CPUE in ICES rectangle 35F1 with a CPUE of 9.

11.5.2.3 Spawning and Nursery Grounds

67. Spawning and nursery grounds defined by Coull *et al.* (1998), Ellis *et al.* (2012) and Aires *et al.* (2014) have been used to indicate which species may have spawning and nursery grounds within the DEP and SEP areas. This data indicates that herring (**Figure 11.6**), Dover sole (**Figure 11.14**), whiting (**Figure 11.22**), sandeel (**Figure 11.30**) and lemon sole (**Figure 11.37**) have defined spawning grounds that overlap with DEP and SEP (see **Table 11.2.3** in **Appendix 11.1** for further details on spawning/nursery grounds and offshore infrastructure overlap as defined by Coull *et al.* (1998), Ellis *et al.* (2012) and Aires *et al.* (2014)). Thornback ray spawning grounds are poorly defined but are thought to generally coincide with nursery areas (Ellis et al., 2012). **Table 11-11** shows the spawning periods for each of these species.

Table 11-11: Spawning periods of species present in DEP and SEP areas.

<table>
<tr><th>Species</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Herring</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td></td><td></td></tr>
<tr><td>Dover sole</td><td></td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#A9D4EA">*</td><td bgcolor="#66F4FF"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Whiting</td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sandeel</td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td></tr>
<tr><td>Lemon sole</td><td></td><td></td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td></td><td></td><td></td></tr>
<tr><td>Thornback ray</td><td></td><td bgcolor="#66F4FF"></td><td bgcolor="#66F4FF"></td><td bgcolor="#A9D4EA">*</td><td bgcolor="#A9D4EA">*</td><td bgcolor="#A9D4EA">*</td><td bgcolor="#A9D4EA">*</td><td bgcolor="#A9D4EA">*</td><td bgcolor="#66F4FF"></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td>Spawning</td><td bgcolor="#66F4FF"></td></tr>
<tr><td>Peak spawning</td><td bgcolor="#A9D4EA">*</td></tr>
</table>

68. DEP and SEP overlap with the defined nursery grounds for the species stated above, and also for cod (**Figure 11.12**), plaice (**Figure 11.16**), mackerel (**Figure 11.20**) and thornback ray (**Figure 11.33**). It should be noted that Dover sole and thornback ray nursery areas are restricted to shallower inshore waters (see also **Figure 11.14** and **Figure 11.33**).

11.5.2.3.1 Herring spawning

69. Herring is a schooling pelagic fish that is an important prey species for piscivorous fish, sharks, marine mammals and seabirds and is also targeted by commercial fisheries. It is listed as a species of principal importance for the purpose of conserving UK biodiversity. Herring are demersal spawners, showing a preference to lay their eggs on gravel and other coarse sediments and substrates (e.g. maerl or shell), characterised by a low proportion of fine sediment and well-oxygenated water (Fugro, 2020a; 2020b). Due to their ecological importance and the specificity of their spawning habitat, potential impacts on herring can be of concern. Eggs can take up to two weeks to hatch, after which the larvae enter a planktonic stage, rising to the surface and drifting to the coastal waters of the eastern North Sea. There are several discrete North Sea stocks of either spring-spawning or autumn-spawning herring. DEP and SEP are in proximity to the spawning grounds of the autumn-spawning (August to October) Banks sub-population.

70. A benthic characterisation survey of the DEP and SEP areas was completed in August 2020 (**Chapter 10 Benthic Ecology Appendix 10.1 and 10.2**). Sediment grab samples were assessed for their suitability as herring spawning habitat based on the distribution of sediment particle sizes.

71. Survey stations have been categorised for herring spawning suitability based on criteria defined by MarineSpace et al. (2013) as summarised in **Table 11-12** along with the equivalent Folk (1954) and British Geological Survey (BGS) modified Folk sediment classifications.

Table 11-12: Herring preference sediment categories

Fractional Composition	Folk (1954) Description	Folk (BGS Modified) Description	Herring Preference (MarineSpace *et al*., 2013)
≤10% muds and >30% gravel	Gravel (G) and sandy gravel (sG)	Gravel (G) and sandy gravel (sG)	Preferred
≤10% muds and 5% to 30% gravel	Gravelly sand (gS)	Gravelly sand (gS)	Marginal
>10% muds or ≤10% gravel	All other sediment types	All other sediment types	Unsuitable

72. Within the DEP wind farm sites, most stations are classified as being ‘Unsuitable’ for herring spawning. Nine samples across four stations are considered ‘Marginal’ and four stations sampled ‘Preferred’ habitat. The ‘Preferred’ sites, with a larger gravel component and very little or no mud content are located in the south of the DEP North and DEP South wind farm sites (Fugro, 2020b) (**Figure 11.2**).

73. Within the SEP wind farm site the majority of the sediments towards the northwest were considered ‘Unsuitable’. However, samples in the southeast and most easterly extent of the wind farm site are classified as ‘Preferred’ herring spawning habitat (Fugro, 2020a) (**Figure 11.2**).

74. Along the offshore export cable corridor and interlink cable corridors, the areas of ‘Preferred’ herring spawning habitat followed the pattern of alternating sand and coarse/mixed sediments observed. Where the sediment was predominantly sand, the habitat is classed as ‘Unsuitable’ or ‘Marginal’, however where the sediment was coarse or mixed with a large gravel component, the habitats are classed as ‘Preferred’ (Fugro, 2020a; 2020b) (**Figure 11.2**).

75. Two methods have been used to map the distribution of the suitability of herring spawning habitat in the areas between samples:

Herring spawning habitat assessment Method A

76. The first method used geophysical survey data obtained by DEP and SEP surveys in 2019 and 2020. Geostatistical processing and spatial statistical analysis of sidescan sonar and bathymetry data classified the survey area for herring spawning preference, informed by 'ground truthing' benthic sample data. Further details are available in **Chapter 10 Benthic Ecology Appendix 10.3** (Envision, 2021). This method has identified Preferred herring spawning habitat in coarse sediment areas along the offshore export cable corridor, and in relatively small areas within the DEP and SEP wind farm sites and interlink cable corridors (**Figure 11.2 Geophysical survey interpretation**). Areas identified as 'Preferred' herring spawning habitat comprise approximately 21% of the DEP wind farm sites and 10% of the SEP wind farm site.

Herring spawning habitat assessment Method B

77. The second method follows MarineSpace et al. (2013) and classifies existing BGS 1:250,000 sediment maps, which show the distribution of BGS modified Folk sediment classes, according to the herring spawning preference categories as described in **Table 11-12**. The results show 'Preferred' herring spawning habitat extending across the majority of the area within the SEP wind farm site and offshore export cable corridor, almost all of the interlink cable corridors area and DEP South, and the eastern half of DEP North (**Figure 11.2 BGS Sediment Class Suitability**). In many areas this interpretation contradicts sediment grab samples taken during the 2020 DEP and SEP benthic survey and it is likely that the accuracy of the BGS maps is relatively low. MarineSpace et al. (2013) acknowledge that is important to note that the habitat sediment classification is not the only parameter that indicates potential spawning habitat. There are other environmental (physical, chemical and biotic) parameters such as: oxygenation, siltation, overlap with range of spawning populations, micro-scale seabed morphological features e.g. ripples and ridges; which all contribute to the suitability of seabed habitat to be used as spawning beds by herring. As such the habitat sediment classes alone will always over-represent the range of habitat with the potential to support spawning events (MarineSpace et al., 2013).

Herring spawning areas

78. The existence of suitable herring spawning habitat does not necessarily mean that the area is used as a herring spawning ground. DEP and SEP are located within a potential herring spawning area identified by Coull et al. (1998), however the confidence in this evidence is lower than the more recent IHLS data (MarineSpace et al., 2013). Unfortunately, the IHLS has not sampled the area near DEP and SEP since 1976. Surveys conducted between 2008 and 2019 recorded no larvae (<11mm in length) from the closest samples to the local study area (see **Appendix 11.1 Figures 11.7**, **11.8** and **11.9**). The September 1976 survey sampled in close proximity to DEP and SEP but recorded no herring larvae at any of the locations except at one station 3.86km west of DEP North, recording low abundance (4 larvae/m^2). The IHLS indicates that herring spawning is located to the northwest off the North Yorkshire coast (Banks herring) as well as further south in the North Sea (Downs herring). It is reasonable to assume that when the IHLS was scaled down it was to focus on the most important areas. However, areas where the IHLS survey has not been undertaken are not necessarily indicative of no spawning activity (MarineSpace et al., 2013).

79. Site specific herring spawning surveys were conducted at the Dudgeon and Sheringham Shoal OWFs between 2008 to 2010, with some transects and trawls overlapping with the DEP and SEP wind farms and the offshore section of the offshore export cable corridor north of the Sheringham Shoal sandbank feature (Brown and May Marine, 2009; 2010). Following these surveys, it was concluded that herring spawning did not occur in the survey areas, possibly as a result of changes to North Sea herring spawning patterns in the 1970s (Brown and May Marine, 2009). See **Appendix 11.1** for further details.

80. Following the method similar to that described by MarineSpace et al. (2013) potential herring spawning habitat has been further assessed through the overlap of data layers that are deemed indicative of spawning habitat or events. The greater the number of overlapping data layers then the greater the ‘heat’ mapped and the higher the confidence that the seabed may be suitable for spawning. The data layers used and the scores they contribute to the heat map, based on a confidence assessment of the data) are presented in **Table 11-13**.

Table 11-13: Indicative herring spawning data layers and relative confidence scores

Data theme	Source	Score	Notes
Preferred sediment	BGS 1:250,000 seabed sediment maps	3	Gravel (G) and sandy gravel (sG)
Marginal sediment		2	Gravelly sand (gS)
High number of small larvae (per m^2)	IHLS	5	0-10 mm length. Highest number recorded over period 2009-2017 for each survey station. Score applied within contoured area with >600 larvae per m^2. The IHLS

Data theme	Source	Score	Notes
			does not cover DEP and SEP area.
Identified spawning grounds	Coull et al. (1998)	3	As indicated by the confidence score, these areas are based on relatively old data.

81. The heat mapping method indicates that the SEP wind farm site is located in an area of medium confidence (score 5) along with offshore cable corridors to the north of SEP due to the presence of Preferred sediments and the area having been identified as a herring spawning area by Coull et al. (1998) (**Figure 11.3**). However, sediment samples within the SEP wind farm site confirm that much of the area classed as Preferred habitat using BGS seabed sediment maps are in fact unsuitable, particularly in the west of the site (**Figure 11.2**). Almost 96% of the SEP wind farm site is estimated to be preferred habitat using BGS maps (Method B) compared to 10% based on recent site geophysical and benthic characterisation surveys (Method A), suggesting that Method B over-represents the extent of habitat in the SEP wind farm site.

82. The heat mapping method indicates that the DEP wind farm sites and the export cable corridor south of the SEP wind farm site are located in an area with a lower confidence score (3 and less) because they are primarily outside the Coull et al. (1998) spawning area (**Figure 11.3**). These areas contain areas classed as Preferred habitat using BGS seabed sediment maps. Again, sediment samples and Method A indicate that heat mapping and Method B over-represent the extent of suitable habitat (**Figure 11.2**). Method A estimates that approximately 68% of the DEP wind farm sites is preferred habitat compared to 21% of the site using BGS maps (Method B).

83. In summary, suitable herring spawning habitat has been identified within the DEP and SEP boundaries and is likely present in surrounding areas, although mapping based on BGS base maps and heat mapping is likely to overestimate the extent of this habitat. There is, however, an absence of evidence that herring spawn in the vicinity of DEP and SEP. Based on the available evidence outlined above, the area is considered to be unlikely to be a hotspot for herring spawning and if spawning does occur it is likely to be at low levels.

11.5.2.3.2 Sandeel habitat

84. Sandeels are a group of shoaling fish which lie buried in seabed sediments at night and feed on planktonic prey such as copepods and crustacean larvae in mid-water during daylight hours. There are five species of sandeel in the North Sea, all found in shallow, turbulent areas of suitable sediment. Sandeel show a preference for medium and coarser (0.25 to <2.0m diameter) sandy sediments and avoid areas of fine sediment. Due to high substrate specificity and limited larval exchange between sandeel populations, they are particularly vulnerable to overfishing and other pressures. Sandeels are an important trophic link in the North Sea food chain, between zooplankton and sandeel predators including piscivorous fish, most seabirds and mammals. As many marine predators rely on sandeels, coupled with their vulnerability to changes in habitat, sandeels are of increasing conservation interest and listed as a species of principal importance in the UK and designated as a nationally important marine feature.

85. Sediment grab samples obtained by the benthic characterisation survey of the DEP and SEP areas (**Chapter 10 Benthic Ecology Appendix 10.1 and 10.2**) were assessed for their suitability as sandeel habitat based on the distribution of sediment particle sizes.

86. Survey stations have been categorised based on criteria defined by Latto et al. (2013) as summarised in **Table 11-14** along with the equivalent Folk (1954) and BGS modified Folk sediment classifications.

Table 11-14: Sandeel preference sediment categories

Fractional Composition	Folk (1954) Description	Folk (BGS Modified) Description	Herring Preference (MarineSpace *et al*., 2013)
≤10% mud and ≤30% gravel	Sand (S), slightly gravelly sand ((g)S) and gravelly sand (gS)	Sand (S) and gravelly sand (gS)	Preferred
≤10% mud and >30% to <80% gravel	Sandy gravel (sG)	Sandy gravel (sG)	Marginal
>10% mud or ≥10% gravel	All other sediment types	All other sediment types	Unsuitable

87. The locations and distribution of sample stations classified as 'Preferred' sandeel habitat in the DEP and SEP offshore areas is illustrated in **Figure 11.4** below. The large majority of sediment samples from the DEP wind farm sites are assessed as 'Preferred' sandeel habitat. Sandeels were present in grabs from stations D19 and D25 in DEP North, both of which have been classed as 'Preferred' sandeel habitat. Examples of 'Preferred' sandeel habitat, along with 'Marginal' or 'Unsuitable' areas were identified on the interlink cable corridors, including 'Preferred' habitat at stations at the northern end of the DEP North to SEP interlink corridor **Figure 11.4**. Sandeels were also recorded in this area from the grab at station CC19, also assessed as 'Preferred' habitat (Fugro, 2020b).

88. All but one sample from the SEP wind farm are assessed as 'Marginal' or 'Unsuitable' for sandeel (**Figure 11.4**). No sandeels were recorded in grabs or photographic data from the SEP wind farm (Fugro, 2020a). This suggests that although the SEP wind farm area may support some sandeels, it is likely to be less important for the species than the area around the DEP wind farm sites.

89. Stations in the export cable corridor are assessed predominantly as 'Preferred' and 'Marginal' sandeel habitat. Lesser sandeels were observed from the video transect at station EC18 on the offshore export cable corridor, an area which has been classed as 'Marginal' sandeel habitat (Fugro, 2020a).

90. Two methods have been used to map the distribution of suitability sandeel habitat in the areas between samples:

<u>Sandeel habitat assessment Method A</u>

91. Like herring spawning habitat assessment Method A, sidescan sonar and bathymetry data obtained by DEP and SEP surveys in 2019 and 2020 were used to predict and map sandeel habitat preference, informed by 'ground truthing' benthic sample data. This method classified seabed as 'Prime', 'Subprime', 'Suitable' or 'Unsuitable' depending on the relationship between the percentages of silt and fine sand and of coarse sand in the sediment, based on Greenstreet et al. (2010). Further details are available in **Chapter 10 Benthic Ecology Appendix 10.3** (Envision, 2021). 'Prime' and 'Subprime' habitat categories can be combined to an equivalent Preferred category and Preferred sandeel habitat was identified in large parts of DEP North and DEP South, with smaller areas present in the southeast of the SEP wind farm and in the offshore cable corridors (**Figure 11.4**). Areas identified as sandeel Preferred habitat comprise approximately 61% of the DEP wind farm sites and less than 4% of the SEP wind farm site.

<u>Sandeel habitat assessment Method B</u>

92. The second method follows Latto et al. (2013) and classifies existing BGS 1:250,000 sediment maps, which show the distribution of BGS modified Folk sediment classes, according to the sandeel habitat preference categories as described in **Table 11-14**. The results show 'Preferred' sandeel habitat in the western part of DEP North with small areas in the offshore cable corridors and in the SEP wind farm site. However, almost all of the SEP wind farm site, the offshore cable corridors and DEP South are marginal sandeel habitat (**Figure 11.4**). In many areas this interpretation contradicts sediment grab samples taken during the 2020 DEP and SEP benthic survey and it is likely that the accuracy of the BGS maps is relatively low.

93. As with herring, the presence of suitable habitat does not necessarily mean that sandeels are present in significant numbers. Sandeels were confirmed to be present at some locations (present in grab samples) by the benthic characterisation survey of the DEP and SEP areas. Otter and beam trawl surveys of the Sheringham Shoal and Dudgeon OWF areas recorded sandeels in relatively low numbers, suggesting that these species are present but not abundant, although it should be noted that the abundance of sandeels in the area may be underrepresented by these survey methods. IBTS data suggest that greater sandeel may be abundant to the north of the DEP wind farm areas, and the extent of a historical sandeel fishery overlapped with part of DEP North. The presence of suitable sediments supports the possibility that the DEP wind farm sites, and particularly DEP North, support sandeel populations. See **Appendix 11.1** for further details.

94. Following the method similar to that described by Latto et al. (2013) potential sandeel habitat has been further assessed through the overlap of data layers that are deemed indicative of sandeel presence. The greater the number of overlapping data layers then the greater the 'heat' mapped and the higher the confidence that the seabed may be suitable and sandeels are present. The data layers used and the scores they contribute to the heat map, based on a confidence assessment of the data) are presented in **Table 11-15**.

Table 11-15 Indicative sandeel habitat data layers and relative confidence scores

Data theme	Source	Score	Notes
Preferred sediment	BGS 1:250,000 seabed sediment maps	4	Sand (S) and gravelly sand (gS)
Marginal sediment		2	Sandy gravel (sG)
Sandeel Fishing Grounds	(Jensen et al., 2011)	2	Mapping of sandeel habitat based on GPS and VMS records of sandeel fishing vessels, and maps provided by fishers.
Identified spawning grounds	Coull et al. (1998)	3	These areas are based on relatively old data.

95. The heat mapping method indicates that the SEP wind farm site is located in an area of medium confidence (score 5) along with most of offshore cable corridors to the north of SEP due to the absence of Preferred sediments from most of these areas and present of marginal sediments (**Figure 11.5**). Sediment samples within the SEP wind farm site confirm that much of the areas are Marginal or Unsuitable (**Figure 11.4**). Both the assessment of recent site geophysical and benthic characterisation survey data (Method A) and use of BGS maps (Method B) estimate that only approximately 4% of the SEP wind farm site is preferred habitat.

96. The heat mapping method indicates that the DEP wind farm sites are located in an area with a higher confidence ranging from medium confidence (5) to higher confidence (7) in parts of DEP North and DEP South, and high confidence score (9) in part of DEP North (**Figure 11.5**). These areas contain areas of both Preferred and Marginal habitat using BGS seabed sediment maps (**Figure 11.4**). Sandeel fishing grounds are located to the North of the DEP wind farm sites and extend into DEP North (**Figure 11.5**), accounting for the high confidence score in this area. Sediment samples and Method A indicate that heat mapping and Method B under-represent the extent of suitable habitat and that the extent of sandeel habitat may be greater in the DEP wind farm sites. Method A estimates that approximately 61% of the DEP wind farm sites is preferred habitat compared to 32% of the site using BGS maps (Method B).

97. The export cable corridor south of the SEP wind farm site contains some areas of Preferred sediment but has a low confidence score because it is outside of recognised spawning or fishing areas (**Figure 11.5**).

98. In summary, although there are relatively small areas of sandeel habitat in the SEP wind farm site and the export cable corridor south of SEP, the DEP wind farm sites are likely to be located in areas used by sandeel. DEP North and DEP South are located in an area characterised by Preferred sandeel habitat and DEP North is close to, and partially within, identified sandeel fishing grounds.

11.5.3 Historic Site Surveys

99. As described in **Section 11.4.2.1**, a variety of surveys have been undertaken in relation to the existing Dudgeon and Sheringham Shoal OWFs. Although these surveys were undertaken as early as 2005, the results provide an indication of the fish and shellfish assemblage that is likely to be present in the vicinity of DEP and SEP.

100. Otter trawl surveys were conducted in the Sheringham Shoal OWF area in April 2005 and in the Dudgeon OWF area in May and October 2008. Over 43 fish and shellfish species were recorded over the three surveys. Whiting (*Merlanguis merlangus*) was the most abundant species caught, followed by velvet crab (*Necora puber*), herring, dab (*Limanda limanda*), harbour crab (*Liocarcinus depurator*), pink shrimp (*Pandalus montagui*) and flying crab (*Liocarcinus holsatus*) (see **Table 11.2.5** in **Appendix 11.1** for full list).

101. Eight beam trawl surveys recording fish and epibenthos were conducted at the Sheringham Shoal and Dudgeon OWF areas between 2005 to 2014 (using 2m and 7m beams). Over 115 fish and shellfish species were recorded (see **Table 11.1.A.1 Annex 1** of **Appendix 11.1** for full list).

102. Crustaceans, and particularly shrimp species, dominated catches. Pink shrimp was the most abundant species. Across all the surveys 908,216 individuals were caught and recorded, totalling almost ten times the next most abundant species, brown shrimp (*Crangon crangon*) (see **Table 11.2.6** of **Appendix 11.1**). The shrimp (*Pandalina brevirostris*) was also recorded in abundance from the surveys conducted in October 2008 and September 2014 at Dudgeon OWF, and the December 2012 survey at Sheringham Shoal OWF. Crabs where also abundant, particularly swimming crab species. The harbour crab (*Liocarcinus depurator*) was the third most commonly recorded species across the surveys.

103. The most prevalent fish species caught were lesser weever fish (*Echiichthys vipera*), followed by dragonet (*Callionymus lyra*) and the painted goby (*Pomatoschistus pictus*). The abundance of these species varied across the surveys, with some species being completely absent from some surveys. The non-native invasive slipper limpet (*Crepidula fornicata*) was the most abundant mollusc recorded across all surveys. It was recorded by all but the December 2012 post-construction survey for Sheringham Shoal OWF and was the fifth most abundant species across all beam trawl surveys.

104. The Sheringham Shoal and Dudgeon OWF areas are broadly similar in terms of species composition, with crustaceans being the most abundant group. Variations in the abundance of species recorded may be attributed to differences in habitats between the DEP and SEP areas, but may also be the result of survey gaps and limitations, as well as seasonal and temporal changes in the distribution and abundance of species related to migrations or natural fluctuations in species abundances over time.

11.5.4 Designated Sites and Protected Species

105. Sandeels are designated as a nationally important marine feature (Furness, 1990; Hammond *et al.* 1994; Tollit and Thompson, 1996; Wright and Tasker, 1996; Greenstreet *et al.*, 1998; Kerby *et al.*, 2013) and, as a prey source, are linked to protected and qualifying features of nearby Special Protection Areas (SPA) and Special Areas of Conservation (SAC) such as the Greater Wash SPA and The Wash & North Norfolk Coast SAC. For these reasons, sandeels are included in the assessment.

106. Designated sites for allis shad (*Alosa alosa*) or twaite shad (*Alosa fallax*) are located in river systems where the species have been recorded and where there is previous evidence of breeding, and where there still appear to be favourable conditions for breeding. However there are no UK designated sites for allis shad or twaite shad on the UK coast of the southern North Sea.

107. River lamprey (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*) are qualifying features of the Humber Estuary SAC, approximately 60km north west of the SEP wind farm area at its closest point. Both species breed in the River Derwent, a tributary of the River Ouse and ultimately the Humber, and both these species are qualifying features of the River Derwent SAC. Records of river and sea lamprey in rivers in Norfolk (and East Anglia as a whole) are relatively scarce compared with other areas of the UK (Kelly and King, 2001).

108. The European eel (*Anguilla Anguilla*) is widely distributed throughout the Anglian region, including Norfolk. A fishery for adult eels existed in the past, although few records were kept (DEFRA, 2010).

109. The Atlantic salmon is a widespread species in the UK and is found in several hundred rivers, many of which have adult runs in excess of 1,000 (JNCC, 2020). Scottish rivers are the most important in terms of spawning sites. There are 79 rivers in England and Wales that support salmon populations. No rivers south of the Esk in Yorkshire or east of the Itchen in Hampshire are classified as salmon rivers, hence East Anglian (including Norfolk) rivers do not support important salmon populations (Cefas, 2019). The nearest UK designated site for salmon is the River Avon SAC on the west coast of Britain.

110. Although sea trout are present in East Anglian rivers, those found off the East Anglian coast, including off Norfolk, are generally thought to originate from the rivers in northeast England and southeast Scotland such as the Esk, Wear, Coquet, Tyne and Tweed (Pawson, 2013). No sea trout were recorded in any of the historic site surveys of the Sheringham Shoal and Dudgeon OWF areas, nor the IBTS in the local study area. However, the species has been recorded occasionally in MMO landings by UK vessels from ICES rectangles 34F1 and 35F1.

11.5.5 Species taken forward for Assessment

111. Key species identified, and the rationale for their inclusion within the assessment, are provided **Table 11-16**. Detailed information about the ecology of these species and the use that they may make of the study area is provided in **Appendix 11.1**. Note that for some impacts, species are not considered on an individual basis but by functional group (e.g. fin fish, shellfish, elasmobranchs or migratory fish).

Table 11-16: Summary of the principal fish and shellfish species in the local study area to be taken forward for assessment

Species	Rational
Molluscs	
Whelk	• Commercially important in the study area; and • Recorded by Sheringham Shoal and Dudgeon OWF surveys.
Crustaceans	
Brown crab	• Commercially important in the study area; and • Recorded by Sheringham Shoal and Dudgeon OWF surveys.
Lobster	• Commercially important in the study area: and • Recorded by Sheringham Shoal and Dudgeon OWF surveys.
Brown shrimp	• Recorded in high abundance by Sheringham Shoal and Dudgeon OWF surveys.
Pink shrimp	• Recorded in high abundance by Sheringham Shoal and Dudgeon OWF surveys.
Fish	
Whiting	• Recorded in high abundance by Sheringham Shoal and Dudgeon OWF surveys; • Of some commercial importance in the study area; • Species of Conservation Interest; and • Low intensity spawning and nursery areas overlap with the DEP and SEP wind farm sites, interconnector and offshore export cable corridors.
Herring	• Recorded in seasonally high abundance by Sheringham Shoal and Dudgeon OWF surveys; • Of some commercial importance in the study area;

Species	Rational
	• Species of Conservation Interest; • Key prey species for fish, birds and marine mammals; • Demersal spawning species; • Suitable spawning habitat within the southeast and most easterly extent of the SEP wind farm area and intermittently along the offshore cable corridors, but spawning surveys suggest no spawning activity; and • Low intensity nursery areas overlap with the DEP and SEP wind farm sites, interconnector and offshore export cable corridors.
Sandeels	• Historic sandeel fishing grounds overlap the DEP North extension area; • Greater sandeel, lesser sandeel and Corbin's sandeel recorded by Sheringham Shoal and Dudgeon OWF surveys and recorded in high abundance by nearby surveys to the north; • Key prey species for fish, birds and marine mammals; • Demersal spawning species; • Low intensity sandeel (*A. marinus*) spawning area and with low intensity nursery areas overlap with the DEP and SEP wind farm sites, interconnector and offshore export cable corridors; and • Suitable sandeel habitat in the DEP wind farm site areas and in the export cable corridor, but most of the SEP wind farm area is less suitable.
Sprat	• Recorded in seasonally high abundance by Sheringham Shoal and Dudgeon OWF herring spawning surveys; and • Important prey species for fish, birds and marine mammal species.
Elasmobranchs	
Starry smoothhound	• The most abundant elasmobranch recorded by Sheringham Shoal and Dudgeon OWF surveys, typically present at low densities, but can occasionally abundant.
Thornback ray	• Present in the study area; • Species of Conservation Interest; and • The most important commercially exploited elasmobranch in the study area, but landings are relatively small.
Diadromous species	
Twaite shad **Allis shad**	• UK BAP listed species; and • Potential (rarely) transit / feed in the study area during marine migration.
River lamprey **Sea lamprey**	• Present in some East Anglian Rivers; • Sea lamprey is present in the offshore cable corridor; • UK BAP listed species and sea lamprey listed by OSPAR as declining and/or threatened; and

Species	Rational
	• May transit / feed in the study during marine migration.
European eel	• Present in almost all East Anglian rivers; • UK BAP listed species and listed as 'critically endangered' on the IUCN Red List; and • May transit / feed in the offshore development area during marine migration.
Sea trout	• Present in some East Anglian rivers; and • May transit / feed in the offshore development area during marine migration.

11.5.6 Climate Change and Natural Trends

112. The existing baseline conditions within the local 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 primarily influenced by global environmental factors and by commercial fishing activity.

113. The baseline will continue to evolve as a result of global trends which include the effects of climate change, such as increasing sea levels and sea surface temperature, as well as trends at the regional and European level such as changes in fisheries regulations and policies.

11.6 Potential Impacts

114. An assessment of the potential impacts from DEP and SEP on fish and shellfish receptors are given in the following sections. These have been informed by a literature review of the potential impacts of offshore wind developments on fish and shellfish species, evidence from research carried out at operational wind farms and information and feedback obtained through consultation with statutory and non-statutory stakeholders. Potential impacts to be considered within the EIA have been agreed with statutory advisors (MMO, Natural England, Cefas and The Wildlife Trust) through the EPP (18th November 2019). A summary of the potential impacts is provided in **Table 11-17**.

Table 11-17: Potential Impact Pathways on Fish and Shellfish Receptors

DEP and SEP Phases	Potential Impact Pathway
Construction	• Physical disturbance; • Temporary habitat loss; • Increased suspended sediments and sediment re-deposition; • Re-mobilisation of contaminated sediment; • Underwater noise; and

DEP and SEP Phases	Potential Impact Pathway
	• Commercially exploited species associated with their displacement from the area of activity/works.
Operation	• Temporary habitat loss; • Permanent habitat loss; • Introduction of wind turbine foundations, scour protection and hard substrate; • Increased suspended sediments and sediment re-deposition; • Re-mobilisation of contaminated sediment; • Underwater noise; • EMFs; and • Commercially exploited species associated with their displacement from the area of activity/works.
Decommissioning	• Physical disturbance; • Temporary habitat loss; • Increased suspended sediments and sediment re-deposition; and • Underwater noise.
Cumulative	• Underwater noise; • Habitat loss; • Introduction of wind turbine foundations, scour protection and hard substrate; • EMF; and • Decommissioning impacts.
Transboundary	The assessment has been conducted independent of national geographical boundaries, with a description of the spatial extent of the impacts provided for each phase.

11.6.1 Potential Impacts during Construction

11.6.1.1 Impact 1: Temporary habitat loss / disturbance

115. During the construction phase, activities such as foundation installation (for wind turbines and OSP/s) along with sea bed preparation (including sandwave levelling, boulder removal and UXO clearance) and cable burial, all have the potential to cause temporary habitat loss / disturbance to all fish and shellfish receptors. This may include, for example, interrupting spawning or feeding behaviours, localised mortality of individuals or deterring some species from undertaking established migration routes to or from overwintering grounds. Similarly, the presence of machinery on the seabed (i.e. jack-up vessels legs, vessel anchors) will result in temporary habitat loss / disturbance.

Magnitude of effect - DEP or SEP in Isolation

116. As detailed in **Table 11-2**, during construction the maximum area of sea bed habitat that would be disturbed for DEP would be 1.93km^2 and the maximum area for SEP would be 0.53km^2. This equates to 1.86% of the DEP offshore development area and 0.57% of SEP.

117. For construction of DEP or SEP in isolation, the disturbance would be temporary for approximately two years (24 months) of offshore construction activity, with the majority of disturbance occurring during installation of foundations and cables. Some elements of disturbance, such as those caused by jack-up vessel legs, will be highly localised and only occur over a short period (see **Chapter 5 Project Description**). Considering the availability of similar suitable habitat both in the offshore development areas and in the wider context of the southern North Sea together with the intermittent and reversible nature of the effect, the magnitude of physical disturbance during construction activities for either DEP or SEP is considered to be negligible for all species.

Sensitivity of effect - DEP or SEP in Isolation

118. Monitoring from North Hoyle and Barrow OWFs in the UK have shown that commercial fish species and their abundance pre and post construction were broadly comparable and consistent with long term trends in the regional areas (Cefas, 2009). In conjunction with this, sampling undertaken at reference sites associated with both of these wind farms, found no significant difference between the reference and wind farm sampling locations, or between fish species and numbers caught before both the wind farms were constructed (Cefas, 2009).

119. Pre and post construction surveys undertaken at the nearby Dudgeon and Sheringham Shoal OWFs found that species composition was similar before and after construction. There were variations in abundance of some species that may be attributed habitat heterogeneity across the survey areas as well as seasonal and temporal changes in the distribution and abundance of species related to migrations or natural fluctuations over time. This suggests that construction of offshore wind farms in areas adjacent to DEP and SEP has had no significant impact on the fish and shellfish communities present.

120. In 2014 the MMO reviewed post-consent monitoring data from constructed Round 1 and Round 2 wind farms in UK waters, identifying changes in fish and shellfish populations, although this was attributed to high natural variability rather than

presence of wind farms (MMO, 2014). This review and other studies since, have noted an increase in fish and shellfish abundance and diversity in some UK and non UK wind farms, acting as artificial reefs similar to oil and gas infrastructures (MMO, 2014; Todd *et al.*, 2018; Fowler *et al.*, 2020). These potential benefits are covered in more detail in operation Impact 3, **Section 11.6.2.4**.

121. Most mobile species will be able to move away from any area of disturbance; however, those that are less mobile, including small crabs and shrimps, and sessile species, such as mussel, cockle and whelk, could be directly impacted by the construction works. These species are likely to be most vulnerable due to their low-mobility.

122. Ovigerous female species such as brown crab carries their eggs under their abdomen (known as 'berried') whereas lobster carry them with their pleopods until hatching. To protect the eggs the crabs bury themselves in the sediment for periods ranging from four to nine months, depending on the species (Haig *et al*, 2015). During this period, they do not feed and remain buried to avoid predation (Tonk and Rozemeijer, 2019). Whereas berried lobster do not bury themselves, they continue to feed but do not appear to make extensive movements (Pawson, 1995).

123. The majority of shellfish 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). During construction, parts of DEP or SEP will be temporarily restricted to fishing activity, this may allow larger, more fecund shellfish to contribute to the spawning stock without fishing pressures (Roach *et al.*, 2018). However it should be noted that the total area from which fishing may be excluded may change depending on the level of works being carried out and the level of infrastructure installed or partially installed at a given time.

124. In comparison to most finfish species, shellfish have more limited mobility and may not be capable of escaping construction activities causing physical disturbance to the sea bed. In particular, the egg masses of ovigerous species would be potentially vulnerable to physical damage. The sensitivity of effect for shellfish is considered to be medium.

125. Other species that spawn on sedimentary habitats (e.g. herring, sandeel, dragonet and elasmobranch species) also have potential to be disturbed during construction. However, herring and sandeel are substrate specific spawners and are therefore potentially more susceptible to physical disturbance.

126. As stated in **Section 11.5.2.3**, DEP and SEP overlap with several defined spawning and nursery areas, including herring (**Figure 11.6**), however historic herring spawning surveys found that there was no significant spawning in the area (see **Section 11.5.2.3** and **Section 11.2.4.5** in **Appendix 11.1**).

127. Suitable herring spawning habitat has been identified within the DEP and SEP boundaries and is likely present in surrounding areas, although mapping based on BGS base maps and heat mapping is likely to overestimate the extent of this habitat. There is, however, an absence of evidence that herring spawn in the vicinity of DEP and SEP. Based on the available evidence outlined in **Section 11.5.2.3.1**, the area is considered to be unlikely to be a hotspot for herring spawning and if spawning does occur it is likely to be at low levels. Both DEP and SEP are within a low intensity herring nursery area and are in close proximity to a high intensity nursery area as defined by Ellis *et al.* (2010) as shown in **Appendix 11.1 Figure 11.6** along with data from Aires *et al.* (2014) presenting the probability of juvenile (0-group) herring.

128. As shown in **Appendix 11.1 Figure 11.30**, DEP and SEP both overlap with sandeel spawning and nursery grounds identified by Coull *et al.* (1998) and the whole offshore development areas of both DEP and SEP overlap with low intensity sandeel spawning and nursery grounds identified by Ellis *et al.* (2010). Due to their limited movement between areas of suitable habitat, and in view of their ecological and conservation status along with their overall spatial distribution throughout the North Sea, they are considered to be of medium sensitivity. Similarly, for herring, whilst they have greater mobility than sandeels, due to their spawning ground specificity, a medium sensitivity has also been assigned.

129. Spawning grounds for elasmobranch species, such as thornback ray, blonde ray and lesser spotted dogfish are not defined by Coull *et al.* (1998) or Ellis *et al.* (2012) (see **Appendix 11 Figure 11.33**). However, it has been reported that adult thornback rays occur in shallow inshore waters during summer months, potentially for spawning and mating (Walker et al, 1997; HOW03, 2018) before returning to deeper offshore waters leaving juveniles in the shallows. Literature on local elasmobranch spawning is limited and elasmobranch abundance are low within the area. Elasmobranchs can be indirectly affected by physical disturbance as it may reduce available spawning and nursery areas, along with preferred sedimentary habitats. However, although there is limited literature on elasmobranch spawning, sensitivity to temporary, discrete and localised areas of disturbance is considered to be low.

130. Other fish receptors in the study area and southern North Sea are considered to have a low sensitivity as they are able to flee from the areas of disturbance, and have a low vulnerability and high recoverability.

Impact Significance - DEP or SEP in Isolation

131. As stated above, the magnitude of effect for temporary habitat loss / disturbance for DEP or SEP is considered to be negligible for all species. A medium sensitivity has been determined for herring and sandeel, resulting in an impact of **minor adverse** significance. For shellfish the sensitivity is also considered to be medium and therefore the resulting impact is also considered to be of **minor adverse** significance. The sensitivity of elasmobranchs is considered to be low and therefore the resulting impact is considered to be of **negligible adverse** significance. For all other fish species, the negligible magnitude of effect and low sensitivity also results in an impact of **negligible adverse** significance.

Magnitude of effect - DEP and SEP Together

132. **Table 11-2** details that a maximum area of 2.47km^2 of seabed habitat within the offshore development area would be disturbed during the construction phase of both DEP and SEP equating to 0.13% of the total offshore development area.

133. As stated previously, the majority of disturbance would occur during the installation of foundations and cables with some caused by jack-up vessels or anchors, and disturbance would be temporary, however the approximate length of construction activity is up to four years (48 months) rather than two. As outlined above, there is similar suitable habitat available locally and in the wider context of the southern North Sea, together with the intermittent and reversible nature of the effect, the magnitude of physical disturbance during construction activities for DEP and SEP together is considered to be negligible for all species.

Sensitivity of effect - DEP and SEP Together

134. Although the area and duration of disturbance is collectively larger than if either DEP or SEP were built in isolation, the sensitivity of all species is considered to be the same as that assessed for DEP or SEP in isolation: medium for herring, sandeel and shellfish; and low for elasmobranchs and all other fish species.

Impact Significance - DEP and SEP Together

135. The potential impact significance for temporary habitat loss / disturbance for all species is the same as has been assessed for DEP or SEP in isolation: **minor adverse** for herring, sandeel and shellfish; and **negligible adverse** for elasmobranchs and all other fish species.

11.6.1.2 Impact 2: Increased suspended sediments and sediment re-deposition

136. Construction activities such as foundation preparation and installation, drilling operations, and cable installation may lead to increased suspended sediment concentrations (SSC) and sediment re-deposition. **Chapter 8 Marine Geology, Oceanography and Physical Processes** describes the anticipated patterns of elevated SSCs and re-deposition across DEP and SEP in further detail.

Magnitude of effect - DEP or SEP in Isolation

137. **Table 11-2** details the worst-case scenario of total volume of sediment released associated with 14MW GBS foundations dredged to 5m, with a maximum preparation volume of 530,929m^3 (DEP) or 398,196m^3 (SEP). One offshore substation platform (OSP) would also yield a dredging volume of 425m^3 in addition to the offshore export cable which would generate 31,000m^3 for DEP or 20,000m^3 for SEP. The interlink and infield cables would yield 151,875m^3 for DEP or 101,250m^3 for SEP.

138. The seabed within the DEP and SEP wind farm sites is predominately comprised of medium and coarse grained sand, therefore sediment disturbed at the sea bed would remain localised and fall from suspension within minutes or a maximum of tens of minutes. The sediment at both sites also comprises some finer sand and a small proportion of mud, these finer sediment fractions will remain in the water column as a measurable but low concentration plume for up to half a tidal cycle settling within a kilometre of the disturbance or rapidly becoming indistinguishable from background levels.

139. Increases in SSCs caused by the installation of foundations are likely to be low and less than the determined background levels of 10mg/l (mean SSC levels in summer are typically less than 10mg/l, and the mean SSC levels in winter are around 30mg/l). These increases in SSCs will be found in the water column over a short period of time (a matter of days) as they are transported by the wave and tidal action. Disturbed material will remain close to the seabed and will rapidly settle out (within tens of minutes).

140. Cable installation is a relatively short term activity and therefore the effect is generally short-lived. Enhanced concentrations will be greatest in the shallowest sections of the offshore export cable corridor. However, in these locations the natural background concentrations are also greater than in deeper waters, typically up to 170mg/l recorded in the vicinity of the coast at Great Yarmouth (ABPmer, 2012). As described in **Chapter 8 Marine Geology, Oceanography and Physical Processes**, the changes in SSCs during cable installation (offshore export, interlink and infield cables) would be less than those expected during the installation of foundations.

141. Disturbance to sea bed sediments during the construction period would be limited in time (within 24 months) and spatial extent due to the temporary nature of the activities and the dominance of sand sized sea bed sediments in the project areas.

142. The expert-based assessments of the dynamic and passive plume effects and SSCs for DEP or SEP are consistent with the findings of the earlier modelling studies for the Dudgeon OWF (which showed limited extent and duration of increased SSCs), therefore there is high confidence in the assessment of effects. Considering the relatively short duration and limited spatial extent of the effect, together with the low level of change relative to background, the magnitude of effect for all species is assessed as low.

Sensitivity of effect - DEP or SEP in Isolation

143. Adult fish have greater mobility than their juvenile counterparts and shellfish species. They have the ability to avoid the localised areas disturbed by increased SSCs and sediment re-deposition during construction. If displaced, these fish are able to move to adjacent, undisturbed areas within their normal habitat range, whereas juvenile fish are more likely to be affected by increased SSCs, due to their decreased mobility (HOW03, 2018). DEP and SEP both overlap with nursery grounds as defined by both Coull *et al* (1998) and Ellis *et al* (2012) of varying fish species (see **Section 11.5.2.3**). Such juvenile species are accustomed to background levels of approximately 10mg/l in summer to approximately 30mg/l in winter and also experience natural increased SSCs during winter storm events. Since the increased SSCs associated with construction are unlikely to exceed background levels other than in very localised areas and for short time periods, it can be expected that both adult and juvenile fish species are unlikely to be affected by a low level increase in SSCs from construction activities. Therefore, they are considered to be of a low sensitivity.

144. Eggs and early larval stages of fish and shellfish however do not have the same capacity to avoid increased SSCs as juveniles or adults, as they are either passively drifting in the water column or present on, or attached to, benthic substrates. There is potential that an increase in SSC could affect their development or survival. Nevertheless as stated above and in **Chapter 8 Marine Geology, Oceanography and Physical Processes**, any increases in SSCs in the area are likely to be less than background levels (tens of mg/l), localised and temporary. Therefore, the risk of potential adverse effects on the development and survival of eggs and/or larvae is considered to be low.

145. The re-deposition of sediments has the potential to smother fish, eggs and larvae. Demersal spawners such as herring and sandeel are more vulnerable to increased SSCs and sediment re-deposition, due to spawning on or near the seabed and the adhesive properties of the egg membranes to sediment.

146. Sandeels utilise a preferred substrate comprised of medium and coarse sand with low silt content for spawning, predation cover and for hibernation. It has been found that they tend to occupy the top 4cm of the seabed and regulate their burial depth based on oxygen availability (Behrens *et al.*, 2007). Sandeels deposit eggs on the seabed in the vicinity of their burrows between December and January. Grains of sand tend to cling to the eggs and currents often cause the eggs to be covered 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). Buried eggs experiencing reduced current flow and lowered oxygen concentration, can delay hatching periods, which is considered a necessary adaptation to survival in a dynamic environment (Pérez-Dominguez and Vogel, 2010; Hassel *et al.*, 2004). In addition to this, Pérez-Dominguez and Vogel (2010) observed that increased SSCs and smothering to be inconsequential to larval and juvenile sandeels. Taking this into account, along with the expected small increases in SSC (tens of mg/l) and on account of the widely available suitable sandeel habitat, sensitivity is considered to be medium.

147. With regard to the effect of increased SSC and re-deposition of sediments on herring and their spawning activity, previous studies have found that Atlantic herring eggs are tolerant to elevated SSCs as high as 300mg/l and can tolerate short term exposure (one day) at levels up to 500mg/l (Kiørboe *et al.,* 1981). Messieh *et al.,* 1981 study (as cited in Engell-Sørensen and Skyt, 2001) recorded that herring eggs successfully hatch at SSCs of 7,000mg/l, although the size at hatching was larger when SSCs were lower. Whereas Griffin *et al.,* (2009) suggested that larval survival rates could be reduced at SSCs as low as 250mg/l in Pacific herring (*Clupea pallasi*). These studies conclude that herring eggs suffer no adverse effects from suspended sediment concentrations in excess of the maximum levels expected from DEP or SEP construction activities. It should be noted that although the survival and development of herring eggs appear to be insensitive to high SSCs, deposition of sediment is expected to be detrimental unless the sediment is quickly removed by currents (Birklund and Wijsmam, 2005). Furthermore, as discussed in **Section 11.5.2.3** of this chapter and **Section 11.2.4.5** of **Appendix 11.1** there is no evidence of herring actively spawning within the boundaries of DEP and SEP, despite the availability of suitable spawning habitats (**Figures 11.2** and **11.3**). With their regional importance, high recoverability but sensitivity to smothering due to re-deposition, a medium sensitivity has been assigned.

148. According to the Marine Evidence based Sensitivity Assessment (MarESA), shellfish species such as brown crab have a low sensitivity to increased SSCs with a high recoverability rate from such impacts (Neal and Wilson, 2008). They are also likely to avoid areas with spoil or increased SSCs as they are reliant on visual acuity to find prey (Neal and Wilson, 2008). Their sensitivity to smothering is also very low with very high recoverability, likely due to their ability to escape from any re-deposition of sediment (Neal and Wilson, 2008). Therefore, brown crab are not considered sensitive to increased SSCs or smothering at the levels expected from DEP and SEP.

149. There is no MarESA information to help define sensitivities or recoverability rates with respect to lobster, however there is for spiny lobster (*Palinurus elephas*) which are of the same taxonomic family (*Nephropidae*) and have a similar size and ecology, and are therefore the most suitable for comparison (NBL, 2019; AQUIND Limited, 2019). Spiny lobster has been found (by MarESA) to be of medium sensitivity and low resilience to increased SSCs as such conditions may alter the proportion of different prey items available, however they do undergo periods of fasting and a temporary change in suspended sediment is unlikely to reduce their total intake (Gibson *et al.*, 2020). They are unlikely to be affected by light smothering (up to 5cm) due to their size and mobility (Gibson *et al.*, 2020).

150. The most vulnerable shellfish to increased SSCs and re-deposition are berried females, as their eggs oxygen levels require regulation and low levels can affect their development (Green *et al.*, 2014). Brown crabs are able to detect oxygen levels and adjust their fanning rate and abdomen movements accordingly. Both lobsters and crabs used changes in maternal behaviour and also physiological adaptation to escape unfavourable egg development conditions (Green *et al.*, 2014). Any increased SSCs or re-deposition during construction activities are likely to localised and short lived with sediments settling quickly into the seabed. With this in mind, both brown crab and lobster are deemed to be of medium vulnerability, high recoverability and of high regional importance in the southern North Sea, with a low overall sensitivity.

Impact Significance - DEP or SEP in Isolation

151. Construction activities causing increased SSC and re-deposition of sediment will be localised, temporary/short-lived and intermittent. These are likely to affect a small proportion of fish and shellfish in the area and most species are expected to have some tolerance to these effects. With a low magnitude and low sensitivity, the impact to the majority of fish and shellfish species will be of **minor adverse** significance.

152. As described above, the sensitivity of herring and sandeel eggs and larvae is considered to be medium. However, taking into account the low magnitude of effect predicted, the impact on fish eggs and larvae (taking herring and sandeel eggs and larvae as the worst case) is assessed to be of **minor adverse** significance.

153. The impact of increased SSCs on fish and shellfish egg and larval development in general is assessed to be of **minor adverse** significance.

Magnitude of effect - DEP and SEP Together

154. Although there will be a larger release volume of sediment and potentially greater SSCs (above background levels) as a result of DEP and SEP being built together, it is predicted that they will still be less than 10mg/l, localised and short-lived as with DEP or SEP in isolation. Therefore, the magnitude of effect for increased SSCs and sediment re-deposition for DEP and SEP together are deemed to remain as low.

Sensitivity of effect - DEP and SEP Together

155. While the total volume of sediment will be greater than if either DEP or SEP were built in isolation, the effects are predicted to be similar and also short lived. Therefore, the sensitivity of the receptors to these effects are considered to remain the same as assessed for DEP or SEP in isolation.

Impact Significance - DEP and SEP Together

156. The potential impact significance for increased SSCs and sediment re-deposition to fish and shellfish species if DEP and SEP are built together is considered to be of **minor adverse** significance.

11.6.1.3 Impact 3: Re-mobilisation of contaminants in seabed sediments

157. Benthic sampling was undertaken in August 2020 in the DEP and SEP wind farm areas and cable corridors, with selected samples being subject to contaminant analysis (for further details refer to **Chapter 9 Marine Water and Sediment Quality**).

Magnitude of effect - DEP or SEP in Isolation

158. Sediment disturbance could lead to the mobilisation of existing contaminants within the seabed sediments. Some of these contaminants could potentially be harmful to fish and shellfish. However, the data from the site specific contaminant analysis, as described in **Chapter 9 Marine Water and Sediment Quality**, illustrates that levels of contaminants within the DEP and SEP project areas are very low and do not contain elevated levels to cause concern, therefore the magnitude of effect is considered to be negligible.

Sensitivity of effect - DEP or SEP in Isolation

159. In the past when pipelines were installed in the study area, the local whelk community was affected, raising some concern that construction activities for DEP or SEP could release organotins that may be found at depth and cause a similar effect. DEP North, and small parts of the DEP North to DEP South interlink cable corridor and SEP overlap with a portion of whelk fishing grounds as mapped in 2010, as shown in **Appendix 14.1 Commercial Fisheries Technical Report**.

160. The MarESA guide (Tyler *et al.*, 2019) shows that, where contaminant levels are within environmental protection standards, marine species and habitats are not sensitive to changes that remain within these standards. All contaminants in all samples analysed from the DEP and SEP project areas were below Cefas Action Level 1. However six samples had levels of arsenic that only marginally exceed Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CSQC) Threshold Effect Levels (TEL) (7.24mg/kg), with concentrations ranging from 8.73 to 14.3mg/kg, which is below Probable Effect Levels (PEL) (41.6mg/kg). Whalley *et al.*, (1999) found that there are elevated arsenic concentrations in sediments off the north east of Norfolk.

161. Several studies have found that organisms higher in the food chain, like fish, have a limited ability for arsenic uptake from the water column, compared to lower trophic organisms (bacteria, plankton, and macroalgae) (De Gieter *et al.*, 2002). Fish predominately accumulate via their diet, however arsenic levels do not biomagnify, unlike mercury (De Gieter *et al.*, 2002). On balance, the sensitivity of all fish and shellfish receptors to the marginally elevated levels of arsenic found in the DEP and SEP project areas is considered to be low.

Impact Significance - DEP or SEP in Isolation

162. All relevant construction activities would be covered by a Project Environmental Management Plan (PEMP), in accordance with the draft DCO, as well as emergency plans in the case of an accidental spillage or leak. In addition to this, all vessels must adhere to the requirements of the MARPOL Convention Regulations with appropriate preventative and control measures. These measures will limit the potential for the introduction of any additional contaminants as a result of project activities (for which there are few sources in any case – see **Chapter 5 Project Description** for further details).

163. Taking into account the absence of significant existing contamination and the application of mitigation to avoid any additional release of contaminants, the re-mobilisation of contaminants from construction works is assessed to be of **negligible adverse** significance.

Magnitude of effect - DEP and SEP Together

164. As with DEP or SEP in isolation, there are no significant levels of contaminants found in the sediment samples, resulting in a negligible magnitude of effect.

Sensitivity of effect - DEP and SEP Together

165. The sensitivity of fish and shellfish receptors is considered to remain low, as assessed for DEP or SEP in isolation.

Impact Significance - DEP and SEP Together

166. With the lack of any significant existing contamination and the application of mitigation to avoid any additional release of contaminants, the re-mobilisation of contaminated sediments during intrusive construction works is assessed to be of **negligible adverse** significance for DEP and SEP together.

11.6.1.4 Impact 4: Underwater noise during foundation piling

167. There are a range of foundation options being considered for DEP and SEP, including GBS, monopile and jacket with pin-piles, screw piles or suction buckets (see **Chapter 5 Project Description**). Piling may be required should monopiles or jackets with pin-piles be used. Pile driving is a source of high level underwater noise that can cause: physiological (mortality, permanent injury or temporary injury); behavioural (startled movements; swimming away from noise source; change migratory patterns or cease reproductive activities); and environmental (changes to prey species or feeding behaviours) impacts on fish and shellfish. Therefore, the worst-case scenario (**Table 11-2**) for underwater noise is that all foundations could be piled.

168. The assessment of the impacts of underwater noise during piling on fish and shellfish is based on the outputs of the underwater noise modelling undertaken by Subacoustech Environmental Ltd and should be read with reference to **Appendix 12.2**. A summary of the sensitivity of the fish receptors found in the DEP and SEP project areas and of the noise modelling results are provided below, followed by the impact assessment.

11.6.1.4.1 Fish and shellfish hearing

169. By listening to the sounds around them, fish obtain substantial information about their environment and use sound to communicate (Popper *et al.*, 2019; Popper and Hawkins, 2019). Each species has differing sensitivity to noise and therefore the potential impact of noise on fish may vary. Anthropogenic sounds can be so intense as to result in death or mortal injury, or lower sound levels may result in temporary hearing impairment, physiological changes including stress effects, changes in behaviour or the masking of biologically important sounds (Popper and Hawkins, 2019; Kastelein *et al*., 2017).

170. Relatively few experiments on the hearing of fishes have been carried out under suitable acoustic conditions, and only a few species have valid data that provide actual thresholds (Popper and Hawkins, 2019). However, recent studies on how noise affects fish and shellfish species have brought to light that there is a lack of clear evidence supporting defined thresholds. This is due to the focus only on sound pressure and not particle motion, when the latter may be critical to understanding the importance of sound to fishes and invertebrates (Popper and Hawkins, 2018).

171. It is evident that there can be substantial differences in auditory capabilities between different fish species. To understand their hearing, the preferred approach is 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). Hawkins, Johnson and Popper (2020) recommend using the criteria as proposed by Popper *et al.* (2014) (as summarised in **Table 11-18**) until more data becomes available, therefore the following groups have been determined:

- Fish species with no swim bladder or other gas chamber (e.g. flat fishes and elasmobranch 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 chamber (e.g. Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure.
- Fish species in which hearing involves a swim bladder or other gas volume (e.g. cod, herring and relatives, Otophysi). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

Table 11-18: Criteria for impact piling used in the assessment (source Popper et al., (2014))

Category	Mortality	Recoverable Injury	Temporary Threshold Shift (TTS)[2]	Behaviour[3]
Fish: no swim bladder (particle motion detection)	> 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: swim bladder is not involved in hearing (particle motion detection)	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: swim bladder involving in hearing (primarily pressure detection)	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
N = Near-field; I = Intermediate-field; F = Far-field				

[2] Causing physiological change to the body or tissues of a fish that recovers and returns to normal over a period of time (Boyle and New, 2018)

[3] Qualitative criteria that summarise the effect of the noise as having either a high, moderate or low effect on an individual in either the (N) near-field (tens of metres), (I) intermediate-field (hundreds of metres), or (F) far-field (thousands of metres).

172. The hearing of shellfish is far less studied than that of fish but studies have shown they are particle motion detectors (Popper and Hawkins, 2018). Of the limited studies, there is growing evidence that shellfish may be capable of detecting sounds traveling through and immediately above substrate but an insufficient number to give a broad overview of potential impacts to them (Popper and Hawkins, 2018; Hawkins and Popper 2016). What evidence there is suggests that those species studied are primarily sensitive to particle motion at frequencies well below 1 kHz (Hawkins and Popper, 2016).

11.6.1.4.2 Summary of DEP and SEP Underwater Noise Modelling

173. Underwater noise modelling was carried out by Subacoustech to estimate the noise levels likely to arise during piling and determine the potential impacts on fish using the INSPIRE v5 (Impulsive Noise Propagation and Impact Estimator) subsea noise propagation model (see **Appendix 12.2**). The INSPIRE model is a semi-empirical noise propagation model based on the use of a combination of numerical modelling and actual measured underwater noise data. It was designed to calculate the propagation of noise in shallow, mixed water, typical of both conditions around the UK.

174. The modelling considers a wide array of input parameters, including variations in bathymetry and source frequency content to ensure as detailed results as possible. It should also be noted that the results presented in this assessment are precautionary as the worst-case parameters have been selected for:

- Piling hammer energies;
- Ramp-up profile and strike rate;
- Duration of piling; and
- Receptor swim speeds.

175. Modelling was undertaken at two representative locations for DEP and SEP, including the deepest point of the sites (typically the worst-case location i.e. the deepest location where piling can take place, which tends to give the greatest noise propagation) (**Table 11-19** and **Appendix 12.2**).

Table 11-19: Underwater noise modelling locations

Modelling Locations	SEP		DEP	
	East (E)	North (N)	North east (NE)	South east (SE)
Latitude	53.1219°N	53.2446° N	53.3657°N	53.1775°N
Longitude	001.2841°E	001.0920°E	001.3897°E	001.5335°E
Water depth (mean tide)	21.3m	18.6m	23.2 m	25.5 m

176. The worst-case scenario was based on the maximum impact range modelled across both locations and was used to inform the assessment of the maximum potential impacts on receptor groups, in order to provide a conservative assessment.

177. Both monopile and pin pile piling worst case scenarios have been modelled with the following hammer energies:

- Monopile with maximum diameter of 16m, maximum hammer energy of up to 5,500kJ and maximum starting energy of 1,000kJ. It should be noted that the most likely worst-case scenario would be up to 4,500kJ with a starting hammer energy of 600kJ; and
- Pin-pile with diameter of 3.5m, maximum hammer energy of up to 3,000kJ and maximum starting hammer energy of 400kJ.

178. A worst case scenario approach to the maximum hammer energy is required to provide a robust assessment. However, there is available evidence from construction surveys that suggest that the maximum hammer energy is rarely required. For example, in 2016 when the Dudgeon OWF was constructed, the predicted maximum hammer energy was 3,000kJ when in fact only 2,870kJ was used, with an average of only 1,367kJ over the 93 days of piling (DOWL, 2016). As another example, during construction of the Beatrice OWF in the Moray Firth, the piling strategy implementation report states that the maximum hammer energy that was required ranged between 435kJ and 2,299kJ, with an average across the site of 1,088kJ. However, the ES had estimated that during construction the maximum hammer energy would be 2,300kJ, taking into account the worst case (Beatrice OWF Ltd, 2018).

179. The cumulative sound exposure level (SEL_{cum}) determines the potential for Permanent Threshold Shift (PTS) or Temporary Threshold Shift (TTS) during installation of an entire pile (either monopile or pin-pile). As the soft-start takes place over the first 30 minutes of piling at the starting hammer energy, the hammer energy will increase (ramp-up) gradually to the maximum hammer energy that is required to safely install the pile.

180. As stated above, the worst-case scenario is assumed to be 100% maximum hammer energy applied for the remaining duration of the pile installation (maximum hammer energy to be applied is only likely to be required at a few of the piling installation locations and for shorter periods of time). The soft-start, ramp-up and piling duration used to assess SEL_{cum} for monopiles and pin piles are summarised in **Table 11-20** and most likely hammer energies in **Table 11-21**. The main difference between the worst case and most likely scenarios is that the most likely scenario uses lower hammer energies and utilises a soft start procedure, whereby single blows of the piling hammer occur at low energy, interspersed with pauses of several minutes before commencing a more continuous strike rate, before ramping up to maximum energy.

Table 11-20: Worst case hammer energy, ramp-up and piling duration

	Starting hammer energy (kJ)	Ramp up (kJ)				Maximum hammer energy (kJ)
Monopile						
Monopile hammer energy	1,000kJ	1,500kJ	2,500kJ	3,500kJ	4,500kJ	5,500kJ

	Starting hammer energy (kJ)	Ramp up (kJ)				Maximum hammer energy (kJ)
Number of strikes	1350	2400	1600	1200	1350	1350
Duration (minutes)	30	40	40	40	45	45
Total duration – 4 hours						
Pin-pile						
Pin-pile hammer energy	400	920	1440	1960	2480	3000
Number of strikes	1200	1200	1200	1200	900	900
Duration (minutes)	30	30	30	30	30	30
Total duration – 3 hours						

Table 11-21 Most likely hammer energy, ramp-up and piling duration for monopile only

	Starting hammer energy (kJ)	Ramp up (kJ)				Maximum hammer energy (kJ)
Monopile						
Monopile hammer energy	600	600	1500	2500	3500	4500
Number of strikes	4	900	2400	1600	1200	900
Duration (minutes)	20	20	40	40	40	30
Total duration – 3 hours 10 minutes						

181. A stationary animal model based on research from Hawkins *et al.* (2014) has been used to cover the SEL_{cum} criteria for the assessment for fish following consultation feedback from the MMO (**Table 11-1**). However it is recognised that most fish species are likely to move away from a sound that is loud enough to cause harm (Dahl *et al.*, 2015; Popper *et al.*, 2014); some may seek protection in the sediment and others may dive deeper in the water column. Although it is feasible that some species will not flee, those that are likely to remain are thought more likely to be benthic species or species without a swim bladder; with these being the least sensitive species. The modelling based on an assumed stationary receptor is therefore likely to give an overly conservative result. All Popper *et al.* (2014) threshold criteria values (SEL_{peak} and SEL_{cum}) are unweighted. Further information on the parameters used for the underwater noise modelling and methodologies can be found in **Appendix 12.2**.

11.6.1.4.2.1 Results

182. Results of the worst case underwater noise modelling using a stationary animal approach in terms of area, maximum, minimum and mean impact ranges are shown in **Table 11-22**. The impact ranges for fish mortality and potential mortal injury, recoverable injury and for temporary auditory injury (TTS) are shown for both the installation of monopiles and pin piles, against their respective maximum hammer energies of 5,500kJ and 3,000kJ.

183. The installation of monopiles results in the greatest spatial impact range for stationary fish species for both SPL_{peak} and SEL_{cum} thresholds for both projects. The greatest impact for each threshold criteria are therefore taken forward as the worst-case spatial impact for assessment (**Table 11-22**).

184. Fish species with swim bladders are shown to have the biggest associated impact ranges from piling noise for SPL_{peak} thresholds, with both mortality and recoverable injury impact ranges of 270m and 250m for monopiles at DEP and SEP respectively, and pin pile impact ranges of 220m and 200m at DEP and SEP respectively. The maximum impact ranges for the cumulative impact ranges are again for fish species with swim bladders for monopile installation, with ranges of 4.4km (SEP) and 5km (DEP) for recoverable injury and 16km (SEP) and 19km (DEP) for TTS (**Table 11-22**).

185. In addition to the worst-case spatial impact for fish species as described above, consideration has also been given to the temporal worst-case scenario. This would be the result of the installation of the maximum number of 136 pin piles (equating to 408 hours (17 days)) for DEP and a maximum of 112 pin piles (312 hours (13 days)) for SEP (**Table 11-2**).

186. Piling would not be constant during the piling phases and construction periods. There will be gaps between the installations of individual piles, and if installed in groups there could be time periods when piling is not taking place as piles are brought out to the site. There will also be potential delays for weather or other technical issues.

187. The duration of piling is based on a worst case scenario and a very precautionary approach and as has been shown at other OWFs, the duration used in the impact assessment is conservative. An example of this conservatism in practice is available from the installation of monopile foundations at the Dudgeon OWF. In this case the impact assessment was based on an estimated time of up to 4.5 hours to install each monopile and the estimated duration of active piling was 301.5 hours (approximately 13 days). However, the actual total duration of active piling to install the 67 monopiles was 65 hours (approximately 3 days) with the average time for installation per monopile of 71 minutes; approximately 21% of the predicted maximum piling duration (DOWL, 2016).

Table 11-22: Underwater noise modelling results for both monopile and pin pile maximum hammer energies, for the worst-case modelling location only (using a stationary animal response). For the full set of modelling results (including for the average water depth modelling location) see Appendix 12.2

Fish Group	Impact Criteria	Potential Impact	Location	Impact Areas and Ranges									
				Monopile (maximum hammer energy 5,500kJ)				Pin pile (maximum hammer energy 3,000kJ)				Monopile (starting hammer energy 1,000kJ)[4]	
				Area	Max	Min	Mean	Area	Max	Min	Mean	Area	Max
Fish: no swim bladder (particle motion detection)	>213 dB unweighted SPL_{peak}	Mortality and potential mortal injury	DEP SE	**0.04km²**	**110m**	110m	110m	**0.02km²**	**90m**	90m	90m	**<0.01km²**	**60m**
			SEP E	**0.03km²**	**100m**	100m	100m	**0.02km²**	**80m**	80m	80m	**<0.01km²**	**<50m**
	>219 dB unweighted SEL_{cum} [stationary]	Mortality and potential mortal injury	DEP SE	**1.4km²**	**700m**	700m	700m	**0.44km²**	**400m**	400m	400m	**<0.01km²**	**<50m**
			SEP E	**1.2km²**	**700m**	600m	600m	**0.44km²**	**400m**	400m	400m	**<0.01km²**	**<50m**
	>216 dB unweighted SEL_{cum} [stationary]	Recovera -ble injury	DEP SE	**3.3km²**	**1.1km**	1.0km	1.0km	**1.0km²**	**600m**	600m	600m	**<0.01km²**	**<50m**
			SEP E	**2.7km²**	**1.0km**	900m	900m	**0.86km²**	**600m**	500m	500m	**<0.01km²**	**<50m**
	>186 dB unweighted SEL_{cum} [stationary]	TTS	DEP SE	**840km²**	**19km**	13km	16km	**540km²**	**15km**	11km	13km	**<0.01km²**	**190m**
			SEP E	**620km²**	**16km**	12km	14km	**400km²**	**12km**	10km	11km	**0.1km²**	**180m**

[4] *Note that the SEL_{ss} parameters presented for the starting hammer energy are not part of the Popper et al. (2014) criteria, but have been modelled to give an idea as to the levels of noise present for the first pile strike and at full energy at the end of the piling operations.*

Fish Group	Impact Criteria	Potential Impact	Location	Impact Areas and Ranges									
				Monopile (maximum hammer energy 5,500kJ)				Pin pile (maximum hammer energy 3,000kJ)				Monopile (starting hammer energy 1,000kJ)[4]	
				Area	Max	Min	Mean	Area	Max	Min	Mean	Area	Max
Fish: swim bladder is not involved in hearing (particle motion detection)	>207 dB unweighted SPL_{peak}	Mortality and potential mortal injury	DEP SE	**0.23km^2**	**270m**	270m	270m	**0.15km^2**	**220m**	220m	220m	**0.06km^2**	**140m**
			SEP E	**0.19km^2**	**250m**	250m	250m	**0.12km^2**	**200m**	200m	200m	**0.05km^2**	**130m**
	210 dB unweighted SEL_{cum} [stationary]	Mortality and potential mortal injury	DEP SE	**15km^2**	**2.3km**	2.2km	2.2km	**5.5km^2**	**1.4km**	1.3km	1.3km	**<0.01km^2**	**<50m**
			SEP E	**12km^2**	**2.0km**	1.9km	2.0km	**4.3km^2**	**1.2km**	1.2km	1.2km	**<0.01km^2**	**<50m**
	203 dB unweighted SEL_{cum} [stationary]	Recovera-ble injury	DEP SE	**72km^2**	**5.0km**	4.7km	4.8km	**31km^2**	**3.2km**	3.1km	3.2km	**<0.01km^2**	**<50m**
			SEP E	**55km^2**	**4.4km**	4.1km	4.2km	**23km^2**	**2.8km**	2.7km	2.7km	**<0.01km^2**	**<50m**
	>186 dB unweighted SEL_{cum}	TTS	DEP SE	**840km^2**	**19km**	13km	16km	**540km^2**	**15km**	11km	13km	**0.12km^2**	**190m**
			SEP E	**620km^2**	**16km**	12km	14km	**400km^2**	**12km**	10km	11km	**0.1km^2**	**180m**
Fish: swim bladder involving in hearing (primarily	>207 dB unweighted SPL_{peak}	Mortality and potential mortal injury	DEP SE	**0.23km^2**	**270m**	270m	270m	**0.15km^2**	**220m**	220m	220m	**0.06km^2**	**140m**
			SEP E	**0.19km^2**	**250m**	250m	250m	**0.12km^2**	**200m**	200m	200m	**0.05km^2**	**130m**
			DEP SE	**31km^2**	**3.3km**	3.1km	3.2km	**12km^2**	**2.0km**	2.0km	2.0km	**<0.01km^2**	**<50m**

Fish Group	Impact Criteria	Potential Impact	Location	Impact Areas and Ranges: Monopile (maximum hammer energy 5,500kJ)				Pin pile (maximum hammer energy 3,000kJ)				Monopile (starting hammer energy 1,000kJ)[4]	
				Area	Max	Min	Mean	Area	Max	Min	Mean	Area	Max
pressure detection)	207 dB SEL_{cum} unweighted [stationary]	Mortality and potential mortal injury	SEP E	**24km²**	**2.8km**	2.7km	2.8km	**9.2km²**	**1.8km**	1.7km	1.7km	**<0.01km²**	**<50m**
	203 dB SEL_{cum} unweighted [stationary]	Recovera-ble injury	DEP SE	**72km²**	**5.0km**	4.7km	4.8km	**31km²**	**3.2km**	3.1km	3.2km	**<0.01km²**	**<50m**
			SEP E	**55km²**	**4.4km**	4.1km	4.2km	**23km²**	**2.8km**	2.7km	2.7km	**<0.01km²**	**<50m**
	>186 dB SEL_{cum} unweighted [stationary]	TTS	DEP SE	**840km²**	**19km**	13km	16km	**540km²**	**15km**	11km	13km	**0.12km²**	**190m**
			SEP E	**620km²**	**16km**	12km	14km	**400km²**	**12km**	10km	11km	**0.1km²**	**180m**

11.6.1.4.3 Magnitude of effect - DEP or SEP in Isolation

188. The worst case scenario spatially considers the greatest area of impact from underwater noise during foundation piling. This would consist of using the maximum hammer energy of 5,500kJ installing 32 x 14MW turbines using monopiles (1 monopile per WTG) at DEP and one OSP (8 pin piles), or 24 x 14MW turbines at SEP and one OSP (8 pin piles) (**Table 11-2**).

189. Temporally, the worst case scenario considers the longest duration for underwater noise during foundation piling. This would consist of 32 x 14MW turbines using pin piles (4 pin piles per WTG, 128 pin piles) installed at DEP or 24 x 14MW turbines (4 pin piles per WTG, 104 pin piles) at SEP (**Table 11-2**). Over the 24 months/2 years construction period up to 17 days (408 hours) of total active piling would be required to install 136 pin piles (32 x WTG and one OSP) at DEP. Total active piling at SEP for 26 x WTG and one OSP (112 pin piles) would be up to 13 days (312 hours).

11.6.1.4.3.1 Mortality and recoverable injury

Fish with no swim bladder

190. From the installation of monopiles, at full hammer energy, there is potential for mortality and potential mortal injury / recoverable injury (>213 dB SPL_{peak}) to occur on fish with no swim bladder at ranges up to 100m for SEP and up to 110m for DEP. The mortality and potential for mortal injury (>219 dB SEL_{cum}) would occur at a range of up to 700m for both projects for fish with no swim bladder. Recoverable injury (>216dB SEL_{cum}) would occur at a range of up to 1km for SEP and up to 1.1km for DEP (**Table 11-22**). For the starting hammer energy of a monopile (of 1,000kJ), there is the potential for mortality and potential mortal injury at a distance of 60m from the pile location, and for recoverable injury at up to 50m, from either DEP or SEP.

191. Taking the small areas potentially affected (minority of the receptor) and the temporary, short term and intermittent nature of piling activity, the magnitude of effect is considered to be low.

Fish with swim bladder not involved with hearing

192. There is potential for mortality / potential mortal injury and recoverable injury, for fish with swim bladders not involved in hearing, at ranges up to 250m for SEP and up to 270m for DEP (for >207dB SPL_{peak} criteria) from the installation of monopiles. There is the potential for the mortality / potential for mortal injury (>210 dB SEL_{cum}) at a range of up to 2km for SEP and up to 2.3km for DEP from the installation of monopiles (**Table 11-22**). Taking the areas potentially affected along with the temporary, short term and intermittent nature of piling activity, the magnitude of effect is considered to be low.

193. There is, however, the potential for recoverable injury to occur on fish with swim bladders not involved in hearing at ranges up to 5km and 4.4km for DEP and SEP respectively (for 203dB SEL_{cum}) from the installation of monopiles (**Table 11-22**).

194. For the starting hammer energy of a monopile (of 1,000kJ), there is the potential for mortality and potential mortal injury at a distance of 140m (at DEP) and 130m (at SEP) from the pile location, and for recoverable injury at up to 50m, from either DEP or SEP.

195. Taking into account the spatial extent of the impact (minority of the receptor) and the temporary, short term and intermittent nature of piling activity, the magnitude of effect is considered to be low.

Fish with swim bladder involved in hearing

196. There is the potential for mortality / potential mortal injury (207dB SEL_{cum}) and recoverable injury (203dB SEL_{cum}) to occur on fish with swim bladders involved in hearing at ranges of up to 3.3km and 5km respectively from the installation of monopiles at DEP and ranges of up to 2.8km and 4.4km respectively for SEP (**Table 11-22**). For the starting hammer energy of a monopile (of 1,000kJ), there is the potential for mortality and potential mortal injury at a distance of 140m (at DEP) and 130m (at SEP) from the pile location, and for recoverable injury at up to 50m, from either DEP or SEP.

197. **Figure 11.6** shows the herring spawning heat mapping combined with the modelled maximum range of mortality and potential mortal injury impacts, on stationary fish receptors with a swim bladder involved in hearing (which include herring), from DEP and SEP worst case monopile installation. Since piling noise sources could be from any location inside the wind farm sites, the maximum modelled range of each impact for each project has been applied around the respective project wind farm sites. However, since the impact distance is based on the maximum extent from modelling of the worst case locations, the distance from the noise sources of these extrapolated contours is greater that would occur in reality. Taking into account the spatial extent of the impact (minority of the receptor) and the temporary, short term and intermittent nature of piling activity, the magnitude of effect is considered to be low.

Eggs and larvae

198. Popper *et al.* (2014) describes the impact criteria for potential mortality / potential mortal injury in eggs and larvae as >210 dB SEL_{cum} or >207 dB SPL_{peak}. These criteria are based on work by Bolle *et al.* (2012) who reported no damage to larval fish at SEL_{cum} as high as 210 dB re 1 μPa 2·s. On the basis of Bolle *et al.* (2012), the levels adopted in Popper *et al.* (2014) are likely to be conservative. As levels proposed in Popper *et al.* (2014) are similar to those described for fish species with a swim bladder not involved in hearing (210 dB SEL_{cum} or >207 dB SPL_{peak}) the modelled impact ranges for this category have been used to provide an indication of the potential impacts on fish eggs and larvae.

199. As outlined in **Table 11-22**, the ranges are as follows for monopiles at DEP: for mortality and potential mortal injury, 270m (>207dB SPL_{peak}) and 2.3km (210dB SEL_{cum}). For monopiles at SEP: for mortality and potential mortal injury, 250m (>207dB SPL_{peak}) and 2km (210dB SEL_{cum}). For the starting hammer energy of a monopile (of 1,000kJ), there is the potential for mortality and potential mortal injury at a distance of 140m (at DEP) and 130m (at SEP) from the pile location, and for recoverable injury at up to 50m, from either DEP or SEP.

200. In reference to herring eggs and larvae, **Figure 11.3** shows the herring spawning heat mapping, including IHLS herring larvae abundance. Heat mapping indicates that the confidence in herring spawning activity in the vicinity of DEP and SEP is low to medium. As discussed above, impact ranges on herring eggs and larvae would be smaller than those indicated in **Figure 11.6** which apply to adult herring.

201. Taking the small areas potentially affected, the temporary, short term and intermittent nature of piling activity, (and for herring the low to medium confidence in spawning activity in the vicinity (**Figure 11.3**)), the magnitude of effect is considered to be low.

Shellfish

202. There are no specific criteria currently published in respect of shellfish species due to insufficient data to establish them (Popper *et al.,* 2014), 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).

203. 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 effect expected to be negligible.

11.6.1.4.3.2 TTS and behavioural

All species

204. The outputs of the noise modelling for the spatial worst case scenario indicate that TTS from the installation of monopiles may occur at distances of up to 19km for all the fish groups modelled for DEP, and 16km for all fish groups at SEP. Behavioural responses are anticipated to occur within this range and potentially in wider areas depending on the hearing ability of the species under consideration. For a starting hammer energy of 1,000kJ (for monopiles), there is the potential for TTS to occur at a distance of up to 190m for DEP and 180m for SEP.

205. The associated impacts of TTS could result in reduced fitness of some species. Behavioural responses to underwater noise can result in decreased feeding activity, lead to the potential avoidance of spawning grounds, or act as a potential barrier to migration. Consequently, there is concern that behavioural responses could have an adverse impact on spawning behaviour and migration of certain species. However, impacts on feeding activity are considered unlikely to cause long term, larger scale effects on fish populations given the wider availability of suitable feeding grounds in the region.

206. As shown in **Table 11-2**, in terms of the temporal worst case scenario, the maximum duration of piling would be the equivalent of 13 days for SEP and 17 days for DEP installing pin piles.

207. Taking account of the spatial extent of the impact with 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 effect for all species is considered to be low.

11.6.1.4.4 Sensitivity of effect - DEP or SEP in Isolation

208. In **Section 11.6.1.4.1**, four categories were identified that defined the sensitivity of fish to sound (see **Table 11-18**). In order to facilitate the assessment, fish receptors have been grouped into these categories, with this being the basis for defining the sensitivity of the fish receptors (**Table 11-23** and **Table 11-24**).

209. Given the lack of specific impact criteria for shellfish, 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 11-23: Hearing Categories of Fish Receptors and Respective Sensitivities for Mortality and Potential Mortal Injury

Category as defined by Popper *et al* (2014)	**Fish receptors relevant to the Projects**	**Sensitivity**
Fish with no swim bladder or other gas chamber	Dab Elasmobranchs River and sea lamprey Lesser weever Dragonet	Low
	Sandeels	Medium
Fish with swim bladder in which hearing does not involve the swim bladder or other gas volume	Sea trout Smelt*	Low
	Gobies	Medium
Fish in which hearing involves a swim bladder or other gas volume	Herring Sprat Whiting European eel* Allis and Twaite Shad	Medium
Eggs and larvae	All fish and shellfish species	Medium

* denotes uncertainty or lack of current knowledge with regard to the potential role of the swim bladder in hearing

210. The following section provides the rationale for these receptor sensitivities.

11.6.1.4.4.1 Mortality and recoverable injury

Fish with no swim bladder

211. The majority of fish receptors included within the group "fish with no swim bladder" (**Table 11-23**) 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.

212. Sandeels are an exception to this because, due to their burrowing behaviour and substrate dependence, they may have limited capacity to flee the area compared to other fish species. They are therefore considered, by exception for this group, to be of medium sensitivity.

Fish with swim bladder not involved with hearing

213. The majority of fish receptors included within the group "fish with swim bladders not involved in hearing" (**Table 11-23**) 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.

214. An exception in this category are sand gobies, similarly to sandeel their mobility is limited due to their burrowing behaviour. They potentially have reduced capabilities to escape the areas affected by the greatest noise levels. However, gobies are abundant over wide areas of the North Sea and it is likely that any noise effects would impact only a small proportion of the population. As they have a relatively short life cycle of 2 years (Teal *et al.,* 2009), the population would be expected to recover quickly if subject to localised impacts associated with piling. As such, they are considered to be receptors of medium sensitivity.

Fish with swim bladder involved in hearing

215. Species within the "fish with swim bladders involved in hearing" category (**Table 11-23**) are highly mobile and likely to depart the area from the onset of 'soft start' piling. These species are susceptible to barotrauma and detect sound pressure as well as particle motion. Therefore, they are regarded to be of medium sensitivity.

Eggs and larvae

216. Due to their lack of mobility, eggs and larvae are vulnerable to barotrauma and exposure may cause physiological abnormalities or defects. Bolle *et al.* (2014) exposed larvae of three species (herring, sole and bass) with different swim bladder development stages to pile driving noise reproduced to up to 210 dB $SPL_{peak.}$ Survival was monitored for seven to ten days and none of the larvae showed significant difference in mortality compared to the control group.

217. Movement of eggs and larvae is determined by currents; they do not have the ability to flee the vicinity of piling activity. However, prolonged exposure could be reduced by any drift of eggs / larvae due to currents, which may reduce the risk of mortality.

218. The distribution of eggs and larvae most species range over large areas, with the exception of herring eggs which are deposited in specific areas as described previously. Injury or mortality of eggs and larvae in close proximity to piling is possible. However, it should be noted that any mortality associated with piling would be a small amount in comparison to the naturally high mortality rates during these life stages. Taking the above into account, egg and larval stages (all species) are considered to be of medium sensitivity.

Shellfish

219. 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 considered to be receptors of medium sensitivity.

11.6.1.4.4.2 TTS and behavioural

220. The assessment of the impact of TTS and behavioural impacts has been focused on key species as stated in **Table 11-16**, 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.

Table 11-24 Hearing Categories of Fish Receptors and Respective Sensitivities for TTS and behavioural

Category as defined by Popper *et al* (2014)	Fish receptors relevant to the Projects	TTS and Behavioural	Sensitivity
Fish with no swim bladder or other gas chamber	Dab Elasmobranchs River and sea lamprey Lesser weever Dragonet Dover sole Plaice Mackerel Lemon sole	(N) High (I) Moderate (F) Low	Low
	Sandeels		Medium
Fish with swim bladder in which hearing does not involve the swim bladder or other gas volume	Sea trout Smelt*	(N) High (I) Moderate (F) Low	Low
	Gobies		Medium
Fish in which hearing involves a swim bladder or other gas volume	Herring Sprat Whiting Cod European eel* Allis and Twaite Shad	(N) High (I) High (F) Moderate	Medium
Eggs and larvae	All fish and shellfish species	(N) Moderate (I) Low (F) Low	Medium

* denotes uncertainty or lack of current knowledge with regard to the potential role of the swim bladder in hearing

Fish with no swim bladder

221. DEP and SEP are located within a low intensity spawning ground for Dover sole, within a spawning ground[5] for lemon sole, and also low intensity nursery grounds for plaice, mackerel and thornback ray (**Appendix 11.1**). It should be noted that the degree of overlap between the spawning and nursery grounds of these species and the area with potential for TTS onset would be very small relative to the total area that the species could use for spawning. In addition, Dover sole, lemon sole and plaice are pelagic spawners and therefore not dependent on discrete spawning grounds with particular substrate characteristics.

[5] As identified by Coull et al. (1998), intensity not defined.

222. Elasmobranchs have no swim bladder or gas chamber, thus are incapable of detecting sound pressure and presumably sense particle motion (Casper *et al.*, 2012). However, studies of their hearing have shown that they can detect sounds from below 50Hz to over 500Hz (Normandeau Associates Inc., 2012).

223. Under the spatial worst case piling scenario, TTS may occur at ranges of up to 19km at DEP and up to 16km at SEP (**Table 11-22**). According to the Popper *et al.* (2014) criteria for behavioural impacts (or TTS), the species listed in **Table 11-24** (excluding sandeels) would be at high risk of behavioural impact near the piling locations (tens of metres), they would be at moderate risk at intermediate distances (hundreds of metres) and at low risk when far (thousands of metres) from the piling location (**Table 11-24**). The potential area affected by TTS and behavioural impacts is very small in the context of the wide distribution ranges of the species listed in **Table 11-24** (excluding sandeels), including those relating to spawning / nursery grounds for relevant species and therefore any impact associated with piling is expected to be low. In respect of the above, these species are considered to be receptors of low sensitivity.

224. Studies monitoring lesser sandeel behavioural reactions to seismic surveys has shown behavioural reactions to noise source levels of 210 dB at 1 µPa (similar to piling see **Appendix 12.2**). The study indicates that seismic noise had a moderate effect on their behaviour, although no immediate lethal effect was observed (Hassel *et al.,* 2004). Hassel *et al.* (2004) also review landings data from Norwegian sandeel trawlers showed a temporary drop for a short period after the experiment. The results of this study indicates that the effects of such noise levels are likely to be short term, localised and constrained to behavioural level impacts only; with no long-term effects likely.

225. DEP and SEP are located within both the low intensity spawning and nursery grounds of sandeel (for greater, lesser, smooth and small sandeel species) (**Appendix 11.1**). As discussed in **Section 11.5.2.3.2**, seabed habitat that has been classified as suitable for sandeel, particularly in and around the DEP wind farm sites and in particular DEP North (**Figure 11.4**). Heat mapping identified medium confidence sandeel habitat in the SEP wind farm site, interlink cable corridors and the DEP wind farm sites, with areas of high sandeel habitat confidence in parts on DEP South and very high confidence in parts of DEP North (**Figure 11.5**). It should be noted however that the degree of overlap between the spawning and nursery grounds of these species and the area with potential for TTS onset would be very small relative to the total area that the species could use for spawning, with extensive areas of high confidence sandeel habitat further to the north and west (**Figure 11.5**).

226. Sandeel species lack a swim bladder, and according to Popper *et al.* (2014), would therefore be at high risk of behavioural impact near (tens of metres) the piling locations, at moderate risk at intermediate distances (hundreds of metres) and at low risk when far (thousands of metres) from the piling location (**Table 11-24**). Taking this into account, together with their seabed specific requirements, sandeels are considered to have medium sensitivity.

Fish with swim bladder not involved with hearing

227. As stated in **Table 11-24** diadromous species included in this category are smelt and sea trout. Studies on how underwater noise affects smelt are limited. Sea trout are only moderately sensitive to underwater sound (Nedwell *et al.*, 2008). As a close relative of salmon (*Salmo salar*), sea trout were used as a model to determine the possible implications to salmon during piling operations at Southampton Water in 2003. Nedwell *et al*. (2008) presents the results from the study conducted simultaneously to the piling operations. Nedwell *et al*. (2008) found no obvious signs of trauma in any examined fish and no increase in activity or startled response was observed at any range from the piling.

228. TTS in fish species could occur at ranges up to 19km at DEP and 16km at SEP for monopiles, the species listed in **Table 11-24** (excluding gobies) would be at high risk of behavioural impact near the piling locations (tens of metres), they would be at moderate risk at intermediate distances (hundreds of metres) and at low risk when far (thousands of metres) from the piling location (**Table 11-24**). The potential area affected by TTS and behavioural impacts is very small in the context of the wide distribution ranges of the species listed in **Table 11-24** (excluding gobies), it should be noted, however, that diadromous species are only likely to occur occasionally in the DEP and SEP area, and therefore the potential for these species to be subject to adverse piling noise impacts is very low. Furthermore, given the distance of DEP and SEP from The Wash and Humber, 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.

229. Sand gobies may be an exception as they have limited mobility and therefore potentially a reduced capacity to escape the areas affected by the greatest noise levels. A recent study found that continuous sound can impact gobies spawning as females are unable to hear sound produced by males (Blom *et al*., 2019). Gobies are, however, abundant over wide areas of the North Sea and therefore any noise effects would impact only a small proportion of the population. Further, given the relatively short life cycle of this species (Teal *et al.*, 2009), the population would be expected to recover quickly if subject to localised impacts associated with piling. As such, they are considered to be receptors of medium sensitivity.

Fish with swim bladder involved in hearing

230. Blaxter and Hoss (1981) found that herring showed startle responses at received sound levels of 122 – 138dB re 1 µPa, and further observed that the response seen depended on the size of the fish. Various studies into the response of herring to underwater noise have found that during spawning and feeding seasons, there is little response to the noise, their urge to undertake these activities are of a higher priority than avoiding passing vessels or seismic surveys compared to reactions during wintering periods (Skaret *et al.*, 2005; Peña *et al*., 2013; Misund 1994).

231. As previously stated, and shown in **Figure 11.3** and **Appendix 11.1 Figure 11.6**, DEP and SEP overlap with historic herring spawning grounds defined by Coull *et al* (1998) however, from historic surveys, there was no significant spawning activity in and around the DEP and SEP project areas. Any herring spawning in and around the project areas are part of the Banks sub population. The ORJIP 2018 study found that Flamborough Head spawning ground was the current hotspot for the Banks component (Boyle and New, 2018).

232. Whilst the Coull *et al.* (1998) data suggests that the projects overlap a portion of the Banks stock, data from the IHLS shows that the important area for herring spawning is located to the north around Flamborough Head as shown in **Figure 11.3** and **Appendix 11.1 Figure 11.9**, which also correlates with the ORJIP findings. The closest point of DEP is approximately 118km to Flamborough Head and SEP approximately 124km.

233. **Figure 11.6** shows that the impact ranges associated with the potential for TTS onset overlap with areas of medium to low herring spawning confidence, including the area identified as the Banks sub-population spawning ground overlapping the wind farm sites.

234. As with the construction of previous OWFs, it is unlikely that maximum hammer energies would reach 100% and therefore the area of potential TTS effects would be considerably smaller than indicated by **Figure 11.6**. There is no overlap of the TTS impact ranges of either DEP or SEP with the area of high larvae abundance revealed by the IHLS to the north around Flamborough Head (**Figures 11.3 and 11.6**).

235. Herring have a swim bladder which is involved in hearing, and are therefore considered to have a high risk of behavioural impact when near (tens of metres) and in the intermediate vicinity (hundreds of metres) of the piling location, but at low risk when far (thousands or metres) from the piling location (**Table 11-18**). As DEP and SEP overlap with herring spawning grounds identified by Coull *et al.* (1998), piling would be expected to have a high behavioural effect. However, taking into account that there is no evidence of significant spawning in this area and the location of peak larval abundance is to the north of DEP and SEP beyond the maximum extent of noise impacts, it could be considered as ‘far’ from the piling location under Popper *et al.* (2014) risk level. Therefore, the potential impact area where TTS and behavioural impacts could occur (as shown in **Figure 11.6**) and the potential for behavioural impact is considered to be low. The substrate specific spawning behaviour of herring means that they are considered to be receptors of medium sensitivity.

236. DEP and SEP are located within the low intensity spawning for whiting and within the nursery grounds for cod. Although the projects do not overlap with any defined sprat spawning or nursery grounds, they were caught in abundance during the historic herring spawning surveys and have been included in the assessment. It should be noted however that the degree of overlap between the spawning and nursery grounds of these species and the area with potential for TTS onset would be very small relative to the total area that the whiting could use for spawning (see **Appendix 11.1**). In addition, these species are pelagic spawners and therefore not dependent on discrete spawning grounds with particular substrate characteristics.

237. These species have a swim bladder which is involved in hearing, and are therefore considered to have a high risk of behavioural impact when near (tens of metres) and in the intermediate (hundreds of metres) vicinity of the piling location, and at low risk when far (thousands of metres) from the piling location (**Table 11-24**). Taking into account the wide distribution ranges of these species, including the areas used as spawning grounds, and the potential impact area where TTS and behavioural impacts could occur, however their low risk to behavioural reactions when 'far field' (thousands of metres) from the piling source, they are considered to be receptors of low sensitivity.

238. Diadromous species included in this category are allis shad and twaite shad, and European eel. As stated above, their behavioural impact is high for both near field and intermediate filed and moderate far field. It should be noted, however, that diadromous species are only likely to occur occasionally in the area of DEP and SEP, and therefore the potential for these species to be subject to piling noise is very low. Furthermore, given the distance of DEP and SEP from The Wash and Humber 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.

11.6.1.4.4.3 Changes to Prey Species or Feeding Behaviour

239. 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 is the potential for changes in the behaviour of these prey species associated with piling noise that may result in indirect impacts on the species that feed on them. The potential impact of their availability as a result of piling for piscivorous fish is given below. The potential impacts on other receptors groups such as marine mammals and seabirds are assessed in **Chapter 12 Marine Mammal Ecology** and **Chapter 13 Offshore Ornithology** and are therefore not discussed here.

240. The outputs of the noise modelling for the spatial worst case scenario indicate that TTS may occur at distances of up to 19km from DEP and up to 16km from SEP for all the fish groups modelled depending on the hearing ability of the species, behavioural responses are expected to occur within this range and potentially in wider areas.

241. As shown in **Table 11-2**, under the temporal worst case scenario (maximum number of piles) for DEP with 32 four-legged jacket foundations and one OSP and would take up to 408 hours (17 days) and 24 four-legged jacket foundations and one OSP and would take up to 288 hours (12 days) for SEP.

242. Although potentially causing changes in the movements of key prey species, TTS and behavioural impacts on herring, sandeels and sprat has not been identified. In addition, where avoidance or behavioural reactions take place, these would occur on both prey species and the fish species that they feed on. Taking this into account, together with the wide distribution ranges of both prey and piscivorous fish, the sensitivity is considered to be low.

Eggs and larvae

243. Studies on TTS or behavioural effect on eggs and larvae are limited and have differing results. Nedelec *et al.* (2015) found that cod larvae exposed to regular and random noise grew less between days 1 and 2 days post hatch (dph), but growth caught up by day 16 dph. Cod larvae exposed to regular noise used their yolk sacs faster after 2 days of exposure and resulted in lower body width-length ratio after 16 dph (Nedelec *et al.,* 2015). Other studies have found that larvae exposed to higher noise levels grew less 12 days dph (Banner and Hyatt, 1978, as cited in Nedelec *et al.,* 2015), while another found that noise had no impact on larval length or weight (Bruintjes and Radford, 2014). From the limited information, these short term impacts are likely to be localised and recoverable.

244. As with fish species, TTS in eggs and larvae could occur at ranges up to 19km at DEP and 16km at SEP for monopiles. **Table 11-24** states that eggs and larvae would be at moderate risk of behavioural impact near the piling locations (tens of metres), they would be at low risk at intermediate distances (hundreds of metres) and at low risk when far (thousands of metres) from the piling location (**Table 11-24**). The potential area affected by TTS and behavioural impacts is very small in the context of the wide distribution of various species eggs and larvae and the potential for these species to be subject to piling noise is low. Therefore, eggs and larvae are considered to be of low sensitivity.

Shellfish

245. Studies of marine bivalves (e.g. mussels *Mytilus edulis*) exposed to pile driving for 50 minutes at a distance of 15m have shown that mussels have high clearance rates[6] during the pile driving compared to ambient noise (Spiga *et al.,* 2016). Spiga *et al.* (2016) suggest that during periods of pile driving, mussels move from a physiologically maintenance state to active metabolism to compensate for the stress caused by pile driving. Similar studies exposing crabs to other anthropogenic noise have also resulted in increased metabolic rate measured by high cardiovascular activity induced by stress (Weilgart, 2018). From such studies, it is clear that noise triggers a stress response to noise and given their low mobility and inability to vacate the area, they are considered to be of medium sensitivity.

11.6.1.4.5 Impact Significance - DEP or SEP in Isolation

246. The following sections describe the significance of impact for each category as defined by Popper *et al.* (2014), based on the negligible to low magnitude of effect defined above and the sensitivity of effect as described in **Table 11-23** and **Table 11-24**.

[6] Clearance rate is the rate that filter-feeders remove suspended particles from water (Spiga *et al.,* 2016).

11.6.1.4.5.1 Mortality and recoverable injury

Fish with no swim bladder

247. The majority of fish species within the group "fish with no swim bladder" (**Table 11-23**) are mobile and would be expected to vacate the area in which the impact could occur within the onset of 'soft start' piling. With low magnitude and sensitivity of effect, the impact is therefore assessed to be of **minor adverse** significance.

248. As sandeels burrow, are substrate dependent and potentially have limited capacity to flee, they are considered to be of medium sensitivity with low magnitude, the impact is therefore assessed to be of **minor adverse** significance.

Fish with swim bladder not involved with hearing

249. The majority of fish receptors included within the group "fish with swim bladders not involved in hearing" (**Table 11-23**) are considered to be of low sensitivity with the exception of gobies, that are deemed to be of a medium sensitivity. These sensitivities in combination with low magnitude are all assessed to result in impacts of **minor adverse** significance.

Fish with swim bladder involved in hearing

250. All the fish receptors within the group "fish with swim bladders involved in hearing" (**Table 11-23**) are considered to be of medium sensitivity. This, in combination with the low magnitude of effect, would result in an impact of **minor adverse** significance.

Eggs and larvae

251. With their limited mobility, eggs and larvae are considered to be of medium sensitivity. This, in combination with the low magnitude of effect, results in an impact of **minor adverse** significance.

Shellfish

252. As shellfish have limited ability to avoid areas in the proximity of piling, they are considered to be receptors of medium sensitivity. This, in combination with the negligible magnitude of effect results in an impact of **minor adverse** significance.

11.6.1.4.5.2 TTS and behavioural

Fish with no swim bladder

253. Most of the receptors listed in **Table 11-24** are considered to be of low sensitivity, with the exception of sandeel, which are deemed to be of medium sensitivity. In combination with a low magnitude of effect, this results in an impact significance of **minor adverse** for all of these species.

Fish with swim bladder not involved with hearing

254. With the exception of gobies, which have been considered to be of medium sensitivity, the remainder of the species in this category are deemed to be of low sensitivity. Combined with a low magnitude of effect, the impact significance has been assessed to be **minor adverse**.

Fish with swim bladder involved in hearing

255. All fish species listed in **Table 11-24** under this category are considered to be of medium sensitivity and with a low magnitude of effect, the impact significance has been assessed to be **minor adverse**.

Eggs and larvae

256. Eggs and larvae are considered to be of medium sensitivity. This, in combination with the low magnitude of effect, results in an impact of **minor adverse** significance.

Shellfish

257. Shellfish have been assessed to be receptors of medium sensitivity. This, in combination with the low magnitude of effect results in an impact of **minor adverse** significance.

11.6.1.4.6 Magnitude of effect - DEP and SEP Together

258. The worst case scenario spatially considers the greatest area of effect from underwater noise during foundation piling. This would consist of using the maximum hammer energy of 5,500kJ for installing 56 x 14MW turbines using monopiles (1 monopile per WTG) and two OSPs (16 pin piles in total) (**Table 11-2**).

259. Temporally, the worst case scenario considers the longest duration for underwater noise during foundation piling. This would consist of 56 x 14MW turbines using pin piles (4 pin piles per WTG, 224 pin piles) and two OSPs (16 pin piles) (**Table 11-2**). Over the 48 months/4 years construction period up to 30 days (720 hours) of total active piling would be required to install 240 pin piles.

260. There is approximately 10km between the DEP and SEP sites and the maximum impact range for mortality / potential mortal injury and recoverable injury is up to 270m (>207dB SEL_{peak}) and up to 3.3km (207dB SEL_{cum}) with a monopile maximum hammer energy of 5,500kJ. Therefore, there will be no overlap between two projects and their assessments in isolation (provided above) and the magnitude of effect for mortality / potential mortal injury and recoverable injury is low for all receptors.

261. The maximum impact range from TTS and behavioural response is up to 19km using the maximum hammer energy (5,500kJ) during the installation of monopiles for all receptors. There is a possibility of overlap between the maximum impact ranges if DEP and SEP are constructed concurrently. However, taking into account the temporary, short term and intermittent nature of piling activity, and that any impact to fish and shellfish receptors would be temporary, the magnitude of effect is considered to remain low.

Sensitivity of effect - DEP and SEP Together

262. As stated above for DEP or SEP in isolation, the sensitivity of effect would be the same as listed in **Table 11-23** for mortality and potential mortal injury / recoverable injury and **Table 11-24** for TTS and behavioural risks for DEP and SEP together, as the same level of impact would occur, regardless of when piling was undertaken.

Impact Significance - DEP and SEP Together

263. The magnitude and sensitivity of effect for DEP and SEP together is the same as DEP or SEP in isolation, therefore the impact of underwater noise on fish and shellfish receptors in the DEP and SEP together scenario is considered to be of **minor adverse** significance.

11.6.1.5 Impact 5: Underwater noise from other activities

264. Piling is not the only source of noise that may impact fish and shellfish receptors during construction. For example, other potential sources of underwater noise include cable laying, trenching, rock placement, drilling, suction dredging and vessels.

11.6.1.5.1 Magnitude of effect - DEP or SEP in Isolation

265. The noise generated from these activities have the potential to disturb fish and shellfish species in and around the project areas by causing avoidance, changes in swimming speed and direction and by altering schooling behaviour (Popper *et al.,* 2014).

266. The duration of the cable installation process is highly variable depending on sea bed composition (**Chapter 8 Marine Geology, Oceanography and Physical Processes**) and the methods used. The cable installation methods that are currently being considered are:

- Ploughing;
- Jetting;
- Trenching;
- Vertical injector; and
- Surface laid with cable protection where burial is not possible;

267. There are no clear indications that underwater noise caused by the installation of subsea cables poses a significant risk to marine fauna. However, it is considered that there is a potential for disturbance to fish species to occur associated with this (OSPAR 2012).

268. In addition to potential noise impacts from cable installation activity, there will also be an increase in the number of vessels associated with construction transiting the project areas. This could also result in increased underwater noise levels and disturbance to fish species.

269. In the context of this assessment, it should be noted that the absolute maximum number of vessels on site at any one-time during construction is 16, however due to construction sequencing not all types of vessel will in reality be on site at the same time.

270. Considering the limited areas as stated in **Table 11-2** that are potentially affected and the temporary nature of the construction phase, the magnitude of effect is considered to be low.

11.6.1.5.2 Sensitivity of effect - DEP or SEP in Isolation

271. Taormina *et al.* (2018) reviewed various underwater noise studies specific to cable trenching and installation that suggest behavioural impacts on fish species would be expected to occur in localised areas in the immediate proximity of the activities/vessels (i.e. from metres to few hundred metres) at noise levels around 186 dB re 1 μPa.

272. The underwater noise generated by other construction activities, including vessel noise, was modelled to determine the potential impact ranges on fish species. The modelling found that for all fish species, the impact range for recoverable injury (using threshold of 170 dB SPL_{RMS}) would occur within 50m of all other activities, and the potential for TTS onset in all fish species (using the shipping and other continuous noise TTS threshold of 158 dB SPL_{RMS}) would occur within 50m of all other activities (see **Appendix 12.2** for more information).

273. Murchy *et al.* (2019) focused on the impacts of shipping noise and seismic surveys on marine invertebrates and found that shipping noise induced physiological responses such as increased respiration rate and heat shock proteins, all indicators of stress. Wale *et al.* (2013a) found that shore crabs exposed to repeated ship noise consumed more oxygen, indicating higher metabolic rate and potentially greater stress. This study also found that after the first exposure to the ship noise, the crabs became habituated to it (Wale *et al.,* 2013a). Not only are they affected physiologically, behaviour such as feeding and anti-predator adaptation are also altered (Wale *et al.,* 2013b).

274. Fish and shellfish species can be expected to adapt and to be habituated to increased levels of such noise to some extent given the existing levels of shipping activity in the DEP and SEP project areas (**Chapter 15 Shipping and Navigation**). As the effects of these noise sources are temporary and recoverable, the sensitivity of effect for fish and shellfish are considered to be low.

11.6.1.5.3 Impact Significance - DEP or SEP in Isolation

275. Taking account of the comparatively wide distribution ranges of fish and shellfish species in the context of the small areas potentially affected, the magnitude and sensitivity of effect are considered to be low, resulting in an impact of **minor adverse** significance.

11.6.1.5.4 Magnitude of effect - DEP and SEP Together

276. The maximum duration for the offshore construction period, including piling and export cable installation, is up to four years for DEP and SEP together. Although, construction activities would not be constant throughout this period, particularly if there is a phased approach to construction, the areas in and around the project areas are likely to be busier with vessels associated with construction. This could result in increased underwater noise levels and disturbance to fish species.

277. In the context of this assessment, the absolute maximum number of vessels on site at any one-time during construction is 25 vessels, for both DEP and SEP together (although as above, not all types of vessel will in reality be on site at the same time).

278. Considering the limited areas as stated in **Table 11-2** that are potentially affected and the temporary nature of the construction phase, the magnitude of effect is considered to be low.

11.6.1.5.5 Sensitivity of effect - DEP and SEP Together

279. As with DEP or SEP in isolation, the sensitivity of effect for DEP and SEP together is also be considered as low.

11.6.1.5.6 Impact Significance - DEP and SEP Together

280. The effects of underwater noise on fish and shellfish from other activities from DEP and SEP together are the same as for DEP or SEP in isolation. With low magnitude and sensitivity of effect the impact is considered to be of **minor adverse** significance.

11.6.1.6 Impact 6: Underwater noise during UXO clearance

281. The southern North Sea still has large quantities of UXO remaining on the seabed as a result from both world wars and sea dumping of expired munitions. There is the potential that controlled UXO clearance may be required prior to construction. Whilst any underwater UXO that are identified would be avoided where possible in preference to clearance, it is necessary to consider the potential for underwater UXO detonation where avoidance is not possible.

Magnitude of effect - DEP or SEP in Isolation

282. Prior to construction, a detailed UXO survey would be undertaken. As such, the exact numbers or types of UXO are currently unknown. A worst case scenario has been assumed that the maximum duration of UXO clearances could be up to 25 days (per project), based on one detonation per 24 hour period. A range of charge sizes have also been assessed, with a maximum charge weight of 525kg.

283. During the construction of the operational Sheringham Shoal OWF, only one UXO was found, out of a potential of 52 targets investigated (Scira Offshore Energy, 2010). A total of 243 targets were investigated for Dudgeon OWF, with 20 of those identified as UXO requiring clearance, in addition to three partial UXO that also required clearance (Statoil, 2015).

284. Should detonation of UXO be required in any of the DEP or SEP project areas, there is potential to result in injury and disturbance to fish species in the vicinity of the detonation. Depending on the size of the charge, physical injury / trauma would occur within close range to the detonation (**Table 11-26**), and TTS and behavioural effects occurring at greater distance (beyond 810m). 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 effect is considered to be low.

Sensitivity of effect - DEP or SEP in Isolation

285. The full understanding of the acoustic waves generated from UXO detonation that propagate on and through seabed is lacking. The waves propagating along the surface of the seabed will not re-radiate into the water column but have the potential to harm benthic species including shellfish, although this is also poorly understood (Cheong *et al.*, 2020).

286. Currently there are no specific data published with respect to shellfish species, however as previously stated under Impact 4, 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). Therefore, they are not assessed any further with regard to underwater noise impacts due to UXO clearance.

287. Whilst it is clear that explosions will result in potential mortality or injury to fish species at close range, there are no data currently available on the effects of explosions on fish hearing (e.g. TTS) or behaviour. 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).

288. Popper *et al.,* (2014) states that there is evidence (e.g. Goertner *et al.*, 1994; Stephenson *et al.*, 2010; Halvorsen *et al.*, 2012) that little or no damage occurs to fishes without a swim bladder except at very short ranges from an in-water explosive event. Popper *et al.,* (2014) also states that Goertner (1978) showed that the range from an explosive event over which damage may occur to a non-swim bladder fish is in the order of 100 times less than that for swim bladder fish.

289. The modelling undertaken to inform this assessment, estimated ranges of impact associated with UXO detonations for different charge weights to provide an indication of the ranges at which mortality / potential injury may occur to fish species (**Appendix 12.2**). As outlined in Popper *et al.* (2014) fish species are considered to be at risk of mortality or potential mortal injury at a peak SPL of between 229dB and 234dB re 1µPa as shown in **Table 11-25**. The ranges at which this noise level could occur are provided in **Table 11-26**.

Table 11-25: Criteria for explosions used in the assessment (source Popper et al., (2014))

Category	Mortality	Recoverable Injury		TTS		Masking	Behaviour
Fish: no swim bladder (particle motion detection)	229 - 234 dB peak	> 216 dB SEL_{cum} Or > 213 dB peak	(N) High (I) Low (F) Low	>> 186 dB SEL_{cum}	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)		203 dB SEL_{cum} Or > 207 dB peak	(N) High (I) High (F) Low	> 186 dB SEL_{cum}	(N) High (I) Moderate (F) Low	N/A	(N) High (I) High (F) Low
Fish: swim bladder involving in hearing (primarily		203 dB SEL_{cum} Or	(N) High (I) High	186 dB SEL_{cum}	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low

Category	Mortality	Recoverable Injury		TTS		Masking	Behaviour
pressure detection)		> 207 dB peak	(F) Low				
Eggs and larvae	> 13mm/s peak velocity	(N) High (I) Low (F) Low		(N) High (I) Low (F) Low		N/A	(N) High (I) Low (F) Low
(N = Near-field; I = Intermediate-field; F = Far-field)							

Table 11-26: Calculated mortal and potential injury impact ranges (m) for any fish species

Popper *et al.* (2014) Unweighted SPL_{peak}	Charge Weight (kg)				
	25	55	120	240	525
234 dB (Mortality and potential mortal injury)	170m	230m	290m	370m	490m
229 dB (Mortality and potential mortal injury)	290m	380m	490m	620m	810m

290. The risk of recoverable injury (including PTS), TTS and behavioural impacts are presented qualitatively in line with the Popper *et al.,* (2014) approach in **Table 11-18**. It should be noted that the risks outlined in **Table 11-25** 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 12.2**). As detailed in **Section 12.3.3** of **Chapter 12 Marine Mammal Ecology**, a MMMP for UXO clearance will be developed in the pre-construction period (in consultation with the relevant Statutory Nature Conservation Bodies (SNCBs) and the MMO), detailing the required mitigation measures to minimise the potential risk of physical and auditory injury (PTS) to marine mammals as a result of underwater noise during UXO clearance. This would potentially also reduce the risk to fish and shellfish species. A draft MMMP will be provided as part of the DCO application.

291. 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, all fish species, as well as eggs and larvae, are considered to be receptors of medium sensitivity.

11.6.1.6.1 Impact Significance - DEP or SEP in Isolation

292. The combination of medium sensitivity with the low magnitude of effect results in an impact of **minor adverse** significance for DEP or SEP in isolation.

11.6.1.6.2 Magnitude of effect - DEP and SEP Together

293. Depending on the outcome from the UXO survey, there is likely to be more possible UXO targets in a DEP and SEP together scenario. However, as with DEP or SEP in isolation the potential to result in injury and disturbance to fish species in the surrounding area will depend on the size of the charge. These will be of a short and intermittent nature (limited to instances when detonation of UXO is required) and for the most part, any effects would be limited to the vicinity of the area where the detonation takes place, therefore the magnitude of effect is considered to be low.

11.6.1.6.3 Sensitivity of effect - DEP and SEP Together

294. As with DEP or SEP in isolation, the sensitivity of effect for DEP and SEP together is considered to be medium.

11.6.1.6.4 Impact Significance - DEP and SEP Together

295. The receptor sensitivity and magnitude of effect for DEP and SEP together is the same as DEP or SEP in isolation, therefore the impact of underwater noise during UXO clearance on fish and shellfish receptors is considered to be of **minor adverse** significance.

11.6.1.7 Impact 7: Impacts on commercially exploited species associated with displacement of fishing from the area of activity / works

296. There is the potential of changes to fishing activity within the study area and surrounding areas during the construction of offshore infrastructure. This is due to the potential displacement of fishing activity in to other areas and may result in changes to commercially exploited species within the study area.

Magnitude of effect - DEP or SEP in Isolation

297. The principal commercial species targeted in the study area include whelk, brown crab, lobster and herring (**Section 11.5.2.1**). Other species caught commercially within the study area include Dover sole, plaice, whiting, mackerel, dab, bass, sprat, brill and cod. These species are some of the most economically important species in UK waters and are targeted across wide areas in the southern North Sea. The project areas account for a small extent in the context of the overall fishing grounds for these species (see **Chapter 14 Commercial Fisheries**). As construction activities are temporary and short term, along with the small spatial extent of effect, the overall magnitude of effect is deemed to be low.

Sensitivity of effect - DEP or SEP in Isolation

298. DEP overlaps historic whelk, crab and lobster fishing grounds whereas SEP primarily overlaps with crab and lobster fishing grounds depicted in 2010 and shown in **Figure 4-5** of **Appendix 14.1 Commercial Fisheries Technical Report**.

299. Closure during construction may act as de-facto no take zones (NTZ), offering respite for adult lobsters (Roach and Cohen, 2020; Roach *et al.*, 2018). It has been demonstrated that where fishing exploitation is absent, the biomass and abundance of lobsters increase (Roach and Cohen, 2020; Roach *et al.*, 2018). However, it should also be noted that this reduction in fishing pressure within the DEP and SEP project area may increase fishing pressure in adjacent areas.

300. Temporary restrictions of fishing activity can allow uninterrupted contribution to the spawning stocks; for example Stelzenmüller *et al.,* (2020) observed that creating de-facto marine protected areas (MPA) with the construction and operation phases of OWFs, might have a beneficial impact on the reproductive output of fish spawning in the area. In addition to this, lower trophic level species like infauna benefit from the absence of disturbance due to mobile fishing gear as well as an increase in macrofaunal diversity (Roach and Cohen, 2020).

301. In Roach *et al.,* (2018), the fishery was able to recuperate some of the economic loss during the closure of the area, by landing larger and better quality lobsters once the area was opened again in 2015.

302. Fishing activity for finfish species are primarily regulated through the setting of annual 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 DEP or SEP, 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).

303. Furthermore, as described in **Chapter 14 Commercial Fisheries**, significant impacts (i.e. exceeding minor adverse significance) in respect of loss of fishing grounds and associated potential for displacement have not been identified for any of the fleets active in the study area. Therefore, the sensitivity of commercially exploited species in respect of potential changes in fishing activity as a result of the project is considered to be low.

Impact Significance - DEP or SEP in Isolation

304. Taking the low receptor sensitivity and magnitude of effect, the resulting impact arising from changes in commercially exploited species is considered to be of **minor beneficial** significance.

Magnitude of effect - DEP and SEP Together

305. The magnitude of effect on commercially exploited species from DEP and SEP together remains low.

Sensitivity of effect - DEP and SEP Together

306. The sensitivity of the commercially exploited species from DEP and SEP together remains low.

Impact Significance - DEP and SEP Together

307. As with DEP or SEP in isolation, with the low receptor sensitivity and magnitude of effect, the resulting impact from changes in commercially exploited species is considered to be of **minor beneficial** significance.

11.6.2 Potential Impacts during Operation

11.6.2.1 Impact 1: Temporary habitat loss / disturbance

308. Certain activities during operation will result in the temporary disturbance of the seabed and consequent impacts on fish and shellfish receptors. This includes any requirement for use of jack-up vessels or anchoring, as well as cable reburial and/or repairs.

Magnitude of effect - DEP or SEP in Isolation

309. Effects will be on a considerably smaller scale and at a much lower frequency than those assessed in relation to construction (**Section 11.6.1.1**), where the potential for negligible to minor adverse impacts has been identified, depending on the species in question.

310. Considering the availability of similar suitable habitat both in the offshore development areas and in the wider context of the southern North Sea, together with the intermittent and reversible nature of the effect, the magnitude of physical disturbance during operation for either DEP or SEP is considered to be negligible for all species.

Sensitivity of effect - DEP or SEP in Isolation

311. Fish and shellfish receptors are considered to have a low sensitivity to temporary disturbance during operation. Many species will be able to move away from the areas of disturbance and in all cases the effects will be highly localised and small in extent relative to changes resulting from natural conditions (e.g. storm events), as described in **Section 11.6.1.1**.

Impact Significance - DEP or SEP in Isolation

312. With a negligible magnitude of effect and low sensitivity, the resulting impact for all species is considered to be of **negligible adverse** significance.

Magnitude of effect - DEP and SEP Together

313. The number of relevant O&M activities that might occur in relation to DEP and SEP together will be approximately double that considered with respect to each project in isolation. However, activities will still be undertaken at a relatively low frequency during the anticipated 35 year design life of the wind farms, and the range of effects from temporary disturbance will not interact between the two projects, as described in **Chapter 8 Marine Geology, Oceanography and Physical Processes**. The magnitude of physical disturbance during operation for DEP and SEP together is therefore considered to remain as negligible for all species.

Sensitivity of effect - DEP and SEP Together

314. Fish and shellfish receptors are considered to have a low sensitivity to temporary disturbance during operation.

Impact Significance - DEP and SEP Together

315. With a negligible magnitude of effect and low sensitivity, the resulting impact for all species is considered to remain as **negligible adverse** significance for DEP and SEP together.

11.6.2.2 Impact 2: Permanent habitat loss

316. Habitat loss will occur during the lifetime of DEP and SEP as a result of structures, scour and external cable protection installed on the seabed. It is currently unknown which structures will be removed or remain in situ at the point of decommissioning. Removal of accessible installed components such as the wind turbine components and foundations (above the seabed level) is expected, however, there is a potential for some structures to be left in situ such as external cable protection or scour protection.

317. A decommissioning plan will be agreed with the relevant authorities at the point of decommissioning. Therefore, it is currently unknown if habitat loss during the operational phase will be lasting/long term or permanent. As a precautionary approach, habitat loss has been considered as permanent with the exception of where the Applicant has made a commitment to removal on decommissioning, which is addressed by Impact 3 (long term habitat loss) below.

Magnitude of effect - DEP or SEP in Isolation

318. The worst case footprint of permanent infrastructure (which may not be decommissioned) includes scour protection of the turbines (14MW) with GBS foundations and up to two OSPs with suction bucket foundations, unburied cable protection and cable crossings. For context, the maximum area of permanent habitat loss is 0.51km^2 for DEP and 0.36km^2 for SEP, which is not considered significant in the context of the amount of similar available habitat in the wider area.

319. The fish and shellfish receptors present in the project areas have comparatively large areas for spawning grounds, nursery grounds (as described in **Section 11.5.2.3**) and foraging, and many have wide distribution ranges; all of which may be spatially and temporally variable. However, species such as herring and sandeel are highly dependent on specific seabed substrates (**Section 11.5**). In summary, suitable herring spawning habitat has been identified within the DEP and SEP boundaries and is likely present in surrounding areas, although mapping based on BGS base maps and heat mapping is likely to overestimate the extent of this habitat. There is, however, an absence of evidence that herring spawn in the vicinity of DEP and SEP. Based on the available evidence outlined above, the area is considered to be unlikely to be a hotspot for herring spawning and if spawning does occur it is likely to be at low levels. (**Figure 11.3**; **Appendix 11.1 Section 11.3.3.1.1** and **Figures 11.10**).

320. Therefore, due to the presence of comparable habitats identified throughout the DEP and SEP project areas and the wider region, as demonstrated by survey data from the Dudgeon and Sheringham Shoal OWFs, as well as Hornsea 3 OWF (RPS, 2018), and the localised spatial extent, the magnitude of effect of permanent habitat loss is considered to be low.

Sensitivity of effect - DEP or SEP in Isolation

321. As the species within the project areas have moderately large areas for spawning, nursery and foraging, and are widely distributed, they are deemed to be of low sensitivity to permanent habitat loss.

Impact Significance - DEP or SEP in Isolation

322. Based on the low sensitivity of fish and shellfish and a low magnitude of effect in relation to permanent habitat loss during the operational phase in either the DEP or SEP offshore area, the impact significance is assessed as **minor adverse**.

Magnitude of effect - DEP and SEP Together

323. The maximum footprint of hard substrate on the seabed causing permanent habitat loss is larger for the DEP and SEP together scenario (0.86km^2). However, the expected loss remains a small proportion of the total available habitats, therefore the magnitude of effect is considered to remain as low.

Sensitivity of effect - DEP and SEP Together

324. The sensitivity to permanent habitat loss for a DEP and SEP together scenario would be the same as DEP or SEP in isolation, with fish and shellfish species considered to be of a low sensitivity.

Impact Significance - DEP and SEP Together

325. With a low magnitude and sensitivity of effect in relation to permanent habitat loss during the operation of DEP and SEP together, the impact is assessed as **minor adverse** significance.

11.6.2.3 Impact 3: Long term habitat loss

326. As described above in relation to Impact 2, a distinction is made between permanent habitat loss where infrastructure is expected or assumed to be decommissioned in situ (assessed in **Section 11.6.2.2**) and long term habitat loss that will result from the installation of infrastructure where the Applicant has made a commitment to removal on decommissioning (this section).

327. Since the extent of long term habitat loss is very small with respect to both the in isolation and together scenarios (see below), one assessment is provided that addresses all potential scenarios.

Magnitude of effect - DEP or SEP in Isolation or Together

328. As described in **Table 11-2**, rock bags may be used for cable protection inside the Cromer Shoal Chalk Beds MCZ, at the offshore export cable HDD exit transition zone and as external cable protection, where necessary, for unburied cables along the offshore export cable route through the MCZ. Rock bags are designed to be removable and the Applicant has committed to remove offshore export cable protection material within the MCZ at the decommissioning stage to avoid permanent impact to MCZ benthic habitats.

329. The worst case footprint of cable protection and HDD exit transition zone in the MCZ, and therefore the maximum area of long term habitat loss, is 900m^2 for DEP or SEP in isolation, or 1,800m^2 for both projects together. With the commitment to remove this infrastructure at decommissioning it is expected that habitat loss will last for the duration of the DEP and/or SEP operational phase (35 years). Therefore, the impact will be temporary (throughout the project duration), but will be very limited in extent, therefore the magnitude of effect is assessed as low.

Sensitivity of effect - DEP or SEP in Isolation or Together

330. The sensitivity to long term habitat loss for the purpose of the assessment is assumed to be the same as assessed for permanent habitat loss, with fish and shellfish species considered to be of a low sensitivity to such small scale and localised effects.

Impact Significance - DEP or SEP in Isolation or Together

331. Based on the low sensitivity of fish and shellfish and a low magnitude of effect in relation to long term habitat loss during the operational phase in the project areas, the impact significance is assessed as **minor adverse**.

11.6.2.4 Impact 4: Introduction of wind turbine foundations, scour protection and hard substrate

332. The introduction of various man-made structures such as foundations and scour protection in soft sediment areas increases and changes habitat availability and type, resulting in locally altered biodiversity as species are able to establish and thrive in previously hostile environments (Birchenough and Degraer, 2020; Coolen *et al.,* 2020). The colonisation of such species may cause indirect effects on fish and shellfish populations if the structures act as artificial reefs, as well as direct impacts due to the potential of foundations acting as fish aggregation devices.

Magnitude of effect - DEP or SEP in Isolation

333. The area of hard substrate within DEP from GBS foundations, associated scour and cable protection that have the potential to be colonised is 0.46km^2 in total and 0.35km^2 within SEP. Although, due to the three dimensional nature of foundation design, the actual area, including that available for colonisation, is likely to be greater.

334. During the lifetime of the project, the associated hard substrate will be of local spatial extent. The magnitude of effect is considered to be low with respect to both indirect and direct potential effects.

Sensitivity of effect - DEP or SEP in Isolation

335. The introduction of new hard substrate in areas that are predominately sandy or soft sediments may cause positive effects through potential habitat enhancement (Roach and Cohen, 2020). Initially structures are colonised with suspension feeders such as mussels, anemones and amphipods in high densities (Birchenough and Degraer, 2020), as described in **Section 10.6.2.4** in **Chapter 10 Benthic and Intertidal Ecology**. Attracted by feeding opportunities, various species of shellfish such as edible crab and European lobster, and fish such as cod and mackerel may aggregate around the structures, resulting in species of higher trophic levels also being drawn to the rich environment with various seabirds and marine mammals being found in higher densities than those in the open sea (Birchenough and Degraer, 2020).

336. As stated previously, the seabed sediments in and around the DEP and SEP project areas are predominantly soft sediments. New species that are drawn to the area are likely to be those normally associated with rocky or hard substrate, providing ideal conditions for certain benthic and fish species, therefore the structures are likely to increase the overall diversity and biomass. In addition to this, the artificial hard substrates have been shown to attract different life stages of fish for foraging, shelter and reproduction, suggesting that they can provide high-quality spawning, nursery and feeding grounds, attributing to indirect evidence of productivity (Stelzenmüller *et al.,* 2020; Fowler *et al.,* 2020; Todd *et al.,* 2018).

337. Studies have concluded that the effect of a Fish Aggregation Device (FAD) result in an increase of the biomass of fish species around foundations compared to areas where there was no FAD present. Fish are attracted and aggregate from the surrounding areas as they are attracted to the new habitat by increased feeding opportunities (Wilhelmsson *et al.,* 2006; Andersson and Ohman, 2010; Bohnsack ,1989). Inger *et al.,* (2009) studied the bases of the foundations at Swedish OWFs finding that they acted as a FAD for both demersal and pelagic species. The study concluded that the presence of the structures have the capacity to act both as artificial reef and FAD which have been used previously to facilitate restoration of damaged ecosystems, and de facto marine-protected areas, which have proven successful in enhancing both biodiversity and fisheries (Inger *et al.,* 2009).

338. Modelling of offshore wind ecosystems have shown that they provide protection and feeding grounds, demonstrating the positive responses for upper trophic level species. In addition to lower level species like infauna benefitting from the absence disturbance due to mobile fishing gear (van Hal *et al.*, 2017; Roach and Cohen, 2020). Reubens *et al.* (2014) observed significant cod and pouting numbers were attracted to the artificial reef created by the turbine foundations.

339. The species assemblage and their dynamics such as changes in dominant species, will vary over the lifetime of the project, as Lindeboom *et al.,* (2011) found during a review of short term ecological effects of the OWEZ in the Netherlands, based on two years of post-construction monitoring. The study found that within the first year the dominant pelagic species switched from herring to sandeel and species richness of demersal fish increased after the first year of construction (Lindeboom *et al.,* 2011). The Lillgrund OWF undertook the longest monitoring programme to date, that showed no overall increase in total abundance, although there was an increase in abundance associated with the base of the foundations for some species (Andersson, 2011). These studies correlate with MMO (2014), where there were minor changes in fish communities reported due to the addition of hard substrate at sites including North Hoyle and Kentish Flats.

340. Scour protection and foundation bases provide similar habitats to those found naturally (e.g. with various crevices and holes) for crustaceans (Linley *et al.,* 2007). Horns Rev 1 OWF post-construction monitoring surveys noted that the hard substrates were used as a hatchery or nursery grounds for several species, which was particularly successful for edible crab. BioConsult (2006) concluded that larvae and juveniles rapidly invade the hard substrates from the breeding areas. Studies in the UK have identified increases of benthic species including crabs and lobsters from colonisation of sub-surface structures by subtidal sessile species on which they can feed (Linley *et al.*, 2007).

341. Based on the results of the post monitoring surveys cited above, any changes in the community structure and abundance of fish and shellfish species within the offshore development area are likely to be small. Therefore, the sensitivity of fish receptors in general are deemed to be low, and shellfish, herring and sandeels are considered to be medium.

Impact Significance - DEP or SEP in Isolation

342. With the magnitude of effect being low in relation to the introduction of hard substrate, in addition to a sensitivity of medium (shellfish) to low (elasmobranch and fin fish species), the impact of the introduction of hard substrate is therefore assessed as **minor adverse** significance for all species. It should be noted that this impact may be considered to be a beneficial one rather than adverse, however to reflect the fact that any impact represents a change from what might be considered natural or baseline conditions, a precautionary approach is to assume that the impact may be adverse.

Magnitude of effect - DEP and SEP Together

343. The area of hard substrate within DEP and SEP from GBS foundations, associated scour and cable protection that have the potential to be colonised is 0.81km^2 in total. Although the total footprint is greater than a DEP or SEP in isolation scenario, the magnitude of effect is considered to be the same for DEP and SEP together, therefore the magnitude is deemed as low.

Sensitivity of effect - DEP and SEP Together

344. The sensitivity of effect for the introduction of hard substrate for a DEP and SEP together scenario would be the same as DEP or SEP in isolation: shellfish, herring and sandeels are deemed to be of a medium sensitivity with other finfish species considered to be of a low sensitivity.

Impact Significance - DEP and SEP Together

345. As with DEP or SEP in isolation, the impact of the introduction of hard substrate is assessed as **minor adverse** significance for all species.

11.6.2.5 Impact 5: Increased suspended sediments and sediment re-deposition

346. Disturbance caused by jack up vessel legs or anchors, as well as cable reburial and/or repair may result in small volumes of sediment being re-suspended. However the volumes of sediment disturbed from such activities, as well as the overall duration of the disturbance, would be significantly reduced relative to construction (**Section 11.6.1.2**).

Magnitude of effect - DEP or SEP in Isolation

347. Increases in SSCs are expected to cause localised and short-term increases at the point of discharge. Released sediment may then be transported in suspension in the water column by tidal currents. As outlined in **Table 11-2**, it is assumed that there could be up to 10 jack-up movements per year for each of DEP and SEP (i.e. 20 in total). Cable repairs or replacements will only be carried infrequently – for example one export and interlink cable repair every 10 years and two infield cable repairs every 10 years. Similarly, for reburial, there may be up to 0.2km per export cable affected every 10 years, and 1% of each of the total interlink and infield cabling every 10 years.

348. As described in relation to construction (**Section 11.6.1.2**), increased SSCs and levels of sediment re-deposition will be localised and short lived. Therefore, the magnitude of effect of SSC and re-deposition during the operational phase is considered to be negligible.

Sensitivity of effect - DEP or SEP in Isolation

349. The sensitivity of fish and shellfish receptors to temporary increases in SSC and sediment deposition is provided in **Section 11.6.1.2**. A worst case scenario of low sensitivity has been assigned in relation to increased SSC and re-deposition for all fish and shellfish species.

Impact Significance - DEP or SEP in Isolation

350. With a negligible magnitude of effect and low sensitivity, the impact significance is deemed to be **negligible adverse**.

Magnitude of effect - DEP and SEP Together

351. Although there will be approximately double the amount of operational activity when considering both projects together, the magnitude of effect is expected to be the same as for DEP or SEP in isolation. As above, any increases in SSC are anticipated to be localised and short-term, therefore the magnitude of effect of SSC and re-deposition during the operational phase is considered to be negligible.

Sensitivity of effect - DEP and SEP Together

352. As with DEP or SEP in isolation, a worst case scenario of low sensitivity has been assigned in relation to increased SSC and re-deposition for all fish and shellfish species.

Impact Significance - DEP and SEP Together

353. With a negligible magnitude and low sensitivity of effect in relation to increased SSC and re-deposition during the operational phase of DEP and SEP together, the impact is considered to be of **negligible adverse** significance.

11.6.2.6 Impact 6: Re-mobilisation of contaminants from seabed sediments

354. As discussed in **Section 11.6.1.3** and in **Chapter 9 Marine Water and Sediment Quality**, contaminants in the study area have not been reported at significantly elevated levels that would be a cause for concern. Any effects from the remobilisation of contaminated sediments and sediment redeposition are likely to be less than during the construction of DEP and SEP, either in isolation or together.

355. Taking into account a negligible magnitude of effect and negligible sensitivity, the resulting impact arising from remobilisation of contaminated sediments and sediment re-deposition is considered to be of **negligible adverse** significance for both the DEP or SEP in isolation and DEP and SEP together scenarios.

11.6.2.7 Impact 7: Underwater noise

356. Operational noise sources may include wind turbine vibration, maintenance activities, and vessels. It is therefore likely that these noise sources would increase the existing baseline noise levels in the project areas.

11.6.2.7.1 Magnitude of effect - DEP or SEP in Isolation

357. Noise from the operating wind turbines will be present for the lifetime of the wind farm/s, however levels are expected to be only slightly elevated above background ambient noise levels (see below). Vessels servicing DEP or SEP during operation would also generate noise, with a maximum of approximately 700 vessel round trips (per project) expected to occur each year to carry out required maintenance. The vast majority of these will be by small O&M vessels, such as the crew transfer vessel (CTV). Overall, levels of activity will be low in the context of the current levels of vessel traffic in the area (see **Chapter 15 Shipping and Navigation**). As described in relation to Impact 5 (**Section 11.6.2.5**), other O&M activities that may generate noise including the use of jack up vessels for major component replacement, cable repairs/replacements and reburial will only be carried out infrequently.

358. As such, during operation it is expected that there will be only a slight and localised increase above background noise levels, therefore the magnitude of effect for either DEP or SEP is considered to be low.

11.6.2.7.2 Sensitivity of effect - DEP or SEP in Isolation

359. Median noise levels of noise in the North Sea were 90.5 dB re 1 µPa in the 63-Hz band, and 93.6 dB re 1 µPa in the 125-Hz band from data obtained in 2013 and 2014 (Merchant*,* 2018). Recent noise monitoring studies have found that noise radiated from individual turbines are low compared to noise radiated from cargo ships, this also includes larger turbines (Tougaard *et al*., 2020). Further studies of operational wind farms such as North Hoyle, Scroby Sands, Kentish Flats and Barrow found the noise generated to be only marginally above ambient noise levels (Cefas 2010, Nedwell *et al*. 2007 and Edwards *et al*. 2007).

360. Noise from the operation of wind turbines would be present for the design life of the project and would contribute to the ambient noise in the region, as described in **Appendix 12.1**. As suggested above, however, this has been shown to be low and only slightly elevated above background ambient noise levels.

361. The underwater noise modelling undertaken for the impact of operational wind turbine noise on fish shows that for all fish species, the impact of recoverable injury (using the shipping and other continuous noise threshold of 170 dB SPL_{RMS}) would occur within 50m of the wind turbine, as would the potential for TTS onset in all fish species (using the shipping and other continuous noise TTS threshold of 158 dB SPL_{RMS}) (see **Appendix 12.2** for more information).

362. The Cefas (2009) review of monitoring data from operational UK offshore wind farms indicated that there was no evidence from post-construction fish surveys that operational noise had resulted in significant impacts on fish populations, either in terms of changes to species composition or reductions in abundance. In addition to this, there is little to no evidence of avoidance by mobile species during the operational period (Leonhard *et al*. 2011; Walls *et al*. 2013), however some species have increased in abundance compared to pre-construction, baseline levels (Leonhard *et al.* 2011).

363. Horns Rev 1 offshore wind farm monitoring during the operational phase (Leonhard *et al.* 2006) revealed that colonisation of scour protection at the base of wind turbine foundations by edible crab had been rapid with up to 1,900 individuals recorded per m^2. As colonisation was rapid and prolific, these results were interpreted to indicate that operational noise had no impact on shellfish populations (Leonhard *et al.* 2006).

364. In view of the above, the sensitivity of fish and shellfish species to operational noise and activities is considered to be low.

11.6.2.7.3 Impact Significance - DEP or SEP in Isolation

365. The low sensitivity of effect combined with the low magnitude of effect, results in an impact of **minor adverse** significance.

11.6.2.7.4 Magnitude of effect - DEP and SEP Together

366. The magnitude of effect of DEP and SEP together is the same as DEP or SEP in isolation. There may be more vessels servicing DEP and SEP during operation, although the increase is small since the majority of vessels and vessel trips would be shared.

367. During operation it is expected that there will be a slight increase above background noise levels that will be localised, therefore the magnitude of effect for DEP and SEP together is considered to remain as low.

11.6.2.7.5 Sensitivity of effect - DEP and SEP Together

368. Operational underwater noise for a DEP and SEP together scenario would be the same as DEP or SEP in isolation with fish and shellfish species considered to be of low sensitivity.

11.6.2.7.6 Impact Significance - DEP and SEP Together

369. With a low magnitude and sensitivity of effect in relation to underwater noise during the operational phase of DEP and SEP together, the impact is assessed as being of **minor adverse** significance.

11.6.2.8 Impact 8: Electromagnetic fields (EMF)

370. OWFs transmit the energy produced along a network of cables. As energy is transmitted, the cables emit low-energy EMF. The electrical (E) and magnetic (B) fields generated increase proportionally to the amount of electricity transmitted.

371. DEP and SEP will involve installing offshore (and onshore) export cable circuits using HVAC technology. Based on the EMF assessment undertaken by Tripp (2021), the following results, shown in **Table 11-27** and

372. **Table** 11-28, were predicted for the offshore magnetic and electrical fields for three scenarios, with cables buried with a minimum of 1m rock coverage.

Table 11-27: Calculated maximum magnetic fields for offshore DEP and SEP export cable circuit scenarios

	Magnetic field (µT)						
	Distance above seabed (m)						
	Cable surface	0m	1m	2m	5m	10m	20m
Scenario 1 DEP and SEP equally rated	1421	20.93	5.45	2.43	0.59	0.17	0.06
Scenario 2 DEP and SEP unequally rated	1653	26.49	6.97	3.13	0.77	0.23	0.07
Scenario 3A SEP circuit only	1217	17.97	4.71	2.13	0.54	0.16	0.05
Scenario 3B DEP circuit only	1653	26.54	7.02	3.18	0.81	0.24	0.07

Table 11-28 Modelled maximum induced electric field (mV/m) in small shark at various distances above SEP and DEP cable circuits

	Electric field (mV/m)						
	Distance above seabed (m)						
	0m	0.3m	1m	2m	5m	10m	20m
Scenario 1 DEP and SEP equally rated	17.00	10.27	4.42	1.98	0.48	0.14	0.05
Scenario 2 DEP and SEP unequally rated	21.53	13.02	5.66	2.55	0.63	0.18	0.06
Scenario 3A SEP circuit only	14.60	8.82	3.83	1.73	0.44	0.13	0.04
Scenario 3B DEP circuit only	21.56	13.12	5.70	2.58	0.66	0.20	0.05

373. Overall, the predicted magnetic fields for DEP and SEP OWFs based on Tripp (2021) are greatest on the seabed and reduce rapidly with vertical and horizontal distance from the circuits. The highest magnetic fields were observed for Scenarios 2 and 3B, due to these options carrying a greater current, but in all cases the maximum magnetic fields were below 27µT at the seabed. The magnetic field at the cable surface had the highest possible exposures and ranged between 1217 and 1653µT. The magnetic fields from all scenarios reduced to very low levels within a few metres from the circuits. It is important to note that these levels do not take account of shielding factors of the cable sheath which would further reduce the fields. For the electrical fields the maximum induced electric field in a small shark was 21.7mV/m at the seabed, but this reduced to below 1 mV/m, 5m from the cable circuits for each option considered. These levels significantly decreased in a smaller fish which was also used. The induced electric field was more than 4.5 times lower than that in the shark due to its smaller size.

374. The main concern with EMF associated with the operation of offshore wind farms, in particular E and B fields emitted by export cables, is that it will interfere with the navigation of sensitive migratory species by affecting the speed and/or the course of their migration, causing subsequent potential problems if they do not reach essential feeding, spawning and nursery grounds. Specifically, interaction may occur if the fish migration route coincides with the cables particularly in shallow waters (<20m) where there is greater probability of encounter the high voltage cables coming to shore. On a more local scale, species like the elasmobranchs (i.e. sharks, rays and skates) that use EMF to detect food may become confused and spend additional time hunting prey as a result of anthropogenic EMF thereby reducing their daily food intake and overall fitness. Likewise, fish and shellfish species that use EMF to detect predators or kin, may alter their behaviour as a result of anthropogenic EMF. If sufficient numbers of individuals are affected this could have consequences at the population and community scale.

375. The principal fish species groups potentially affected by EMF emitted by the interlink, infield and export cables during the operational phase of DEP and SEP which are assessed in this section are as follows:

- Elasmobranchs;
- Diadromous migratory species: European eel, river and sea lamprey, sea trout and shad (twaite & allis);
- Other fish species: cod and plaice; and
- Shellfish species.

11.6.2.8.1 Magnitude of effect - DEP or SEP in Isolation

376. Because of the physical properties of EMFs, specifically that they are what is known as “vectors” not “scalars” (i.e. have direction as well as magnitude), the magnitudes of the EMFs from two different sources do not simply add together. The addition of EMFs from different sources is complex, but has the general effect that, when the field from one source is larger than the other, the larger field dominates, with the smaller field making only a small difference to the resulting field. Based on Tripp (2021), the maximum magnetic fields produced by the worst-case scenario, which was with the DEP OWF in isolation (3B), was 26.5µT at the seabed, reducing to 1µT at 4.4 m vertically above the cables (see Table 11.23). Background measurements of the magnetic field are approximately 50µT in the southern North Sea (Tasker et al., 2010). The potential magnitude of effect on fish and shellfish will not increase above the aforementioned predicted EMF value of 26.5µT at the seabed (which is under background measurements), therefore the overall magnitude of effect of EMF for either DEP or SEP on fish and shellfish is considered to be low.

11.6.2.8.2 Sensitivity of effect - DEP or SEP in Isolation

377. With regard 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 *et al*., 2005), including elasmobranchs; diadromous migratory species, such as European eel, river and sea lamprey, sea trout and shad; other fish species, such as cod and plaice; and shellfish.

<u>Elasmobranchs</u>

378. Elasmobranchs are the major group of organisms known to be electrosensitive. They possess specialised electroreceptors called Ampullae of Lorenzini and naturally detect bioelectric emissions from prey, conspecifics and potential predators / competitors (Gill *et al*. 2005). They are also known to detect magnetic fields.

379. Few sharks and rays have been recorded within the DEP and SEP sites, with only one starry smoothhound recorded in the export cable corridor just south of the wind farm array (Brown & May Marine, 2013). However, starry smooth-hounds represented the greatest numbers caught in the pre-construction cable installation elasmobranch survey (Brown & May Marine, 2010), while 23 different elasmobranch species have been recorded in the North Sea (Daan, 2005), with elasmobranchs typically having wide distribution range and defined nursery grounds. Literature on elasmobranch spawning is limited and elasmobranch abundance is overall low within the area of the DEP and SEP sites.

380. EMF emitted by interlink, infield and export cables during operation is expected to result in temporary behavioural reactions, rather than long term impacts on feeding, migration or confusion in elasmobranch species. A medium level of interaction between elasmobranchs and EMF is therefore predicted. Elasmobranch species are considered to be of medium vulnerability, medium recoverability and local value; therefore, they are receptors of medium sensitivity.

<u>Diadromous migratory species</u>

381. European eel possess magnetic material of biogenic origin of a size suitable for magnetoreception and are thought to use the geomagnetic field for orientation (Moore and Riley, 2009). In addition, their lateral line has been found to be slightly sensitive to electric current (Vriens and Bretschneider 1979). Research carried out on sea trout also indicates that these species are able to respond to magnetic fields (Formicki and Winnicki 2009). The presence of magnetic material suitable for magnetoreception has been found in salmonids (Moore et al. 1990), as has the ability of this species to respond to electric fields (Rommel and McLeave 1973).

382. Lampreys possess ampullary electroreceptors that are sensitive to weak, low frequency electric fields (Bodznick and Preston 1983); however, 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 (Normandeau *et al*. 2011).

383. DEP and SEP will be more than 25km offshore, therefore it is expected that diadromous migratory species will not be subject to EMF associated with interlink, infield and export cables prior to river entry or immediately after leaving the Wash and River Humber. They may, however, occasionally transit the area of the DEP and SEP sites, and there is, therefore, potential for EMF associated with the array to affect these species during migration and/or feeding activity (further detailed below).

384. Various studies have been carried out in relation to the migration of eels and the potential effect of EMFs derived from OWF cables. For example, 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. Öhman et al. (2007) suggested that even if an effect on migration was demonstrated, the effect was small, and on average the delay caused by the passage was approximately 30 minutes. Based on the above, a medium degree of interaction between EMF and European eel is expected to occur. European eel are therefore considered to be of medium vulnerability, medium recoverability and national importance; therefore they are deemed to be of medium sensitivity.

385. Any potential impacts on movement and behaviour in sea trout 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 salmonids, including sea trout (with Shad having similar migratory behaviour) would be dependent on the depth of water and the proximity of home rivers to development sites. During the later stages of marine migration, 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. The level of effect-receptor interaction between EMF associated with the interlink, infield and export cables and sea trout (along with Shad) is considered to be small. These species are considered to be of medium vulnerability, medium recoverability and regional to national importance therefore they are deemed to be of medium sensitivity.

386. Lampreys, like elasmobranchs, possess electroreceptors that are sensitive to weak, low-frequency electric fields (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, with the overall degree of interaction between lampreys and EMF is anticipated to be very small. Lampreys are considered to be of low vulnerability, medium recoverability and international importance; therefore, they are deemed to be of low sensitivity.

Other fish species

387. Further to the species described above, there is some evidence of a response to EMF in other fish species, such as cod and plaice (Gill *et al*. 2005). The results of post-construction monitoring carried out in operational wind farms do not suggest that EMF have resulted in significant detrimental impacts on these species. Lindeboom et al. (2011) suggest that the presence of the foundations and scour protection and potential changes in the fisheries related to OWF development would have the most impact upon fish species. Similarly, Leonhard and Pedersen (2006) indicate that noise from the wind turbines and EMF 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. In line with this, research carried out at the Nysted OWF (Denmark), focused on detecting and assessing possible effects of EMF on fish during power transmission, and found no differences in the fish community composition after the wind farm was operational (Hvidt *et al*.2005). Whilst effects on the distribution and migration of four species were observed (European eel, flounder, cod and Baltic herring), it was recognised that the results were likely to be valid on a very local scale, and only on the individual level, and that an impact on a population or community level was likely to be very limited.

Shellfish

388. Research on the ability of marine invertebrates to detect EMF has been limited. Although there is no direct evidence of effects to invertebrates from undersea cable EMF (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.

389. Crustacea, including lobster and crabs, have been shown to demonstrate a response to B fields, with the spiny lobster *Panulirus argus* shown to use a magnetic map for navigation (Boles and Lohmann; 2003). 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). Indirect evidence from post construction monitoring programmes undertaken in operational wind farms do not suggest that the distribution of potentially magnetically sensitive species of crustaceans or molluscs have been affected by the presence of submarine power cables and associated magnetic fields. In addition, for the brown crab, this species generally moves offshore to overwintering grounds with mature females displaying a northerly long distance migration, with limited contact with EMF emitted by the DEP and SEP OWF array. Based on the research available, shellfish are considered to be of low vulnerability, medium recoverability and local regional importance; and therefore, they are deemed to be of low sensitivity.

11.6.2.8.3 Impact Significance - DEP or SEP in Isolation

390. With regard to elasmobranchs; diadromous migratory species, such as European eel, river and sea lamprey, sea trout and shad; other fish species, such as cod and plaice; and shellfish, as previously stated, the overall magnitude of effect regarding EMF is considered low. Therefore, EMF effects on elasmobranchs; diadromous migratory; other fish species and shellfish, taking into consideration their sensitivities, are assessed to result in an overall impact of **minor adverse** significance during the operation of DEP or SEP in isolation.

11.6.2.8.4 Magnitude of effect - DEP and SEP Together

391. As stated for DEP or SEP in isolation, because of the physical properties of EMFs, specifically that they are what is known as “vectors” not “scalars” (i.e. have direction as well as magnitude), the magnitudes of the EMFs from two different sources do not simply add together. The potential magnitude of effect on fish and shellfish will not increase above the predicted EMF value of 26.5μT at the seabed (which is the worst case scenario and under background measurements of 50μT in the southern North Sea), therefore the overall magnitude of effect of EMF for DEP and SEP on fish and shellfish is considered to remain as low.

11.6.2.8.5 Sensitivity of effect - DEP and SEP Together

392. Operational EMF associated with the interlink, infield and export cables for the DEP and SEP OWFs together would result in the same sensitivity as DEP or SEP in isolation, with fish and shellfish species considered to be of low to medium sensitivity.

11.6.2.8.6 Impact Significance - DEP and SEP Together

393. With a low magnitude and low to medium sensitivity of effect in EMF associated with the interlink, infield and export cables for the DEP and SEP OWFs together, the impact is assessed to remain as **minor adverse** significance.

11.6.2.9 Impact 9: Impacts on commercially exploited species associated with the displacement of fishing from the area of activity / works

394. As a result of the presence of DEP or SEP infrastructure during operation, fishing activity may be reduced within the wind farm sites, this may cause changes in commercially exploited species within the area due to the displacement of fishing activity elsewhere.

<u>Magnitude of effect - DEP or SEP in Isolation</u>

395. Changes in fishing activity during operation are expected to be similar, if not less, than during the construction of either DEP or SEP, as discussed in construction Impact 7 above and in **Section 14.6.2.5** in **Chapter 14 Commercial Fisheries**.

<u>Sensitivity of effect - DEP or SEP in Isolation</u>

396. The sensitivity of effect on commercially exploited species associated with their displacement from the area of activity / works are provided in **Section 11.6.1.7** in relation to construction Impact 7.

397. A worst case scenario of low sensitivity has been determined in relation to impacts on commercially exploited species associated with their displacement from the area of activity / works.

<u>Impact Significance - DEP or SEP in Isolation</u>

398. Taking the low receptor sensitivity and magnitude of effect the resulting impact arising from changes in fishing activity is considered to be of **minor beneficial** significance.

<u>Magnitude of effect - DEP and SEP Together</u>

399. Although the total area would be greater than either DEP or SEP, the magnitude of effect is expected to be same and is considered to be low.

<u>Sensitivity of effect - DEP and SEP Together</u>

400. The sensitivity of DEP and SEP together would be the same as DEP or SEP in isolation, therefore the sensitivity is deemed to be low.

<u>Impact Significance - DEP and SEP Together</u>

401. Taking the low receptor sensitivity and magnitude of effect the resulting impact arising from changes in fishing activity is considered to be of **minor beneficial** significance.

11.6.3 Potential Impacts during Decommissioning

402. 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 would be agreed with the relevant authorities at the time of decommissioning. Offshore, this is likely to include removal of all the turbine elements, part of the foundations (those above sea bed level), removal of some or all of the infield cables, interlink cables, and export cables. Scour and cable protection would likely be left *in situ*, other than in the MCZ where it may be removed (as assessed above in **Section 11.6.2.3**).

403. During the decommissioning phase, there is potential for wind turbine foundation and cable removal activities to cause changes in suspended sediment concentrations because of sediment disturbance effects.

404. The types of effect would be comparable to those identified for the construction phase, with the key impacts including:

- Impact 1: Temporary habitat loss / disturbance;
- Impact 2: Increased suspended sediments and sediment re-deposition; and
- Impact 5: Underwater noise from other activities.

405. The sensitivity of receptors during the decommissioning is assumed to be the same as described for the construction phase. The magnitude of effect is considered to be no greater and, in all probability, less than that considered for the construction phase. Accordingly, given the construction phase assessments concluded no significant impacts (i.e. minor impact or lower) for fish and shellfish receptors, it is anticipated that the same would be valid for the decommissioning phase regardless of the final decommissioning methodologies for either the DEP or SEP in isolation or DEP and SEP together scenarios.

11.7 Cumulative Impacts

11.7.1 Identification of Potential Cumulative Impacts

406. The initial step in the cumulative assessment is the identification of which residual impacts assessed for DEP and/or SEP on their own have the potential for a cumulative impact with other plans, projects and activities (described as 'impact screening'). This information is set out in **Table 11-29** below, together with a consideration of the confidence in the data that is available to inform a detailed assessment and the associated rationale. Only potential impacts assessed in **Section 11.6** as negligible or above are included in the CIA (i.e. those assessed as 'no impact' are not taken forward as there is no potential for them to contribute to a cumulative impact).

407. **Table 11-29** concludes that in relation to fish and shellfish there is the potential for cumulative effects with other plans or projects arising from: underwater noise impacts (all phases); habitat loss; introduction of foundations, scour protection and hard substrate; and impacts from EMF (during operation).

Table 11-29: Potential Cumulative Impacts (impact screening)

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Construction			
Impact 1: Temporary habitat loss / disturbance	No	High	Impacts are time-limited in duration and local in nature with a low magnitude. This applies to DEP or SEP in isolation, and DEP and SEP together.
Impact 2: Increased suspended sediments and re-deposition	No	High	

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Impact 3: Re-mobilisation of contaminants	No	High	Management measures in place for DEP and SEP will also be in place on other projects reducing their risk of occurring.
Impact 4: Underwater noise during foundation piling	Yes	High	Other developments within the southern North Sea have the potential to also have a noise impact on fish and shellfish sensitive receptors. Therefore, in the context of noise impacts, there could be cumulative effects.
Impact 5: Underwater noise from other activities	Yes	High	
Impact 6: Underwater noise during UXO clearance	Yes	High	
Impact 7: Impacts on commercially exploited species from displacement of fishing activity	No	High	Chapter 14: Commercial Fisheries has concluded that this impact pathway does not lead to cumulative impacts with other plans or projects.
Operation			
Impact 1: Temporary habitat loss / disturbance	No	High	Impacts are time-limited in duration and local in nature with a low magnitude. This applies to DEP or SEP in isolation, and DEP and SEP together.
Impact 2: Permanent habitat loss	Yes	High	Additive habitat loss across the region can have cumulative impacts.
Impact 3: Long term habitat loss	Yes	High	As above

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Impact 4: Introduction of foundations, scour protection and hard substrate	Yes	High	Additive introduction of other hard substrates from foundations and scour protection throughout the region may have a cumulative effect.
Impact 5: Increased suspended sediments and re-deposition	No	High	Impacts are time-limited in duration and local in nature with a low magnitude. This applies to DEP or SEP in isolation, and DEP and SEP together.
Impact 6: Re-mobilisation of contaminants	No	High	Management measures in place for DEP and SEP will also be in place on other projects reducing their risk of occurring.
Impact 7: Underwater noise	Yes	High	Other developments within the southern North Sea have the potential to also have a noise impact on fish and shellfish sensitive receptors. Therefore, in the context of noise impacts, there could be cumulative effects.
Impact 8: Electromagnetic fields (EMF)	Yes	Medium	Other plans or projects with EMF impacts may have cumulative effects with DEP and SEP. Medium confidence reflects some gaps in the understanding of effects of EMF on some receptors.

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Impact 9: Impacts on commercially exploited species from displacement of fishing activity	No	High	Chapter 14: Commercial Fisheries has concluded that this impact pathway does not lead to cumulative impacts with other plans or projects.
Decommissioning			
Impact 1: Physical disturbance	No	High	Impacts are time-limited in duration and local in nature with a low magnitude. This applies to DEP or SEP in isolation, and DEP and SEP together.
Impact 2: Temporary loss of habitat	No	High	
Impact 3: Increased suspended sediments and re-deposition	No	High	
Impact 4: Underwater noise	Yes	High	Other developments within the southern North Sea have the potential to also have a noise impact on fish and shellfish sensitive receptors. Therefore, in the context of noise impacts, there could be cumulative effects.

11.7.2 Other Plans, Projects and Activities

408. Following impact screening, the next step in the cumulative assessment is the identification of the other plans, projects and activities that may result in cumulative impacts for inclusion in the CIA (described as ‘project screening’). This information is set out in **Table 11-30** below, together with a consideration of the relevant details of each, including current status (e.g. under construction), planned construction period, closest distance to DEP & SEP, status of available data and rationale for including or excluding from the assessment.

409. The project screening has been informed by the development of a CIA Project List which forms an exhaustive list of plans, projects and activities in a very large study area relevant to DEP and SEP. The list has been appraised, based on the confidence in being able to undertake an assessment from the information and data available, enabling individual plans, projects and activities to be screened in or out.

410. In addition to the CIA method outlined in **Section 6.8** in **Chapter 6 EIA Methodology**, the following considerations were also used to determine which plans and projects are screened into the CIA for potential impacts to fish and shellfish:

- those that overlap with the same spawning and/or nursery grounds for fish and shellfish species as the proposed Projects; and
- are located in the same regional study area and, therefore, are likely to impact the same fish and shellfish receptors.

411. Note that projects in Tier 1 are already operational and, therefore, are considered as part of the baseline and are not included in the CIA. The exception is where there is detailed information available in relation to operation and maintenance activities of operational wind farms (i.e. marine licences or applications), which will be carried out over the lifetime of those projects.

Table 11-30 Summary of projects considered for the CIA in relation to DEP and SEP (project screening)

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
OWFs							
Dudgeon	In operation	n/a	0.0	DEP North, South and interlink cable corridor	High	Y	The operational phase of the OWF will overlap with DEP and SEP.
Sheringham Shoal	In operation	n/a	0	SEP wind farm site	High	Y	The operational phase of the OWF will overlap with DEP and SEP.
Race Bank	In operation	n/a	10	SEP wind farm site	High	Y	The operational phase of the OWF will overlap with DEP and SEP.
Triton Knoll	In construction	2020-2022	13.15	DEP wind farm site	High	Y	The operational phase of the OWF will overlap with DEP and SEP.

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
Hornsea Project Two	In construction	Complete in 2022	52.36	DEP wind farm site	High	Y	The operational phase of the OWF will overlap with DEP and SEP.
Hornsea Project One	Commissioning	N/A	54.9	DEP wind farm site	High	Y	The operational phase of the OWF will overlap with DEP and SEP.
Norfolk Vanguard	Consented – redetermination process underway	TBC	58.44	DEP wind farm site	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
Norfolk Boreas	Awaiting consent decision	2025-2029	82.96	DEP wind farm site	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.
Hornsea Project Three	Consented	2022-2025	83 (0 – export cable)	DEP wind farm site	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
East Anglia THREE	Consented	2023-2026	94.83	DEP wind farm site	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.
East Anglia ONE North	Application submitted	2023-2026	95.38	Export cable corridor	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
East Anglia TWO	Application submitted	2023-2026	103	DEP wind farm site	High	Y	There is the potential for overlap in the construction and operational phases of the OWF and DEP and SEP.
Dogger Bank A and B	In construction	2022-2024 (offshore)	148.95	DEP wind farm site	High	N	There will be no spatial overlap of effects given the distance between the OWF and DEP and SEP.
Dogger Bank C and Sofia	In construction	2024-2025 (offshore)	173.51	DEP wind farm site	High	N	There will be no spatial overlap of effects given the distance between the OWF and DEP and SEP.
Aggregate Extraction							

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
Area 254 Marcon - aggregate dredging (Tarmac Marine Dredging Ltd).	Marine license (MLA/2018/00349/1) granted. Variation requested (on hold)	1992-present	100	Export cable corridor	High	N	Aggregate extraction at Area 254 has been ongoing since 1992, with the latest marine licence a continuation of existing activities. Therefore, effects from the aggregate dredging form part of the baseline.
Oil and Gas							

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
Independent Oil and Gas / Blythe Hub Development. Elgood well tied back via production pipeline to a new production platform (Blythe)	Consented	Approved in 2020 (subject to subsequent permit applications) and first gas is expected Q3 2021.	0.5	Elgood well to DEP wind farm site	High	N	First gas is expected in Q3 2021 (at the earliest), therefore the project will be operational before DEP and SEP construction begins in 2024 at the earliest. Given all impacts were considered not significant and are local in nature, it is considered there is no impact pathway for interaction between the two projects.

Project	Status	Construction Period	Distance from Project (km)	Nearest Project Element (km)	Confidence in Data	Included in the CIA (Y/N)	Rationale
Other							
EIFCA Byelaw 12 Inshore trawling restriction and Byelaw 15 Towed gear restriction for bivalve molluscs	Active	N/A	0.0	Export cable corridor	High	N	The restrictions on the use of bottom towed gear will be beneficial to fish and shellfish ecology receptors that may be impacted by DEP and SEP. Therefore, there is no potential for cumulative adverse impacts.
EIFCA Restricted area 35 (closed to bottom towed gear)	Active	N/A	0.0	Export cable corridor	High	N	

11.7.3 Assessment of Cumulative Impacts

412. Having established the residual impacts from DEP and/or SEP with the potential for a cumulative impact (**Section 11.7.1**), along with the other relevant plans, projects and activities, the following sections provide an assessment of the level of impact that may arise.

11.7.3.1 Cumulative Impact 1: Underwater Noise

Underwater Noise from Piling

413. There is the potential for piling at DEP and SEP and other wind farm projects to result in cumulative impacts from noise on fish and shellfish species. Cumulative impacts from piling noise may arise from either a spatial or temporal overlap with DEP and SEP resulting from either concurrent or sequential piling, or both.

414. Of particular concern is the potential for cumulative impacts to occur on species that use the overlapping area for spawning, although consideration for other species has also been given. Species with spawning grounds that overlap with DEP and SEP include the following:

- Herring;
- Dover sole;
- Whiting;
- Sandeel;
- Lemon sole; and
- Mackerel.

415. Herring, sandeel, and whiting have been assessed as having medium sensitivity to underwater noise with Dover sole, mackerel and lemon sole having low sensitivity to underwater noise (**Table 11-24**).

416. It should be noted that in the case of mackerel, DEP and SEP do not overlap spawning grounds; however, the closest spawning grounds are located approximately 15km to the north and north east and are, therefore, close enough to be potentially affected by cumulative piling noise impacts (see **Appendix 11.1 Figure 11.20**).

417. With regard to sandeels, DEP and SEP overlap with low intensity spawning grounds, with high intensity spawning grounds located to the north over the Dogger Bank area, approximately 70km away. Sandeel habitat assessments identify suitable sandeel habitat in the project areas and indicate that the DEP wind farm sites are located in an area with a higher confidence for sandeel presence based on heat mapping (**Figure 11.4**). Being substrate dependent, sandeels have limited capacity to flee underwater noise. The range at which TTS and behavioural impacts are expected from the construction of DEP and SEP are a maximum of 19km and 16km respectively (**Figure 11.40**). Similarly, in the case of mackerel, the maximum range at which TTS and behavioural changes are expected are also 19km and 16km for DEP and SEP respectively. At these ranges, only one other project, Triton Knoll OWF, is within the range where noise effects may overlap with those from DEP/SEP. However, the construction of Triton Knoll is expected to be completed by 2022, at least four years prior to the earliest proposed offshore construction phase of DEP and

SEP. Whilst there is spatial overlap with piling noise effects between the two projects, there is no temporal overlap.

418. Both DEP and SEP are found within identified herring spawning grounds, with further spawning grounds approximately 13km to the north west. However, as discussed in **Section 11.5.2.3.1** and **Figure 11.3** the confidence in herring spawning activity in the vicinity is low to medium and the area is considered to be unlikely to be a hotspot for herring spawning. DEP and SEP are also found within low intensity spawning grounds for whiting. Both herring and whiting have medium sensitivity to underwater noise and the range of TTS and behavioural changes have been modelled as having a maximum range of 19km and 16km from DEP and SEP respectively (**Table 11-22**; fish whose swim bladders are involved in hearing) (**Figure 11.6**). Within this maximum TTS/behavioural changes range, only Triton Knoll OWF is within the spatial range of potential underwater noise cumulative impacts. However, as indicated above, there is no temporal overlap of construction phases between both projects.

419. DEP and SEP are also found within Dover sole and lemon sole spawning grounds, with the latter being of low intensity. Similar to mackerel, both Dover and lemon sole are considered to have low sensitivity to underwater noise with the maximum range for TTS/behavioural changes at 19km and 16km for DEP and SEP respectively. As already discussed, the only other project with potential underwater noise cumulative effects is Triton Knoll OWF which, whilst there is spatial overlap there is no temporal overlap.

420. The remaining species with known spawning grounds in the vicinity of DEP and SEP have very wide spawning grounds in the context of the relatively small spatial extent over which piling may have an effect.

421. In view of the above, the cumulative impact of construction noise from piling at DEP and SEP together on fish species is considered to be **negligible** and, therefore, not significant.

<u>Underwater Noise from Other Construction Activities</u>

422. In addition to piling noise there may be other activities during construction and decommissioning at other projects that could result in potential disturbance to fish and shellfish, such as transiting vessels, cable laying, rock placement and dredging. As described in **Section 11.6.1.5**, potential impacts on fish and shellfish would occur over very small areas, i.e. within the immediate proximity of the construction activity/vessel.

423. The magnitude of underwater noise effects from other construction activities is much lower than from piling. As such, there is unlikely to be an interaction with other project activities. Therefore, the magnitude of the cumulative impact is considered to be negligible.

424. The fish species that may potentially be affected by cumulative underwater construction and decommissioning noise are the same as for the cumulative piling noise assessment. Taking this and the above into account, the cumulative impact is considered to be **negligible** and, therefore, not significant.

Underwater Noise from UXO clearance during Construction

425. The detonation of UXO associated with other offshore wind farm projects could result in adverse effects on fish species in the vicinity of the detonation. Physical injury could occur in close proximity to the detonation, with TTS/behavioural effects occurring at greater distances.

426. Whilst it is recognised that there is the potential for an increase in the number of UXO detonations from other projects, UXO clearance is a short term activity that is intermittent in nature. 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 effect is considered to be low.

427. Taking into account the severity of the impact at close range, which would occur at an individual level, rather than population level, fish and shellfish receptors are considered to be of medium sensitivity. This combined with a low magnitude results in a cumulative impact of **minor adverse** significance.

Underwater Noise from Operational Activities

428. The operational underwater noise source with the potential for cumulative effects is vessel noise. Underwater noise generated from the operational wind turbines is not considered further as the TTS impact range has been modelled as being <50m (**Section 11.6.2.7**, with further details in **Appendix 12.2**) and, therefore, does not have the potential for cumulative effects with other projects.

429. Operational noise assessed for DEP and SEP alone has determined that the increase in noise levels above background would be very small and localised in nature. With this in mind and the distance between DEP and SEP and other projects (**Table 11-30**), the magnitude of effect is considered to be low.

430. Monitoring data from other operational wind farms suggest that operational noise does not have the potential to result in any discernible effect on fish and shellfish species. Therefore, fish and shellfish receptors are considered to have low sensitivity. This combined with a low magnitude of effect, results in a cumulative impact of **minor adverse** significance.

11.7.3.2 Cumulative Impact 2: Habitat Loss

431. There will be a loss of habitat supporting fish and shellfish receptors due to the presence of the project infrastructure, such as the turbine and OSP foundations and associated scour protection. It is expected that during the decommissioning stage, project infrastructure will be removed and the site returned to its natural state, as much as is feasibly possible. It is recognised that some infrastructure cannot be decommissioned and, therefore, will remain in place causing permanent habitat loss. Project infrastructure that is expected to remain in place includes cable and scour protection and piles. With regard to piles, however, they will be cut below the seabed; therefore, the seabed surface is expected to return to its natural state.

432. Given that it is currently unknown which structures will be removed or remain in situ at the point of decommissioning, permanent habitat loss has been assumed in the majority of cases. The only exception being where the Applicant has made the commitment to removal on decommissioning (namely any external cable protection that is used in the MCZ – see **Section 11.6.2.3**). In this instance, the loss is assessed as long term i.e. for the lifetime of the projects only.

433. Together, 0.86km^2 of permanent habitat loss from the foundations and associated scour protection and external cable protection is expected (**Section 11.6.2.2**) from DEP and SEP. There would be up to 1,800m^2 of long term habitat loss from external cable protection in the MCZ, which will be removed on decommissioning. Habitat loss will be widely dispersed throughout the DEP and SEP sites and the cable corridors. The area of habitat loss is small compared to some other recent OWFs in the southern North Sea. Hornsea Project Three, for example, will result in a permanent loss of up to 4.2km^2 of habitat.

434. It is not possible to say with certainty what percentage of the cumulative habitat loss across different projects will affect particular fish and shellfish ecology receptors, such as a spawning ground or nursery area. For example, it is highly unlikely that the 0.86km^2 of permanent habitat loss from DEP and SEP will all be in sandeel habitat or herring spawning grounds.

435. The fish and shellfish species in the region use comparatively large areas for spawning and nursery grounds, and for foraging. Whilst it is recognised that across the southern North Sea there will be additive effects with respect to loss of spawning grounds or other important fish and shellfish habitat, the overall combined magnitude of these will be negligible relative to the scale of the fish and shellfish receptors potentially affected. Therefore, impacts as a result of habitat loss are expected to be minimal, and the fish and shellfish species receptors are considered to be of low sensitivity to this pathway of effect. With regard to sandeel and herring, given their dependence on specific substrates and, therefore, more limited habitat availability, they are considered to be of medium sensitivity.

436. With the above in mind, the cumulative impact of habitat loss of DEP and SEP together is considered to be of **minor adverse** significance.

11.7.3.3 Cumulative Impact 3: Introduction of Foundations, Scour Protection and Hard Substrate

437. The introduction of hard substrate from DEP and SEP, together with other offshore projects could result in cumulative impacts on fish and shellfish species in terms of changes to the species assemblage.

438. As with the loss of habitat, the introduction of hard substrate would occur in a dispersed manner throughout the DEP and SEP wind farm sites and cable corridors, rather than being concentrated in one main area. Taking this into account, together with the distance to other projects as identified in **Table 11-30**, the magnitude of effect is considered to be low.

439. As described in **Section 11.6.2.4,** post-construction monitoring surveys undertaken at operational wind farms suggest that changes in fish and shellfish community structures associated with the introduction of hard substrate would be highly localised and limited to the immediate vicinity of the foundations. With this in mind, the sensitivity of the fish and shellfish species is considered to be low, resulting in a cumulative impact of **minor adverse** significance.

11.7.3.4 Cumulative Impact 4: Electromagnetic Fields (EMF)

440. As outlined for DEP and SEP alone, both elasmobranch and migratory species are considered to be receptors of medium sensitivity to EMF. Based on the anticipated low magnitude of effect, this was assessed as resulting in a minor adverse impact for these species. However, both elasmobranchs and migratory fish have a wide distribution range in the North Sea and, given the overall wide ranging and/or migratory behaviour of both elasmobranch and migratory fish species, the cumulative impacts of EMF from DEP and SEP with other relevant projects is overall considered to be negligible and therefore not significant for these species. No cumulative impacts are predicted for other fish species and shellfish as a result of the localised nature of the predicted impacts and their low sensitivity.

11.7.3.5 Cumulative Impact 5: Decommissioning Impacts

441. As outlined for the project alone (**Section 11.6.3**), it is anticipated that the effects on fish and shellfish receptors during the decommissioning phase in a cumulative context would be comparable to those identified for construction.

442. The sensitivity of receptors during decommissioning is assumed to be the same as for the construction phase. The magnitude of effect is considered to be no greater than for construction. Therefore, it is anticipated that any cumulative impacts during the decommissioning phase would be no greater than those assessed for the construction phase.

11.8 Transboundary Impacts

443. The distribution of the populations of fish and shellfish species assessed are independent of national geographical boundaries. The alone assessment for DEP and SEP has been undertaken taking into account the distribution of fish stocks and populations irrespective of national jurisdictions. In addition, the alone assessments for DEP and SEP have demonstrated that the spatial extent of impacts from the construction, operation and decommissioning of DEP and SEP together do not stretch beyond UK waters and have been assessed as not significant in all cases.

444. It should also be noted that the anticipated impacts on fish and shellfish ecology are generally localised in nature, being restricted to the project boundaries and surrounding area. DEP and SEP are a minimum of 187km from any international territory boundary.

11.9 Inter-relationships

445. The construction, operation and decommissioning phases of DEP and SEP could cause a range of effects on fish and shellfish ecology. The magnitude of these effects has been assessed using expert assessment, drawing from a wide science base.

446. These effects not only have the potential to directly affect the identified fish and shellfish receptors but may also manifest as impacts upon receptors other than those considered within the context of fish and shellfish ecology. All of the identified inter-relationships have been considered in the relevant chapters, as indicated in **Table 11-31**.

Table 11-31: Chapter topic inter-relationships

Topic and description	Related chapter	Where addressed in this chapter	Rationale
Construction			
Increased suspended sediments and sediment re-deposition	**Chapter 8 Marine Geology, Oceanography and Physical Processes**	**Section 11.6.1.2**	Changes in SSCs and associated sediment re-deposition, described in Chapter 8, could have potential impacts on fish and shellfish ecology.
Re-mobilisation of contaminated sediment	**Chapter 9 Marine Water and Sediment Quality**	**Section 11.6.1.3**	Re-mobilisation of contaminated sediment, described in Chapter 9, could have potential impacts on fish and shellfish ecology.
Benthic ecology	**Chapter 10 Benthic and Intertidal Ecology**	**Section 11.6.1.1**	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.
Prey species	**Chapter 12 Marine Mammal Ecology**	Throughout **Section 11.6.1**	

Topic and description	Related chapter	Where addressed in this chapter	Rationale
	Chapter 13 Offshore Ornithology		Potential impacts on fish and shellfish could affect the prey resource for marine mammals and birds.
Commercially exploited species	**Chapter 14 Commercial Fisheries**	**Section 11.6.1.7** and throughout **Section 11.6.1**	Changes to the fish and shellfish resource could affect commercial fisheries. Changes to fishing activity could affect fish and shellfish ecology.
Operation			
Increased suspended sediments and sediment re-deposition	As above	**Section 11.6.2.5**	As above
Re-mobilisation of contaminated sediment	As above	**Section 11.6.2.6**	As above
Benthic ecology	As above	**Sections 11.6.2.1** to **11.6.2.3**	As above
Prey species	As above	Throughout **Section 11.6.2**	As above
Commercially exploited species	As above	**Section 11.6.2.9** and throughout **Section 11.6.2**	As above
Decommissioning			
As for construction			

11.10 Interactions

447. The impacts identified and assessed in this chapter have the potential to interact with each other. The areas of potential interaction between impacts are presented in **Table 11-32**. This provides a screening tool for which impacts have the potential to interact. **Table 11-33** then provides an assessment for each receptor (or receptor group) as related to these impacts.

448. The impacts are first assessed relative to each development phase ('phase assessment', i.e. construction, operation or decommissioning) to see if (for example) multiple construction impacts affecting the same receptor could increase the level of impact upon that receptor. Following this, a 'lifetime assessment' is undertaken which considers the potential for impacts to affect receptors across all development phases.

449. None of the potential interactions identified with respect to fish and shellfish ecology are expected to result in a synergistic or greater impact than those assessed in **Section 11.6**.

Table 11-32: Interactions between impacts – screening

Potential Interaction between Impacts									
Construction									
	Impact 1 Temporary habitat loss / disturbance	Impact 2 Increased suspended sediments and sediment re-deposition	Impact 3 Re-mobilisation of contaminants	Impact 4 Underwater noise during foundation piling	Impact 5 Underwater noise from other activities	Impact 6 Underwater noise during UXO clearance	Impact 7 Impacts on commercially exploited species associated with their displacement from the area of activity / works	-	-
Impact 1 Temporary habitat loss / disturbance	-	Yes	No	No	No	No	No	-	-

Potential Interaction between Impacts									
Impact 2 Increased suspended sediments and sediment re-deposition	Yes	-	No	No	No	No	No	-	-
Impact 3 Re-mobilisation of contaminants	No	No	-	No	No	No	No	-	-
Impact 4 Underwater noise during foundation piling	No	No	No	-	Yes	Yes	No	-	-
Impact 5 Underwater noise from other activities	No	No	No	Yes	-	Yes	No	-	-
Impact 6 Underwater noise during UXO clearance	No	No	No	Yes	Yes	-	No	-	-

Potential Interaction between Impacts									
Impact 7 Impacts on commercially exploited species associated with displacement of fishing from the area of activity / works	No	No	No	No	No	No	-	-	-
Operation									
	Impact 1 Temporary habitat loss / disturbance	Impact 2 Permanent habitat loss	Impact 3 Long term habitat loss	Impact 4 Introduction of wind turbine foundations, scour protection and hard substrate	Impact 5 Increased suspended sediments and sediment re-deposition	Impact 6 Re-mobilisation of contaminants from seabed sediments	Impact 7 Underwater noise	Impact 8 EMF	Impact 9 Impacts on commercially exploited species associated with their displacement from the area of activity / works
Impact 1 Temporary habitat loss / disturbance	-	Yes	Yes	Yes	Yes	No	No	No	No

Potential Interaction between Impacts									
Impact 2 Permanent habitat loss	Yes	-	Yes	Yes	Yes	No	No	No	Yes
Impact 3 Long term habitat loss	Yes	Yes	-	Yes	Yes	No	No	No	Yes
Impact 4 Introduction of wind turbine foundations, scour protection and hard substrate	Yes	Yes	Yes	-	No	No	No	No	No
Impact 5 Increased suspended sediments and sediment re-deposition	Yes	Yes	Yes	No	-	No	No	No	No
Impact 6 Re-mobilisation of contaminants from seabed sediments	No	No	No	No	No	-	No	No	No

Potential Interaction between Impacts									
Impact 7 Underwater noise	No	No	No	No	No	No	-	No	No
Impact 8 EMF	No	No	No	No	No	No	No	-	No
Impact 9 Impacts on commercially exploited species associated with displacement of fishing from the area of activity / works	No	Yes	Yes	No	No	No	No	No	-
Decommissioning									

It is anticipated that the decommissioning impacts will be similar in nature to those of construction, with the key impacts including;

- Impact 1: Temporary habitat loss / disturbance;
- Impact 2: Increased suspended sediments and sediment re-deposition; and
- Impact 5: Underwater noise from other activities.

Potential Interaction between Impacts									
	Impact 1 Temporary habitat loss	Impact 2 Increased suspended sediments and sediment re-deposition	Impact 5 Underwater noise from other activities	-	-	-	-	-	-
Impact 1 Temporary habitat loss	-	Yes	No	-	-	-	-	-	-
Impact 2 Increased suspended sediments and sediment re-deposition	Yes	-	No	-	-	-	-	-	-
Impact 5 Underwater noise from other activities	No	No	-	-	-	-	-	-	-

Table 11-33: Interactions between impacts – phase and lifetime assessment

	Highest significance level				
Receptor	**Construction**	**Operation**	**Decommissioning**	**Phase assessment**	**Lifetime assessment**
Fish and shellfish species	Minor adverse	Minor adverse	Minor adverse	**No greater than individually assessed impact** ***Construction*** Underwater noise impacts will be greatest in spatial extent for piling and UXO clearance, but these will occur only during a short part of the construction phase, therefore there is limited potential for interaction with habitat disturbance from sea bed preparation, installation of cables etc. and associated effects (increased SSC). The effects resulting from habitat disturbance will be localised, temporary and episodic with limited potential for interaction. Any reduction in fishing effort would be beneficial, although likely to be of low magnitude. It is therefore considered that these impacts would not interact to change the significance level overall. ***Operation*** Disturbance to or loss of habitat will be confined to the immediate	**No greater than individually assessed impact** The greatest magnitude of effect will be the spatial footprint of construction noise (i.e. UXO clearance and piling) and the habitat disturbance from sea bed preparation, installation of cables etc. Once this disturbance impact has ceased all further impacts during construction, operation and decommissioning will be small scale, localised and episodic. There is no evidence of long term displacement of fish or shellfish from operational wind farms. It is therefore considered that over the project lifetime these impacts would not interact to change the significance level overall.

	Highest significance level				
Receptor	**Construction**	**Operation**	**Decommissioning**	**Phase assessment**	**Lifetime assessment**
				footprint of the infrastructure/activities. The magnitude of effect is, in all cases, low to negligible. EMF and noise effects will also be locally confined and again the magnitude of effect is low to negligible and relates to largely the same spatial footprint. It is therefore considered that none of these impacts would interact to increase the significance level overall. ***Decommissioning*** It is anticipated that the decommissioning impacts will be similar in nature to those of construction.	

11.11 Potential Monitoring Requirements

450. As described in this chapter, a large amount of geophysical, benthic and fish ecology monitoring data is available from the existing Dudgeon and Sheringham Shoal OWFs, much of which will be highly relevant to DEP and SEP given their close proximity and the similarity of the developments. Given the outcomes of the assessment, no specific monitoring requirements are proposed with respect to fish and shellfish ecology, although it is expected that a programme of benthic and potentially noise monitoring will be agreed with a focus on benthic and marine mammal ecology respectively, both of which will provide information that is also relevant to fish and shellfish receptors.

451. These monitoring requirements will be described in the in-principle monitoring plan (IPMP) submitted alongside the DCO application and further developed and agreed with stakeholders prior to construction based on the IPMP and taking account of the final detailed design of DEP and SEP.

11.12 Assessment Summary

452. Numerous literature and data sources have been used to determine and characterise the fish and shellfish species and populations that may be impacted by DEP and SEP. This has included extensive site specific geophysical and benthic surveys and an associated habitat mapping process, as well as historical surveys of the operational Dudgeon and Sheringham Shoal OWFs.

453. The fish and shellfish ecology receptors identified include a number of species of interest due to their ecosystem, commercial and/or conservation value, for example sandeel, herring, edible crab, lobster and European eel.

454. The magnitude of effects identified and the sensitivity of the receptors to each effect has been assessed drawing from a wide science base, including project-specific surveys, underwater noise modelling and other assessments from the inter-related chapters of this PEIR. The assessment has established that there will be some **minor adverse** residual impacts during the construction, operation and decommissioning phases of DEP and SEP. Impacts are generally localised in nature, being restricted to the project boundaries and surrounding area.

455. A summary of the impact assessment for fish and shellfish ecology is provided in **Table 11-34**.

Table 11-34 Summary of potential impacts on fish and shellfish ecology

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Construction						
Impact 1 Temporary habitat loss / disturbance	Herring and sandeel	Medium	Negligible	Minor adverse	n/a	Minor adverse
	Shellfish	Medium				
	Elasmobranchs	Low		Negligible adverse		Negligible adverse
	Other finfish species	Low				
Impact 2 Increased suspended sediments and sediment re-deposition	Herring and sandeel	Medium	Low	Minor adverse	n/a	Minor adverse
	Other fin fish species	Low				
Impact 3 Re-mobilisation of contaminants	All fish and shellfish species	Low	Negligible	Negligible adverse	n/a	Negligible adverse
	Fish with no swim bladder or other gas chamber					

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Impact 4A Underwater noise during foundation piling – Mortality and recoverable injury	Dab Elasmobranchs River and sea lamprey Lesser weever Dragonet	Low	Low	Minor adverse	n/a	Minor adverse
	Sandeels	Medium				
	Fish with swim bladder in which hearing does not involve the swim bladder or other gas volume					
	Sea trout Smelt	Medium				
	Gobies	Low				
	Fish in which hearing involves a swim bladder or other gas volume.					
	Herring Sprat Whiting European eel Allis and twaite shad	Medium	Low	Minor adverse	n/a	Minor adverse
	Eggs and larvae					

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
	All fish and shellfish	Medium	Low	Minor adverse	n/a	Minor adverse
Impact 4B Underwater noise during foundation piling – TTS and behavioural	**Fish with no swim bladder or other gas chamber**					
	Elasmobranchs	Low	Low	Minor adverse	n/a	Minor adverse
	Sandeels	Medium				
	Fish with swim bladder in which hearing does not involve the swim bladder or other gas volume					
	Sea trout Smelt	Low	Low	Minor adverse	n/a	Minor adverse
	Gobies	Medium				
	Fish in which hearing involves a swim bladder or other gas volume.					
	Herring Sprat Whiting Cod	Medium	Low	Minor adverse	n/a	Minor adverse

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
	European eel Allis and twaite shad					
	Eggs and larvae	Medium	Low	Minor adverse	n/a	Minor adverse
	Shellfish	Medium	Low	Minor adverse	n/a	Minor adverse
Impact 5 Underwater noise from other activities	All fish and shellfish	Low	Low	Minor adverse	n/a	Minor adverse
Impact 6 Underwater noise during UXO clearance	All fish and shellfish	Medium	Low	Minor adverse	n/a	Minor adverse
Impact 7 Impacts on commercially exploited species associated with displacement of fishing from the area of activity / works	Commercial exploited fish species	Low	Low	Minor beneficial significance	n/a	Minor beneficial significance

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Operation						
Impact 1 Temporary habitat loss	Fish and shellfish receptors	Low	Negligible	Negligible adverse	n/a	Negligible adverse
Impact 2 Permanent habitat loss	Fish and shellfish receptors	Low	Low	Minor adverse	n/a	Minor adverse
Impact 3 Long term habitat loss	Fish and shellfish receptors	Low	Low	Minor adverse	n/a	Minor adverse
Impact 4 Introduction of wind turbine foundations, scour protection and hard substrate	Other finfish species	Low	Low	Minor adverse	n/a	Minor adverse
	Shellfish, herring and sandeels	Medium				

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Impact 5 Increased suspended sediments and sediment re-deposition	All fish and shellfish species	Low	Negligible	Negligible adverse	n/a	Negligible adverse
Impact 6 Re-mobilisation of contaminants from seabed sediments	All fish and shellfish species	Negligible	Negligible	Negligible adverse	n/a	Negligible adverse
Impact 7 Underwater noise	All fish and shellfish species	Low	Low	Minor adverse	n/a	Minor adverse
Impact 8 EMF	All fish and shellfish species	Low	Low	Minor adverse	n/a	Minor adverse

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Impact 9 Impacts on commercially exploited species associated withdisplacement of fishing from the area of activity / works	Commercial exploited fish species	Low	Low	Minor beneficial significance	n/a	Minor beneficial significance
Decommissioning						
It is anticipated that the decommissioning impacts will be similar in nature to those of construction, with the key impacts including; • Impact 1: Temporary habitat loss / disturbance; • Impact 2: Increased suspended sediments and sediment re-deposition; and • Impact 5: Underwater noise from other activities.						
Impact 1 Temporary habitat loss / disturbance	All fish and shellfish species	Equal to construction phase	No greater and, in all probability less than construction phase	No significant impacts (minor adverse or lower)	n/a	Not significant impacts (minor adverse or lower)

Potential impact	Receptor	Sensitivity	Magnitude	Pre-mitigation impact	Mitigation measures proposed	Residual impact
Impact 2 Increased suspended sediments and sediment re-deposition	All fish and shellfish species	Equal to construction phase	No greater and, in all probability less than construction phase	No significant impacts (minor adverse or lower)	n/a	Not significant impacts (minor adverse or lower)
Impact 5 Underwater noise from other activities	All fish and shellfish species	Equal to construction phase	No greater and, in all probability less than construction phase	No significant impacts (minor adverse or lower)	n/a	Not significant impacts (minor adverse or lower)

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