Appendix E.1:
Literature Review of Electromagnetic Field (EMF) and Sediment Heating Effects on Marine Ecological Receptors

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Summary

This report reviews the known sensitivities of various fish and shellfish species to Electromagnetic Fields (EMFs) and elevated sediment temperatures presented in studies in published literature. This review has then been used to set targets for EMF and sediment heating levels at the seabed and through the water column for the proposed NorthConnect project.

The literature reviewed indicates that species have different levels of sensitivity to EMFs and elevated sediment temperatures, and the thresholds of effects will be different for different species. There is also limited unequivocal evidence of adverse behavioural or physiological effects caused by either EMFs or elevated sediment temperatures, at an individual or population level from any existing projects. Given the very low thresholds of detection and behavioural responses found within the literature (<10µT above background levels), it will not be possible to mitigate against all magnetic fields produced for all species. The literature review identified that if the magnetic field remains below 300µT then some less mobile species such as crustaceans and shellfish, are unlikely to experience behavioural or physiological effects.

The vertical distribution of species has also been considered in this review, along with the depth of water above the seabed along the cable route, to identify the likely levels of magnetic field that individuals of various species would be exposed to. For those sensitive species that may be exposed to higher levels of magnetic field, impacts are expected to be negligible on mobile species, such as European eel (*Anguilla anguilla*) or elasmobranchs, or localised on non-mobile species (such as benthic invertebrates and molluscs).

NorthConnect have carried out sediment heating calculations for a cable depth of lowering of 0.5m. This produces a sediment and water temperature at the seabed of 1^{o}C above background levels. For key species which spawn on the seabed, Atlantic herring (*Clupea harengus*) and sandeel (*Ammodytes spp.*), the effect of these elevated water temperatures upon the survival of eggs, yolk-sac larvae and post-larvae juvenile lifestages has been considered and shown that effects will be small, and negligible at the population level.

1 Introduction

A number of fish, shellfish and benthic invertebrate species in the North Sea are sensitive to electromagnetic fields (EMFs), with some fish species also utilising the earth's natural magnetic field for orientation and to guide migrations. Currents running though High Voltage Direct Current (HVDC) cables, such as those proposed for use for the NorthConnect project, give rise to static magnetic fields, but not electric fields or induced-electric fields as they are shielded and don't have a time-varying alternating current.

Anthropogenic magnetic fields of different intensities have been shown to be detectable to various fish species and also to cause behavioural and physiological changes in individuals. A literature review has therefore been completed by APEM Ltd. to provide an understanding of magnetic field levels that may affect various species relevant to the NorthConnect project. This review has been utilised to identify magnetic field levels on the seabed surface which will minimise environmental impacts and to provide advice to the burial protection report, as differing burial depths and cable separations will affect the magnetic field levels on the seabed surface.

The cables proposed for use for the NorthConnect project also emit heat which is transmitted to the surrounding sediments and water column. A review of sediment heating effects has also been carried out by APEM and the summarised results are shown in Section 2.

2 EMF and Sediment heating literature review.

2.1 EMF sensitivity literature review

Tables 2.1 and 2.2 provide a summary of the available literature on EMF levels which could be detectable or cause behavioural and physiological changes in various fish, shellfish and benthic invertebrate species relevant to the NorthConnect project. The sensitivity of species with a commercial value, such as pelagic and demersal marine species and shellfish, have been considered. In addition, species which are of recreational and conservation value, such as diadromous species or elasmobranchs, and species key to the wider marine and ornithological food chains, such as sandeels and benthic invertebrates, have also been considered by the review.

The review shows that elasmobranchs are the group of species which are generally most sensitive to anthropogenic magnetic fields, with other species less sensitive but with documented behavioural or physiological changes caused by magnetic fields at certain levels. Some species have been reported to be sensitive to very low magnetic field levels:

- Elasmobranchs (sharks, rays and skates) have the ability to detect very low-level magnetic fields and have shown behavioural responses to fields as low as 25µT above background levels;
- European eels have shown to temporarily divert their migration because of magnetic fields as low as 5µT above background levels. They have also been shown to orientate towards a magnetic field at 200µT above background levels; and
- Benthic invertebrate embryos show physiological changes from 1µT above background levels.

No behavioural change has been shown in Atlantic salmon or sea trout in magnetic fields below 600µT, with documented behavioural changes at 1000 µT. At very low level magnetic fields (<50µT), improvements in growth and performance have been shown for trout species, but deterioration in egg quality has been shown at magnetic fields of >2000µT.

Low-level magnetic fields may induce behavioural change in other marine pelagic and demersal species, but empirical evidence on this is limited. No physiological changes to these species have been found below 3,700µT. Shellfish species have not been found to show a behavioural or physiological response to magnetic fields below 300µT. Finally, no studies have been identified on the sensitivity of lamprey species or cephalopods to magnetic fields.

Assumptions made in carrying out the review and assessment were as follows:

- Electric fields will be contained within cable armouring due to shielding effects. Magnetic fields can, however, be detected outside of the cable (Gill, 2005), and may also cause an induced electric field to form if they are time-varying alternating currents. As the NorthConnect project uses a direct current cable, then no induction of an electric field will occur;
- Electric fields (or induced electric fields) are usually expressed in units of kilovolts per metre (kV/m). The magnetic field produced by an electric current can be expressed in terms of Magnetic Flux Density for which the applicable SI unit is the Tesla (T) or micro-Tesla (µT, one-millionth of a Tesla)). All magnetic field levels are expressed in µT for consistency;
- Species that are sensitive to magnetic fields (B-fields) based on magnetite or chemical mediated detection and species that respond to an induced electric (iE) field have been considered;

- The earth's geomagnetic field baseline is around 30-60µT between equator and poles, and 45µT for the NorthConnect project. Magnetic field strengths quoted are those above the Earth's natural geomagnetic field; and
- It is noted that induced electric fields are associated with alternating current (AC), whereas direct current (DC) gives rise to static magnetic fields hence reference to induced electric fields are provided for reference only.

APEM has not attempted to define a specific ‘threshold’ for what levels of magnetic fields will cause effects on various species, as the majority of existing studies simply report on whether a single EMF or temperature level has an effect on a particular species. Studies do not generally look at the effects of incremental increases of EMF or temperature levels and identifying the level at which a particular response (detection, behavioural, physiological) occurs. Therefore, this review can only state at what levels particular responses did and did not occur with the threshold likely to fall somewhere in between but to be variable between individuals, populations and species.

At an overarching level to this literature review, no studies have concluded to a level of statistical significance that EMF or elevated sediment temperatures from cabling projects causes mortalities or population reductions for fish, shellfish or benthic invertebrate species. The majority of studies have tested for a physiological or behavioural response in an individual, but even positive identification of a response may not necessarily have any effect on the individual in terms of its survival or reproductive efficacy, or on the population in terms of its extent or abundance. An assessment to this effect for each receptor will be provided within the ES chapters, also considering the wider population unit’s extent, structure and health, once the final EMF and temperature outputs are available.

A summary table of the lowest published magnetic and induced electric field levels triggering certain responses is presented in Table 2.1. This is a precautionary scenario as the whole population of each species will not be affected at field levels of this magnitude, but it provides a useful generalised summary and also shows a general trend towards higher magnetic field levels causing more severe effects, as illustrated in Figure 2.1.

Table 2.1 Lowest published magnetic and induced electric field levels of fish, shellfish and benthic ecology species

Species group	**Lowest published detection levels**		**Lowest published behavioural response levels**		**Lowest published physiological change levels**	
	Induced electric fields (iE-field) (µV/m)	**Magnetic field (B-field) (µT)**	**Induced electric fields (iE-field) (µV/m)**	**Magnetic field (B-field) (µT)**	**Induced electric fields (iE-field) (µV/m)**	**Magnetic field (B-field) (µT)**
Salmonids	8µV/m	No data identified	No data identified	600-1000µT	7,000µV/m	2000µT (improvements at low magnetic fields 0.1-50µT)
European eel*	8µV/m	No data identified	No data identified	5µT	7,000µV/m	12.6µT*
Lampreys	8µV/m	No data identified	No data identified	No data identified	No data identified	No data identified
Other marine pelagic species	8µV/m	No data identified	No data identified	No data identified	No data identified	>10,000µT
Other marine demersal species	8µV/m	No data identified	No data identified	No data identified	No data identified	>3,700µT
Elasmobranchs	0.0061µV/m	0.000037µT	<600µV/m (attraction) >400µV/m (avoidance)	25µT	No data identified	No data identified
Shellfish: Crustaceans	No data identified	No data identified	No data identified	314µT	No data identified	>3,700µT

Species group	Lowest published detection levels		Lowest published behavioural response levels		Lowest published physiological change levels	
Shellfish: Molluscs (excluding cephalopods)	No data identified	No data identified	No data identified	No data identified	No data identified	300µT
Cephalopods	No data identified	No data identified	No data identified	No data identified	No data identified	No data identified
Benthic Invertebrates	No data identified	No data identified	No data identified	No data identified	No data identified	1µT

**This value is for Japanese eel not European eel. Japanese eel was included in this case as it is the lowest reported level of physiological change in eel species. The European eel studies only cite behavioural changes rather than physiological.*

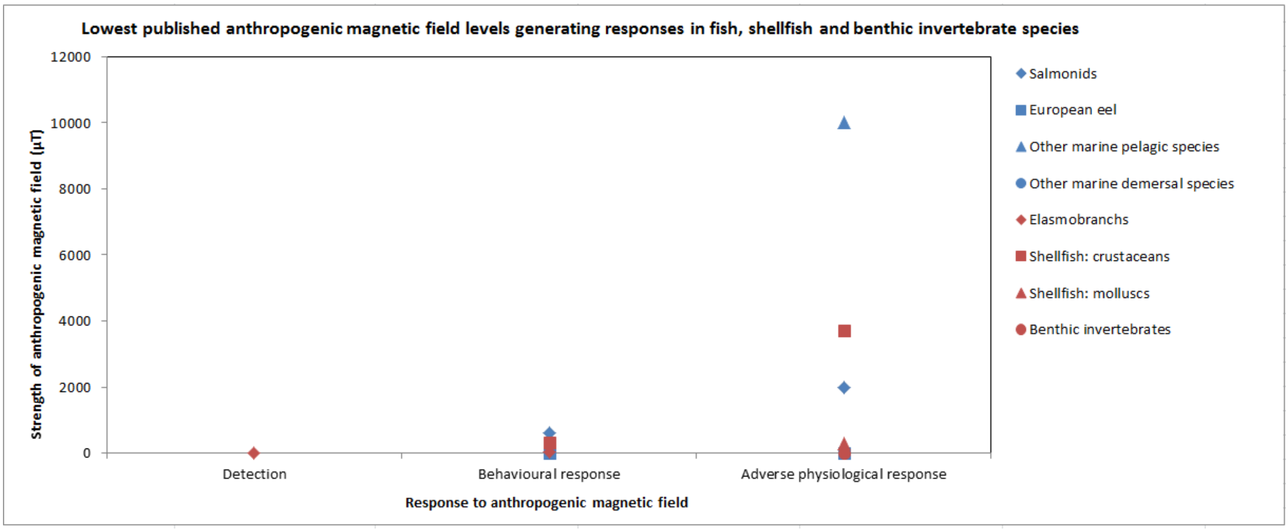

Figure 2.1 Lowest published magnetic fields levels triggering detection, behavioural response or adverse physiological responses

No published literature or project monitoring studies have shown population reductions or individual mortalities for fish or benthic invertebrate species as a result of EMF. Love (2016) showed that a magnetic field of 73-100µT above background levels resulted in no change in an overall fish assemblage.

A number of diadromous and marine fish species can detect induced electric fields from 8µV/m, but no evidence of a behavioural response to this detection has been demonstrated at these low levels. Avoidance and repulsion occurs at very high field levels (>6,000,000µV/m).

European eels respond to magnetic fields by orientating migration temporarily towards magnetic fields of >5µT, and also show physiological responses at low magnetic fields from 12.6µT. Salmonids orientate migration towards larger magnetic fields starting at between 600-1,000µT, and show a physiological response at 2,000µT. Other marine species show a temporary cessation of movement from 10µT and limited physiological change below 3,700µT.

Elasmobranchs can detect very small induced electric fields and magnetic fields, with attraction response shown up to between 600-1000µV/m, and avoidance response from >400µV/m. No evidence of physiological implications of exposure to induced electric fields or magnetic fields has been identified.

Behavioural changes in crustaceans have been shown at >314µT and physiological changes in crustaceans and shellfish at >300µT. No evidence of the sensitivity of cephalopods has been identified.

Benthic invertebrate embryos show physiological changes from >1µT for selected species, but there is limited available data on the sensitivity of the majority of these species and lifestages and no evidence of community composition or assemblage changes as a result of EMF.

A full table of the primary data sources for each relevant species (or species group) is provided in Table 2.2.

When considering the implications of EMF on species, proxy species for particular species have been used where there is a lack of data for a species whose native range is within the cable corridor route. For example, yellowfin tuna (*Thunnus albacares*) are used for assessment for a pelagic species as there is data available on reported level effects of EMF for this species, unlike the Atlantic Bluefin tuna (*Thunnus thynnus*), and the ecology and biology of these species is similar due to sharing genus. There are data gaps on some North Sea species with regard to the implications of EMF on their ecology and behaviour, so where data has been found it can be regarded with higher confidence but for areas where there is a paucity of available literature, a proxy species is used and the confidence in the assessment should be adjusted accordingly.

Table 2.2 Full literature review of sensitivities of fish, shellfish and benthic ecology species to magnetic and induced electric fields and vertical distribution of species in the water column

Species group	**Electromagnetic field reported effect levels**				**Vertical distribution in the water column**
	Physiological change		**Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)**		
	Induced electric fields (iE-field) (µV/m)	**Magnetic field (B-field) (µT)**	**Induced electric fields (iE-field) (µV/m)**	**Magnetic field (B-field) (µT)**	
Diadromous species (Atlantic salmon, sea trout, European eel, sea lamprey, river lamprey)	**7,000-70,000µV/m** *Increased heart rate in Atlantic salmon and European eel (McCleave and Power, 1978)*	**2,000µT** *Increased water permeability of bulltrout, rainbow trout and Atlantic salmon eggs (Sadowski et al., 2007)* **12.6-192.4µT** *Decreased heart rate in glass eel Japanese eel (Nishi and Kawamura, 2005)* **0.1-50µT** *Improved growth performance and immunological parameters in juvenile rainbow trout (Nofouzi et al., 2015)*	**6,000,000-15,000,000µV/m** *Avoidance/repulsion of teleost species (Uhlmann, 1975; Poléo et al., 2001)* **8-25µV/m** *Detection by Atlantic salmon, European eel, sea lamprey and river lamprey (Gill et al., 2005)* **10µV/m** *Behavioural response in sea lamprey (Peters et al., 2007)*	**1,000µT** *Directional preference towards field in Atlantic salmon fry (Tanski et al., 2012)* **>600µT** *No behavioural change in chum salmon (Yano, 1997)* **200µT** *Directional orientation to magnetic field in adult European eel. In constant magnetic field eels showed a preference to move along the induction line (attraction)(Branover et al., 1971)* **>60-120µT** *No behavioural change in Atlantic salmon or sea trout (Swedpower, 2003)* **12.6-192.4µT*** *Directional change in glass eel Japanese eel (Nishi and Kawamura, 2005).* **5µT**	**Atlantic Salmon** Post-smolt – 95% at <5m depth, some to 37m depth (Renkawitz et al., 2012); top 3m during the day, deeper during the night (Davidsen et al., 2008). Adult – 72-85% at <5m depth, maximum dive depth of 118m, similar to available water column depth (Godfrey et al., 2015); 75-96% at <5m depth, with deeper dives (Kjellman, 2015); mean depths of between 0-15m (Halttunen et al., 2009). **Sea trout** 0-10m (Sturlaugsson and Johannsson, 1996; Rikardsen et al., 2007; Hantke et al., 2011; Davidsen et al., 2014; Sturlaugsson, 2016) **European Eel** Glass eel – migrates using ocean

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	
				Temporary diversion of migrating European eel (Westerberg and Begout-Anras, 2000).	currents and then selective tidal stream transport in coastal and estuarine environments (Harrison et al., 2014) therefore it is likely to be distributed through the water column. Silver eel - Distributed throughout water column, to at least 800m depth and showing diurnal vertical migrations (Ernst, 1975; Tesch, 1978a, 1978b, 1989; Tesch et al., 1979 cited in Tesch and White 2008; Righton et al., 2016). **Sea lamprey** Usually 0-200m (Beamish, 1980), but maximum recorded depth is 4099m (Haedrich, 1977).
Marine pelagic species (e.g. clupeids, gadoids, mackerels)	No studies identified by APEM to date	**10,000–50,000µT** *Conditioned magnetisation of cells in yellowfin tuna (Walker, 1984)*	**6,000,000-15,000,000µV/m** *Avoidance/repulsion of teleost species (Uhlmann, 1975; Poléo et al., 2001)* **8-25µV/m** *Detection by cod (Gill et*	No studies identified by APEM to date	Pelagic fish species occupy the majority of the water column apart from the near-bed, demersal zone, so these species will be distributed widely throughout the water column apart from near the bed.

Species group	**Electromagnetic field reported effect levels**				**Vertical distribution in the water column**
	Physiological change		**Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)**		
	Induced electric fields (iE-field) (µV/m)	**Magnetic field (B-field) (µT)**	**Induced electric fields (iE-field) (µV/m)**	**Magnetic field (B-field) (µT)**	
			al., 2005)		
Marine demersal species (e.g. sandeels, flatfish)	No studies identified by APEM to date	**>3,700µT** *No physiological change or additional mortality in flounder (Bochert and Zettler, 2004)*	**6,000,000-15,000,000µV/m** *Avoidance/repulsion of teleost species (Uhlmann, 1975; Poléo et al., 2001)* **8-25µV/m** *Detection by plaice (Gill et al., 2005)*	No studies identified by APEM to date	Demersal fish species occupy the bed and near-bed areas of the water column, and so will be concentrated in these areas rather than distributing through the water column.
Elasmobranchs (e.g. sharks, skates, rays)	No studies identified by APEM to date	No studies identified by APEM to date	**1000µV/m** *Avoidance by small-spotted catsharks, silky sharks, white tip reef sharks and zebra sharks (Gill & Taylor, 2001; Yano et al., 2000)* **400 to 600µV/m** *Attraction and avoidance in elasmobranchs (Kimber, 2008)* **60µV/m** *Attraction in elasmobranchs (Kalmijn,*	**25-100µT** *Behavioural (directional) change in sandbar shark and scalloped hammerhead shark (Meyer et al., 2004)* **0.0012µT** *Detection by round stingray (Klimley, 1993)* **0.000037µT** *Detection by scalloped hammer head sharks, geomagnetic topotaxis where the sharks are attracted features in the relief of magnetic field intensities. (Klimley, 1993)*	Ray and skate species are generally demersal, with some movements from the bed into the water column. Dogfish, tope etc are generally demersal and other larger shark species can distribute widely through the water column: **Cloudy catshark** 0-320m (Nakaya et al., 2000) **Silky sharks** 0-500m (Bonfil, 2005) **Zebra shark** 0-600m (Dudgeon et al., 2016)

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	
			1982; Kimber et al., 2011) **2-150µV/m** *Behavioural response in lesser-spotted dogfish (Peters et al., 2007)* **10µV/m** *Attraction in lesser spotted dogfish (Gill and Taylor, 2001)* **1-10µV/m** *Behavioural response in thornback ray (Peters et al., 2007)* **0.5–100 µV/m** *Detection by elasmobranchs (Gill et al., 2005; Gill and Taylor, 2001)* **0.005-0.02µV/m** *Detection by elasmobranchs and chimaeras (Kalmijn, 1982; Tricas & New, 1998)* **0.0061µV/m**		**White tip reef sharks** Usually 8-40m, max 330m (Randall 1977; Smale et al., 2005), **Lesser spotted dogfish** Usually 0-80m (Capapé et al., 2008), max 780m (Mytilineou et al., 2005) **Thornback ray** 0-300m (Snowden, 2008) **Round stingray** 15-91m (Lyons et al., 2015) **Scalloped hammerhead shark** 0-275m (Baum et al., 2007)

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	
			Temporary freeze response in Thornback ray embryos (Ball et al., 2015)		
Shellfish: Crustaceans	No studies identified by APEM to date	**>200,000-800,000µT** *No neural response in European lobster (Ueno et al., 1986)* **25,000µT** *Increased hatching rate of brine shrimp (Shckorbatov et al., 2010)* **10,000µT** *Increases and decreases in regeneration rate of fiddler crabs Uca pungilator and Uca pungnax (Lee and Weiss, 1980)* **>3,700µT** *No physiological change or additional mortality in shrimp (Bochert and Zettler, 2004)*	No studies identified by APEM to date	**314-1,103µT** *Behavioural change in Dungeness crab and American lobster (directional, though not statistically significant) (Woodruff et al., 2012).*	Crustaceans are generally benthic or attached to the seabed apart from in very high currents or flows: **European lobster** 0-150m, more common above 50m (Butler et al., 2011) **Brine shrimp** 0-2m (Conte and Conte, 1988) **Dungeness Crab** 0-230m (Johnsen et al., 1986) **American lobster** 0-700m (Wahle et al., 2011)

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	
		>3,700µT *No physiological change or additional mortality in round crab and isopods (Bochert and Zettler, 2004)*			
Shellfish: Molluscs (excluding cephalopods)	No studies identified by APEM to date	**>3,700µT** *blue mussel (Bochert and Zettler, 2004)* **300-600 µT** *Changes shape of immunocytes in Mediterranean mussel (Malagoli et al 2003)* **300-1,000 µT** *Changes shape of immunocytes in Mediterranean mussel (Ottaviani et al 2002)* **400µT** *Increased concentration of heat shock proteins in Mediterranean mussel (Malagoli et al 2004)*	No studies identified by APEM to date	No studies identified by APEM to date	Crustaceans are generally benthic or attached to the seabed apart from in very high currents or flows: **Blue mussel** 0-5m (Tyler-Walters, 2008) **Mediterranean mussel** 0-40m (Lichtfouse, 2011)

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	
Cephalopods	No studies identified by APEM to date	No studies identified by APEM to date	No studies identified by APEM to date	No studies identified by APEM to date	N/A given lack of EMF sensitivity studies identified
Benthic Invertebrate species	No studies identified by APEM to date	**30,000µT** *Affects embryonic development: collapsed embryos effects cell division times. No increase in exogastrulation in sea urchin and purple sea urchin (Levin and Ernst 1997)* **100µT** *Affects embryonic development: delayed development in purple sea urchin (Zimmerman et al 1990)* **1-100µT** *Interferes with cell proliferation at the morula stage of embryonic development in purple sea urchin embryos (Cameron et al 1993)*	No studies identified by APEM to date	No studies identified by APEM to date	Benthic invertebrate species live on or in the seabed.

Species group	Electromagnetic field reported effect levels				Vertical distribution in the water column
	Physiological change		Detection / Behavioural response (e.g. diversion, slowed swimming speed, avoidance, attraction)		
	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	Induced electric fields (iE-field) (µV/m)	Magnetic field (B-field) (µT)	

2.2 Sensitivity to elevated sediment and water temperatures

Very few studies have been identified on the impact of elevated sediment and water temperatures on fish and benthic invertebrate species. For the majority of fish species, if the elevated sediment and water temperatures are localised then effects will be negligible as fish can move away from the area. It is only an issue where species spawn on the seabed and their eggs may remain in close proximity to the elevated sediment and water temperatures for a longer period of time.

Pepin (1991) conducted a review of available data on the temperature response of the early lifestages (egg, yolk-sac larvae and post-larvae) of marine fish species. The study found that egg and yolk-sac lifestage mortality rates (and thus survivorship) were significantly correlated with temperature, but that the post-larvae lifestage was not. The study found that at the egg stage, an increased temperature increased mortality rates, but that at the yolk-sac stage an increased temperature reduced mortality rates. Temperature did not influence the mortality rates of post-larvae.

The proposed development is situated in areas where Atlantic herring and sandeel are understood to spawn. These species spawn on the seabed and the eggs remain there until hatching. Once hatched, yolk-sac larvae and post-larvae of Atlantic herring and sandeels are carried by ocean currents and so those eggs that are laid on the seabed within the vicinity of the proposed development will not remain in the vicinity of locally elevated sediment and water temperatures once hatched, and therefore no effect on these lifestages from the proposed development is anticipated. The only lifestage of these individuals, therefore, that may be affected by elevated sediment and water temperatures is prior to the hatching of eggs.

Baseline seabed water temperature data for the North Sea are provided by Berx and Hughes (2008). Given that Atlantic herring from the Buchan / Shetland stock spawn in August and September, then the baseline water / sediment temperature is likely to be between 8-12^{o}C depending upon water depth. If these eggs were exposed to a 1^{o}C temperature increase for the whole lifestage then it would result in a reduced survivorship from 23.8-33.2% to 21.6-30.8%. A 2^{o}C temperature increase would result in a reduced survivorship of 19.4-28.4%.

Given that sandeel spawn in December and January, then the baseline water / sediment temperature is likely to be around 4-8^{o}C depending upon water depth. If these eggs were exposed to a 1^{o}C temperature increase for the whole lifestage then it would result in a reduced survivorship from 33.2-42.9% to 30.8-40.5%. A 2^{o}C temperature increase would result in a reduced survivorship of 28.4-38.1%.

Yolk-sac sandeel individuals that were laid and hatched in other areas of the spawning grounds may encounter localised elevated sediment and water temperatures from the proposed development. This may lead to reduced mortality rates and increased survivorship.

This would reduce any population-level effects of the reduced survivorship for those individuals that are laid in locally elevated water and sediment temperatures, though it is acknowledged that as this lifestage will be carried by ocean currents the duration of time spent in the elevated water and sediment temperatures may be limited.

3 Magnetic Field effects of the NorthConnect project

3.1 Depth preferences of relevant species

As the proposed cable for the NorthConnect project will be laid on (or within) the seabed, Table 2.2 provides a summary of the likely proximity to the seabed and distribution through the water column of the species under consideration. The vertical distribution of species has been considered in this review, along with the depth of water above the seabed along the cable route, to identify the likely magnetic field levels that individuals of various species would be exposed to, for comparison with their published sensitivities to magnetic fields.

A depth profile across the North Sea is shown in Figure 3.1, which indicates that apart from the near coastal zone, water depth in UK waters along the cable corridor is between 75m and 150m. Water depth for the first c. 6km from the coast of eastern Scotland is up to approximately 50m, reducing as you move nearer to the coast. As the NorthConnect project proposes to use Horizontal Directional Drilling (HDD) to install the cable at the coast, then the cable will only be laid on the seabed to a minimum water depth of 25m.

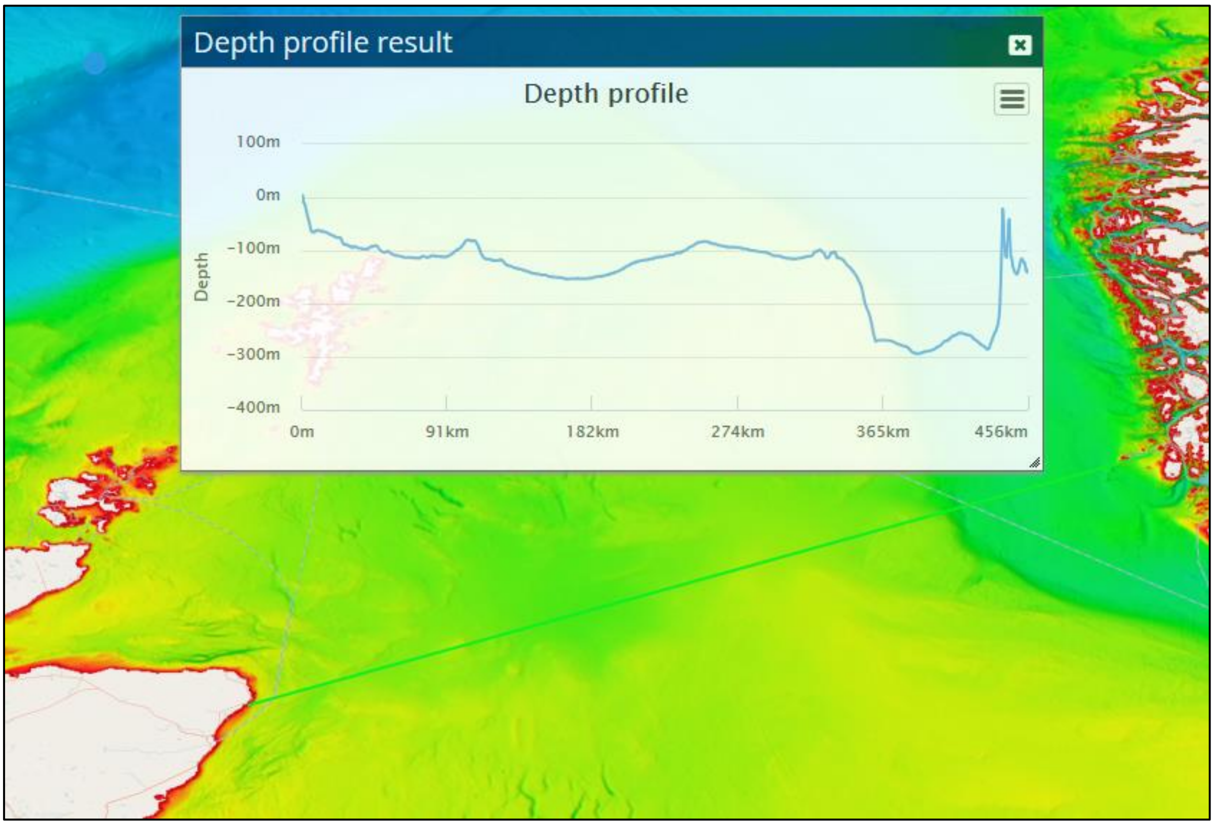

Figure 3.1 Depth profile across the North Sea, extracted from http://portal.emodnet-bathymetry.eu/

The review of the vertical distribution of species within the water column has found that salmonids are generally surface orientated, with pelagic species also some distance from the seabed within the water column. European eels, lamprey species and some elasmobranch species are widely distributed through the water column, and have highly variable depths. Demersal species, other elasmobranch species (such as rays, skates and dogfish), shellfish and benthic invertebrates are seabed orientated or live on the seabed. Some fish species such as sandeels and herring also spawn on the seabed.

In addition to the vertical distribution of species within the water column, the spatial distribution of species along the route will also vary.

3.2 Likely EMFs effects on species present in the NorthConnect cable corridor

The literature review has considered the sensitivity of the various species to magnetic fields as well as their likely distribution in the water column.

It is acknowledged that it will not be possible to reduce magnetic field levels from the NorthConnect project to below a level which would be undetectable to all species in all parts of the water column. However, as the magnetic field generated by the NorthConnect project would dissipate rapidly in the water column then the focus on further assessment should be on those species which live on the seabed, or are orientated towards the seabed in their vertical distribution in the water column, as these will generally be the species that would encounter the higher magnetic field levels generated by the NorthConnect project. The highest magnetic field levels are closest to the cable, reducing quickly with distance, hence species living on the seafloor such as crustaceans, are more likely to be in close proximity to higher magnetic field levels than those which utilise waters nearer the surface.

Some elasmobranch species inhabit the lower sections of the water column and can feed on the seabed. These species would likely be able to detect even the very smallest perturbations in the earth’s natural magnetic field, given their biology and presence of ampullae of Lorenzini, but behavioural changes have only been detected at magnetic fields of over 25µT. Other marine demersal species may also be able to detect magnetic fields of a similar order of magnitude, though empirical evidence is limited for species which inhabit the North Sea. Whilst both some elasmobranch species and marine demersal species will be seabed orientated, given their mobile nature and swimming capacities they would have the ability to swim higher into the water column above the magnetic field to avoid it should they have the propensity to do so. No negative physiological effects have however, been identified at magnetic fields below 3,700µT, should they not show this avoidance behaviour.

Shellfish species (both molluscs and crustaceans) inhabit the seabed and so would be in closer proximity to the cable and thus higher magnetic fields. Behavioural changes of crab and lobster species have been observed between 314 and 1,103µT. Changes in shapes of immunocytes, the cells that create antibodies, have also been observed in Mediterranean mussels at 300µT. No behavioural or physiological changes have however, been identified to shellfish species below 300 µT. Given their significantly lower ability to move vertically into the water column than the elasmobranch and marine demersal species discussed above, they would be less likely to avoid the magnetic fields if exposed to them.

Benthic invertebrate species are, by definition, associated with the seabed and have been shown to be physiologically affected by magnetic fields of below 100µT, down to just 1µT. It is therefore not considered to be possible to reduce the magnetic field at (or below) the seabed from the cables to a level which would mitigate for these potential physiological effects on benthic invertebrates.

Given the distribution of species in the water column, then the species that will be likely to come into close proximity to the magnetic field from the NorthConnect project are European eel, lamprey, marine demersal species, elasmobranchs, shellfish and benthic invertebrates. Some behavioural changes in the form of altered swimming direction or speed may be expected by the European eel, lamprey, marine and pelagic fish species, elasmobranchs and crustaceans swimming or moving near the bed. These behavioural changes are however, anticipated to be highly localised to the near-bed area, with individuals moving freely above the cable in the rest of the water column. These behavioural changes are not anticipated to result in any additional risk of mortality or effects to the population. No effects are anticipated to salmonid species given their likely separation distance from the cables whilst swimming near the surface.

For European eel, and mollusc and benthic invertebrate species, prolonged exposure to the magnetic field from the NorthConnect project has the potential to cause some physiological change. Given that European eels are highly mobile and at the glass eel and silver eel lifestages will be conducting long and relatively swift migrations (Righton et al., 2016) however, then a prolonged period of exposure is unlikely, especially as there are published behavioural responses of this species to magnetic fields also. The physiological effects to molluscs and benthic invertebrates are possible given the limited mobility of these species which may lead to slight increases in mortality rates. Impacts are however, likely to be confined to the immediate vicinity of the seabed surrounding the cables given the dissipation of the magnetic field away from the cables.

4 Sediment heating effects of the NorthConnect project

The proposed cable corridor crosses 3.6km of Atlantic herring suitable spawning habitat and 14km of sandeel suitable spawning habitat. These species spawn on the seabed and the eggs remain there until hatching. Once hatched, yolk-sac larvae and post-larvae of Atlantic herring and sandeels are carried by ocean currents and so those eggs that are laid on the seabed within the vicinity of the proposed development will not remain in the vicinity of locally elevated sediment and water temperatures once hatched. No effect on these lifestages from the proposed development is therefore, anticipated. The only lifestage of these individuals that may therefore, be affected by elevated sediment and water temperatures is prior to the hatching of eggs.

The sensitivity of sandeel and herring eggs are provided in Section 2.2 above, and this shows potential for slightly reduced survival at sediment and water temperature increases of 1°C, with survival rates decreasing further as temperatures increase.

Effects on Herring

Baseline seabed water temperature data for the North Sea are provided by Berx and Hughes (2008). Given that Atlantic herring from the Buchan / Shetland stock spawn in August and September, then the baseline water / sediment temperature is likely to be between 8-12°C depending upon water depth. **If these eggs were exposed to a 1°C temperature increase for the whole lifestage then it would result in a reduced survivorship from 23.8-33.2% to 21.6-30.8%. A 2°C temperature increase would result in a reduced survivorship of 19.4-28.4%.**

Effects on Sandeel

Given that sandeel spawn in December and January, then the baseline water / sediment temperature is likely to be around 4-8°C depending upon water depth. **If these eggs were exposed to a 1°C temperature increase for the whole lifestage then it would result in a reduced survivorship from 33.2-42.9% to 30.8-40.5%. A 2°C temperature increase would result in a reduced survivorship of 28.4-38.1%.**

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