Inch Cape Offshore Wind Farm

New Energy for Scotland

Offshore Environmental Statement:

VOLUME 2E

Appendix 13C: Electromagnetic Field Assessment

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Contents

List of Tables

Abbreviations and Acronyms

AoL	Ampullae of Lorenzini
AC	Alternating Current
CMaCS	Centre for Marine and Coastal Studies, University of Liverpool
DC	Direct Current
EIA	Environmental Impact Assessment
EMF	Electromagnetic Fields
ICOL	Inch Cape Offshore Limited
HVDC	High Voltage Direct Current
RMS	Root Mean Square

List of Units

A	amps
Hz	hertz
kV	kilovolts
kV/m	kilovolts per metre
MW	megawatts
T	Tesla’s
V	Volts
µm	micrometers
µV/m	microvolts per metre

13C Electromagnetic Field Assessment

13C.1 Introduction

Electrical transmission cabling are known to produce electric and magnetic fields, collectively known as electromagnetic fields (EMF's) that can be detected by a number of marine animals. Although studies have identified species able to detect EMF's there is a paucity of information testing the biological implications of any effects on a population.

Marine taxa reported to utilise the earth's geomagnetic fields, and thus assumed to be magneto-sensitive, have been identified among cetaceans and teleosts (Kirshvink, 1997). Magento sensitive species are thought to be those that undertake large scale migrations and use the earth's geomagnetic fields for orientation and navigation (Boehlert and Gill, 2010). Species that utilise low frequency electro reception to locate prey have been identified amongst the Chondricthyes fish, the Agnathans and the Chondrostei (Collin and Whitehead, 2004). Identification of the sensory capabilities of some of these species has been addressed primarily through laboratory experiments and so there is great uncertainty in interpreting such effects in relation to natural populations interacting with electrical cabling.

Environmental Impact Assessments (EIAs) for subsea power cables primarily refer to industry research undertaken by COWRIE (CMaCS, 2003; Gill *et al.*, 2005; 2009). Gill *et al.* (2009) conducted one of the few field studies directly relevant to offshore electrical cabling in relation to offshore wind energy. The experimental mesocosm study focused on elasmobranchs and indicated that individuals were attracted to EMF's produced by offshore export cables, however, this varied between species and individuals of the same species. Gill and Bartlett (2010) undertook a detailed review of published literature to determine the level of understanding in relation to subsea export cabling for the wave and tidal sector. The review highlighted the uncertainty in applying the available evidence at a population level scale to determine effect and identified various research needs to address the uncertainty associated with offshore renewable EIAs.

Marine Scotland are currently conducting experimental studies into the potential behavioural effects on European eel and Atlantic salmon smolts to reduce uncertainty in the assessment of environmental effects in relation to offshore renewable cables. The study aims to determine the behavioural response of salmon and eels passing a range of EMF's produced using Helmholtz Coils. The EMF generating system will use varying input currents from 1/16 V AC to 8 V AC to produce EMF strengths ranging from <1 µT to nearly 100 µT. The behavioural effects of fish passing the EMF will be measured using overhead and underwater video cameras. Marine Scotland Science is expected to report the results of this study in 2013; no preliminary results were available for incorporation into the current review.

There are a number of fish species in Scottish waters that have the potential to interact with offshore wind farm transmission infrastructure. Of relevance to the Development Area and the Offshore Export Cable Corridor and of particular concern to UK regulators and their statutory and technical advisors are magento-sensitive migratory fish such as Atlantic salmon (*Salmo salar*) and the European eel (*Anguilla anguilla*) and species with highly evolved electrosensory organs such as elasmobranchs and lamprey species.

13C.1.1 Objectives of this Report

The aim of the this report is to review the current understanding and state of knowledge in relation to EMF effects on fish receptors to inform the EIA process for the Development Area and Offshore Export Cable Corridor. This will support the EIA reported in Chapter 13: Natural Fish and Shellfish.

In particular the report will address the following objectives:

- Present the potential effects of electric E-fields associated with subsea electrical transmission cabling;
- Present the potential effects of magnetic B-fields associated with subsea electrical transmission cabling;
- Identify the potentially sensitive receptor species that may be present in the Development Area and Offshore Export Cable Corridor;
- Propose an approach for addressing effects on receptor species in the context of EIA.

13C.2 Electromagnetic Fields Produced by Subsea Electrical Cables

13C.2.1 Electromagnetic Field Analysis

Power cables which transmit electricity produce electric and magnetic fields due to potential voltage differentials between the conductor and earth ground which is nominally at zero volts, and the current passing along the conductor.

The types of fields produced, and their strengths, will be determined by the voltage and current, either Alternating Current (AC) or Direct Current (DC), which passes along the cable. Electric fields (also known as E fields) are produced by voltage and they increase in strength as voltage increases, while magnetic fields (also known as B fields) are generated by flow of current and increase in strength as current increases (Portier and Wolfe, 1998). The EMF produced and the effects on the surrounding environment depend on the type of cable, its physical characteristics (e.g. the amount and type of shielding) its construction parameters and its orientation and configuration.

Electric fields produced externally around a three core cable will be minimised when the cable is carrying balanced electrical loads and will be shielded additionally by the insulating properties of the armour wires and cable sheath. Similarly, external magnetic fields at a distance from a three core cable carrying balanced currents will be minimised under such load conditions.

For three core cables carrying unbalanced three phase AC, loads or the strength of external electric and magnetic fields is dependent upon the degree of unbalance and / or the separation distance between the single core cables.

Electric fields are usually expressed in units of kilovolts per metre (kV/m). The magnetic fields which are the result of AC or DC current passing through a cable will radiate outwards as a circular plane at right angles to its longitudinal axis. As the distance from the source increases, the field strength produced as a result of electricity flow (AC or DC) will decrease rapidly as per the inverse square law. 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. To provide some context, a magnet in the door of a fridge would produce a magnetic field of approximately 10,000 to 50,000 µT and a hand held appliance such as a hair dryer a magnetic field of 60-70 µT. The earth's magnetic field in the northern United States is approximately 57 µT (Gradient Corporation, 2008). In an AC cable the magnetic field will change at the same frequency as the alternating current which creates it, leading to a constantly changing modulation and polarity of the resulting magnetic field.

Many causes and sources of EMF exist in the marine environment, ranging from the earth's magnetic field, and movements of ocean currents through it, solar winds at high latitudes and the natural magnetic variability of surface geology. Anthropogenic sources of marine EMF also exist, usually as a result of infrastructure such as pipelines or communications and electrical cables.

While armouring around modern cabling is sufficient to shield the surrounding environment from E fields, the magnetic field (B-field) will escape into the environment. This B-field can induce a second electric field (also known as an iE-field) in any nearby electrical conductors, for example organisms, seawater, metallic objects, etc which are present within the influence of the cable's magnetic field. This phenomenon occurs as a result of a potential difference which is created within different parts of the conductor due to the constantly changing modulation and polarity of the magnetic field. The strength of the iE-field which is produced will depend on the distance from the cable, the strength of the B-field (the strength of which itself depends on the current flow), the speed and direction of water flow, and to a lesser extent the chemical composition of the water. iE fields are also measured in kV/m, or more usually µV/m as these induced electric fields are of a much smaller magnitude of strength compared to the electric current in cables.

Gill e*t al.* (2005) report that B fields will not be significantly reduced by burial of a cable. The iE field at the water sediment interface will be dependent on the strength of the B-fields and a number of site specific physical parameters. As field strength drops with distance, burial will create a physical barrier between the areas of highest field strength and any species that may be affected by the field.

13C.2.2 Predicted Field Strength

To transport power to shore over relatively short distances, offshore turbine arrays of larger generating capacity (e.g. 40 MW and above) generally use AC cables at transmission voltages of 132 kV and above. Variation in design and shielding of AC cables results in variability in levels of electromagnetic fields (E-fields or B-fields) they emit and so modelling can aid prediction of EMF emissions (CMaCS, 2003).

Information on the electromagnetic fields emitted by AC cables may be provided by the manufacturer. There is variability in the manufacturers' specifications and therefore also in the level of electromagnetic fields emitted by these type of cables, with Pirelli stating in communication with COWRIE (CMaCS, 2003) that as a result of the design and shielding, no E-fields or B-fields would be emitted by the cables they manufacture. AEI cables in contrast stated that while the 33 kV cable they manufacture emits no E-field, it will emit B-fields of 1.45 and 0.24 µT at a distance of 0 and 2.5 m respectively when carrying a current of 359 A. They also state that when the current is increased to 641A, the B-field emitted would increase to 1.7 and 0.61 µT at distances of 0 m and 2.5 m respectively (CMaCS, 2003).

In the absence of any standardisation on levels emitted, modelling can be a useful approach to predict the strength of electromagnetic fields emitted from power cables. CMaCS (2003) reported the results of modelling undertaken by Eltra who modelled potential EMF produced by sub-sea cables at the Horns Rev offshore wind farm. An induced electric field of more than 1000 µV/m was predicted up to 4 m from the cable for a 150 kV cable, which extended to 100 m before dissipating. It was also predicted that a 33 kV cable (in the range of the voltage levels in the Project inter-array cables) carrying a current of 400 A would generate a lower induced electric field of 1000 µV/m at the cable skin (within millimetres). This field extended for a similar distance to the 150 kV cable, but the field strength decreased more rapidly, being reduced by 50% at 4 m distance. It should be noted that this modelling was likely to have been for single phase conductors, which probably explains why the iE-field was relatively high, as this would have resulted in unbalanced loads.

Modelling undertaken directly by COWRIE (CMaCS, 2003) for the offshore wind farm standard 3 core 132 kV XLPe cable (i.e. a three phase cable), found that the sheaths of the cable provided effective insulation of E-fields, but that due to the AC flowing through the cable they would not shield B-fields. A strong magnetic B-field of approximately 1.6 µT was predicted on the skin of the cable which would add to the background level of the earth's geomagnetic field (approximately 50 µT). It was predicted that the strength of this field would decrease quickly in a non linear manner with distance, such that background levels would prevail within 20 m from the cable. This B-field would induce an iE-field in seawater and the substrate in which the cable is buried, irrespective of any shielding. The level would be higher in seawater due to higher conductivity and permittivity, assuming the same distance between cable and substrate, and was calculated at 91.25 µV/m, assuming a conductivity pertaining to fully marine conditions. The iE-field will dissipate more rapidly in the substrate than in the seawater; however the induced current levels on the skin of the cable and on the seabed would be almost identical, so the iE-field would not be reduced by burial.

The modelling work was compared to field measurements made in the River Clwyd Estuary (water with 10% salinity) of fields emitted by 33 kV and 11 kV cables (CMaCS, 2003). Near a 33 kV cable the B-field was measured as 50 µT RMS and fell quite rapidly to 10 µT RMS at 5 m distance from the cable, with an induced iE-field in excess of 70 µV/m at a distance 1000 m from the power cable. It was discovered from the manufacturers that the cable does not have steel wire armouring. It was thought that this factor makes a contribution to but does not fully explain the large iE-field detected, and the reasons for this would require further investigation.

Additional modelling was done by the University of Liverpool for a Centre for Marine and Coastal Studies (CMaCS) Study at the Kentish Flats offshore wind farm site (Gill *et al.*, 2005) for two 33 kV cables carrying maximum loads of 530 A and 265 A. The maximum iE-field predicted as a result was 2.5 µV/m, which is significantly less than that for the 2003 CMaCS study for a 132 kV cable reported above. This would not be expected as iE fields normally increase as voltage increases.

The results reported above are for single cables laid in a linear orientation. Cable networks which emit EMFs, and where the cables are located in close proximity to each other, for example at substations where cables may be less than 10 m apart, may have interactions (e.g. constructive in-phase interactions may occur between 50 Hz cables due to the relatively long wavelength of the EMF they emit) between them. This means that modelling would not give an accurate prediction of the magnitude of EMF emissions, and a site specific analysis may be required. It is reported that EMF effects are additive where in close proximity (Gill *et al.*, 2005.), which it is thought could result in iE-fields of several hundred µV/m if appropriate mitigation such as cable orientation, bundling and burial is not factored into the transmission infrastructure design.

In all the modelling studies reported above, the predicted levels of iE-field are within the range which it is reported they are able to be detected by elasmobranchs (i.e. 0.5 – 100 µV/m) (Gill *et al.*, 2005), and it is likely that arrays of cable would lead to larger levels of emitted iE-field.

Modelling of EMF’s was undertaken in 2012 by TNEI to inform the EIA for the Moray Offshore Renewables Limited development in the Moray Firth Round 3 Zone. In accordance with the Design Envelope approach a range of scenarios was modelled to encompass the realistic worst case scenario. TNEI concluded that 750 MW DC export cables will produce EMF’s of 35 µT at the seabed if buried to 1 metre and 560 µT if surface laid and protected with 0.25 m of graded rock. Installation of 800 mm^2 or 300 mm^2 220 kV AC cables buried to a depth of 1 m for inter-platform electrical transmission was also considered. EMF’s produced from the inter-platform connectors will be 21 µT and 13 µT at the sea bed for the 800 mm^2 cables and 300 mm^2 cables respectively. At 5 m the EMF strength will reduce to 0.8 and 0.5 µT respectively. For inter-array connections, modelling was conducted based on 66 kV AC cables and 33 kV AC cables buried to a depth of 1 m; at the seabed EMF strength will be 15 and 13 µT respectively rapidly attenuating to negligible levels within metres. To put this in context the Earth's natural magnetic fields are assumed to be 50 µT, therefore cabling from renewable developments are likely to be masked by background EMF levels in close vicinity to the electrical transmission infrastructure.

The modelling conducted by TNEI confirms that burial may reduce the attenuation of EMF's around electrical cabling. However, Gill *et al.* (2009) states that it is not practically achievable to bury cables to a depth sufficient to reduce B and iE fields to levels undetectable to marine fish. In addition, cable design and orientation is likely to be more effective at reducing magnetic fields and therefore induced electric fields however, the ability to maximise the benefits of this are often limited by offshore design constraints.

The electrical cabling for the Inch Cape Development Area and Offshore Export Cable Corridor is likely to be similar to that proposed at the MORL wind farms in the Moray Firth. Based on TNEI's modelling outputs for the MORL project only the 750 MW cables laid on the surface and protected with graded rock placement will exceed natural magnetic field values within metres of the cable. The effects of weak EMF's on marine faunal populations is unknown and in many cases based on experimental laboratory based surveys as opposed to field studies. Nonetheless, effects are likely to be small in magnitude based on the limited spatial extent of EMF's and the relatively large natural range of affected species.

13C.3 Species Sensitivity to Electromagnetic Fields

13C.3.1 Electroreception

13C.3.1.1 Fish

Transmission infrastructure associated with offshore wind energy is most likely to affect those species that use EMF's for spatial location, large scale migrations, orientation, feeding or finding a mate. The most common use is detecting prey (Gill *et al.*, 2005).

Animals naturally produce weak bioelectric fields through muscle contraction, respiratory movements, cardiac contraction and locomotion, and from the electrochemical difference between an individual's internal environment and seawater (Gill *et al.*, 2001). It is likely that these weak electric fields are used by predators to detect prey presence during feeding.

Induced iE fields produced as a result of water movements interacting with geomagnetic flux lines associated with subsea cables is most likely to affect species with specialised sensory organs adapted for detecting weak bioelectric fields (Gill *et al.*, 2005). Species of the taxonomic classes of Chondricthyes, the Agnathans and Chondrostei all possess specialised sensory organs for electroreception although examples of electrosensitivity in fish species are not restricted to these classes (Boelhert and Gill, 2010). These classes are reported to incorporate those species particularly sensitive to induced electric field generation. For example, the elasmobranchs, a subclass of Chondrichthyes, are known to have developed highly specialised ampullary electroreceptors to detect animate and inanimate electric fields. Elasmobranchs possess Ampullary of Lorenzini (AoL), a group of pores on the surface of the skin which are the entrance to epithelial canals up to 20 cm long and 1 mm in diameter containing a mucopolysaccharide jelly that conduct electricity with a similar resistance to seawater (Collin and Whitehead, 2004). These canals lead to a number of alveoli each containing hundreds of ampullary receptors. The clusters are restricted to the head in sharks but are distributed over the pectoral fins of rays and skates.

In comparison teleosts do not have such specialised electroreceptors. Similar ampullary receptors exist in teleosts but are characterised by shorter canals around 50-100 µm in length with much fewer receptor cells per ampullae (an order of magnitude less than in elasmobranchs) (Collin & Whitehead, 2004). However, it is thought that some teleosts are still able to detect induced iE fields created as a result of peak tidal movements (Gill *et al.*, 2005).

To date, reports of attraction or repulsion to electric fields have been tested using predominately laboratory methods with many focusing on physiological effects. It is evident from historical research that a number of species are able to detect weak electric fields. McCleave and Power (1978) reported that the heart rate of Atlantic salmon (*Salmo salar*) and European eel (*Anguilla anguilla*) are elevated when exposed to electric fields between 0.007 to 0.07 V/m. Kalmijn (1982) and Gill and Taylor (2001) observed a response by elasmobranchs to electric fields as low as 5 x 10-9 V/m and 5 x 10-7 V/m respectively. However, few studies have actually reported the ecological implications of electric fields generated by human development in the marine environment.

Of the few studies reporting effects on species in field conditions none have been sufficient to identify population level effects. Gill and Taylor (2001) reported that the lesser spotted dogfish (*Scyliorhinus canicula*) were attracted to electric fields of 0.01 mV/m but avoided fields of 1 mV/m. Marra (1989) observed shark bites on a telecommunications optical cable; however, this was observed along one cable route and was not observed in subsequent experiments. Poddubny (1967) observed a reduction in swimming speed in a Russian sturgeon (*Acipenser gueldensaedtii*) when passing under overheard cables but the overall effect of a population, if any, cannot be determined from these observations. In contrast Walker (2001) observed the interaction of sharks and other marine fauna with a HVDC cable crossing from Australia to Tasmania. No significant behavioural effects were observed although it was suggested that benthic species are more at risk of significant interactions due to their closer proximity to the higher source levels of fields.

A COWRIE funded projected investigated effects on induced electric fields produced by a cable similar to that used in offshore wind farms. Gill *et al.* (2009) used an experimental mesocosm approach to observe behavioural responses of three elasmobranchs species spiny dogfish (*Squalus acanthias)*, lesser spotted dogfish (*Scyliorhinus canicula*) and thornback ray (*Raja clavata*). The study found that there was evidence of a response in benthic elasmobranchs to cabling of the size and intensity associated with a wind farm. However, responses were unpredictable and varied between species and between individuals of the same species.

Research conducted at the Nysted offshore wind farm in Denmark was conducted to identify effects of the 132 kV AC export cable on fish assemblages. Pound nets were deployed along the cable route before and after installation of the cable to determine change. Pederson & Leonhard (2006) used this methodology to investigate changes in species of Atlantic cod (*Gadus morhua*), flounder (*Platichthys flesus*) and Baltic herring (*Clupea harengus membras*). Atlantic cod and flounder were significantly more abundant following installation of the cable route. It was concluded that this increase in Atlantic cod and flounder were a result of improved food conditions due to seabed disturbance (Pederson and Leonhard, 2006). During periods of high power production cod appeared to avoid the cable route and exhibited a random distribution around the remainder of the study area. Conversely, flounder appeared to cross the cable route more readily during low power production. This indicates that both species were affected by the electric fields (Pederson & Leonhard, 2006). Baltic herring distribution differed significantly before and after installation of the export cable. However, there was no correlation between the distribution of herring individuals and power production and so it was concluded that effects on herring are not a result of electric fields (Pederson & Leonhard, 2006). Peters *et al.* (2007) summarised research conducted to identify the range of electric field strengths likely to invoke behavioural responses in marine species.

In the UK, FEPA licence conditions have required monitoring at a number of offshore wind farms. FEPA monitoring data collected at Burbo Bank and Kentish Flats before and after construction was reviewed by Cefas (2010) as part of a project to assess the effectiveness of monitoring programs to validate outputs reported in the project Environmental Statements. At Kentish Flats any changes to fish assemblages occurred within the site and reference locations suggesting that varying catch rates were a result of natural fluctuations and not attributable to the wind farm. At Burbo Bank trawl surveys to date have yielded similar results with fluctuating fish abundance not attributable to wind farm construction or operation. Trawl surveys at both sites focussed on demersal species and so effects on pelagic species cannot be fully inferred. The trawl locations were not undertaken over cabling infrastructure making determinations of any local level effects from electric fields difficult. However, they do allow consideration at a macro level of the overall wind farm. At Burbo Bank, Cefas (2010) report that EMF's fall within the predicted field strengths modelled prior to construction however, the modelling has failed to draw any conclusions with regards to electrosensitive fish species specifically. Nonetheless, ongoing monitoring has indicated that there does not appear to be any effects on marine fish within the offshore wind farm project area.

Entec UK (2012) conducted a review of fish monitoring data collected at Robin Rigg wind farm in the Solway Firth to determine any changes as a result of the operation of the wind farm. Operational monitoring data was not analysed in the report however, based on the low numbers of elasmobranchs at the site and the limited spatial extent of EMF's Entec UK (2012) concluded that there has not been any change in elasmobranch presence that can be attributed to the presence of the wind farm. The spatial and temporal replication of sampling stations associated with the monitoring program of the wind farm was such that it is not possible to infer the response of electro sensitive species to the presence of EMF's.

However, the results of the surveys did not detect any impacts to fish populations within the Solway Firth as a result of the construction and operation of the offshore wind farm.

Of the species reviewed the elasmobranchs *Scyliorhinus canicula* and *Raja clavata* and the sea lamprey *Petromyzon marinus* are relevant to the current study (Table 13C.1; a full list of electrosensitive marine species found in the UK is shown in Annex 13 C.1).

Table 13C.1: Reported Behavioural Thresholds for Species that Have the Potential to Interact With the Project (Peters *et al.*, 2007).

Species	Behavioural threshold (µV/m)
Lesser spotted dog fish (*Scyliorhinus canicula*)	2 - 150
Thornback Ray (*Raja clavata*)	1 - 10
Sea lamprey (*Petromyzon marinus*)	10

13C.3.1.2 Invertebrates

Bullock (1999) reported that no concerted effort has been made to identify electroreception in benthic invertebrates. The study suggested that there is a possibility that electroreception capabilities could be possible in species of molluscs, arthropods and annelids. The evidence base has not improved with respect to electroreception in benthic invertebrates with studies focusing on fish species or magnetoreception instead.

13C.3.2 Magnetoreception

13C.3.2.1 Fish

Detection of magnetic fields in marine species has been widely reported for a number of species throughout their lifecycle. Formicki and Winnicki (1986) found that embryos of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) developed more slowly when exposed to low magnetic B-fields. In addition a strong orientation response has been observed in fish embryos when exposed to artificial magnetic fields compared to natural geomagnetic fields alone although this study focussed largely on salmonid species (Tanski *et al.*, 2005). Physiological changes in the Japanese eel (*Anguilla japonica*) have been observed with significant reduction in heart rate as a result of exposure to magnetic fields ranging from 12.6 to 192.4 µT (Nishi and Kawamura, 2005). However, the ecological consequences to a population as a result of detection of anthropogenic magnetic fields are still unknown.

It is widely believed that species that undertake long distance migrations rely on detection of the Earth's natural magnetic fields to navigate. However attempts to determine exactly how these magnetic fields are used for orientation remain inconclusive (Walker *et al.*, 2003).

Wiltschko and Wiltschko (2005) postulate that species are likely to use these magnetic fields in two ways: either as a magnetic vector that could provide directional information that an animal may use as a compass or by differentiating between different intensities and/or inclination to determine a navigational position. It is hypothesised that detection of magnetic fields by animals is through one of three possible mechanisms: electromagnetic induction, chemical reactions affected by magnetic fields and magnetite based magneto reception.

If anthropogenic EMF disrupts these mechanisms of detecting the Earth's natural geomagnetic fields, depending on the characteristics of the B-field, the impact could be a small short lived change in swimming speed or direction, such as those observed by Westerberg and Lagenfeldt (2008) on migrating European eel over an high voltage DC (HVDC) cable or possibly more serious disorientation leading to a significant delays during long distance migration (Walker *et al.*, 2002). A list of species which have been shown to respond directly to geomagnetic or magnetic fields or are close relatives in the case of cetaceans or chelonians is provided in Annex 13 C 1 (please note some of the species in the table are not found in UK waters, but have relatives which are).

Westerberg (2000) observed European eel (*Anguilla anguilla*) crossing HVDC power cables; small variations in swimming direction were noted but there was no overall alteration to migratory behaviour within individuals crossing the cable route area with the same probability in the presence and absence of the cable (Westerberg, 2000). Westerberg and Begout-Anras (2000) recorded similar results with eels exhibiting a constant magnetic compass course with small variations in the vicinity of the magnetic anomaly caused by the cable. Due to the spatial resolution no firm conclusion could be reached regarding the effect of such deviations, however, it was noted that depth and ambient water currents would also need to be considered (Westerberg and Begout-Anras, 2000).

European eel were captured, tagged and released along the cable route at the Nysted offshore wind farm to detect any disruption during migration. Pederson & Leonhard (2006) reported that European eel did not freely cross the cable route following installation however; this observation was not correlated to periods of power transmission. It was postulated that the presence of the trench where the cable was not completely backfilled may have resulted in barrier effects to eel movements. Effects as a result of magnetic fields during power transmission were therefore inconclusive. Further research by Westerberg and Lagenfeldt (2008) reported a reduction in swimming speed of European eel when crossing an HVDC cable in the Baltic sea. Westerberg (2000) concluded that a cable does not result in a permanent obstacle to migration and overall effects on a population are likely to be small.

Yano *et al.* (1997) studied swimming behaviour in the migratory salmonid (*Oncorhynchus keta*) by attaching tags which could be triggered remotely to generate a magnetic field. Using ultrasonic telemetry Yano *et al.* (1997) observed no variation in horizontal or vertical movements of chum salmon as a result of electromagnetic fields.

Bochert and Zettler (2004) exposed juvenile flounder (*Platicthys flesus*) to static magnetic fields of 3 mT for three weeks to assess mortality effects. No significant effect on mortality rate was recorded between the control group and treatment group.

Elasmobranchs have also exhibited an ability to detect magnetic fields in experimental studies conducted by Meyer *et al.* (2004). Two species of shark, namely the sandbar shark (*Carcharhinus plumbeus*) and the scalloped hammerhead shark (*Sphyrna lewini*) showed behavioural changes in response to localised magnetic fields which ranged from 25 to 100 µT.

Information describing the full nature of how fish may respond to magnetic fields and how this may manifest itself at the population level is limited. However, research suggests that species in the vicinity of offshore wind farm cabling are likely to detect produced magnetic fields with possible behavioural and cellular effects (Gill *et al.*, 2005).

13C.3.2.2 Invertebrates

Studies investigating electroreception in benthic invertebrates have been limited in comparison to fish species. Boles and Lohman (2003) conducted an experiment on European lobster (*Homarus gammarus*) by exposing them to magnetic fields. During exposure lobster were observed to navigate away from the source of the magnetic fields. The ICES Benthic Ecology Working Group reported that studies on the brown shrimp (*Crangon crangon*) were positively attracted to magnetic fields similar to those produced by offshore wind transmission cabling.

In contrast Bochert and Zettler (2004) exposed brown shrimp (*Crangon crangon*), the round crab (*Rhithropanopeus harrisii*), the isopod (*Saduria entomon*) and the blue mussel (*Mytilus edulis*) to magnetic fields for a period of at least three weeks and found no affect on survival of the species. This suggests, at least for *Crangon crangon*, that small behavioural responses do not result in a deleterious effect on individuals within a population.

13C.4 Project Specific Receptors

13C.4.1 Survey Results

Research indicates that a wide range of marine fish species are able to detect electric and magnetic fields. Exactly how marine species use electric and magnetic fields has proved elusive to determine conclusively. However, it is widely assumed that species with specialised electro sensory organs, such as the elasmobranchs, will be most sensitive to changes in electric fields as a result of offshore electrical transmission cables. Species, such as Atlantic salmon and European eel, that undertake large scale migrations to very specific areas to complete important stages in their lifecycle most likely rely on the Earth’s geomagnetic fields for navigation and orientation.

Inch Cape Offshore Ltd (ICOL) commissioned AMEC Infrastructure and Environment Ltd. (hereafter referred to as AMEC) to conduct a survey program to characterise demersal fish and epibenthic invertebrate communities across the Development Area. Quarterly surveys were completed in January, May, July and October to account for seasonal variation using a commercial otter trawl at ten sampling locations across the Development Area (*Appendix 12A Benthic Ecology Baseline Development Area, Appendix 13A Natural Fish and Shellfish Survey Report*). Sampling stations have been placed within the Development Area, within one tidal excursion of the site and beyond one tidal excursion (reference locations). The otter trawl data was supplemented by data collected during a 2 m epibenthic beam trawl survey conducted during May 2012, also by AMEC. Survey data collected has been used to identify a list of species potentially sensitive to EMF from the Project within the survey area. The species identified from the survey data considers data collected in the Development Area and within one tidal excursion.

Only two elasmobranch species were recorded; three cuckoo rays (*Raja naevus*) were recorded during the winter surveys and 17 lesser spotted dogfish (*Scyliorhinus canicula*) in spring, summer and autumn. Over the four surveys conducted at the Development Area 19,510 individual fish were recovered during the trawls, of these electrosensitive elasmobranchs accounted for an extremely small proportion of the catch. The species present that are potentially sensitive to electromagnetic fields are shown in Table 13C.2 below.

Cefas has reviewed spawning grounds for a selection of demersal species around the UK (Ellis *et al*., 2012). Using data collected as part of the Scottish North Sea groundfish survey the report identifies potential nursery grounds for a number of elasmobranch species. Of these species spurdog (*Squalus acanthias*) was recorded in more than 70% of tows within the region and low intensity nursery grounds were identified in the vicinity of the Development Area and Offshore Export Cable Corridor. Tope (*Galeorhinus galeus*) were recorded in less than 40% of tows within the region this was concluded to be representative of low intensity nursery grounds. Catch rates for the common skate (*Dipturus batis*-complex)(the taxonomic nomenclature is currently under review for common skate) was far sparser in the region, but this was deemed indicative of low intensity spawning grounds around the northern periphery of the Development Area.

Table 13C.2: Species Present within the Inch Cape Offshore Wind Farm Survey Area Potentially Sensitive to Electromagnetic Fields (Both Electro and Magnetic fields)

Species	Common Name	Sensitivity (E/B fields)	Relative occurrence in the study area
Scyliorhinus canicula	Lesser spotted dogfish	E	Rare*
Raja naevus	Cuckoo Ray	E/B	Rare*
Squalus acanthias	Spurdog	E	Rare^{+}
Galeorhinus galeus	Tope	E	Rare^{+}
Dipturus batis - complex	Common skate	E	Rare^{+}

Species	Common Name	Sensitivity (E/B fields)	Relative occurrence in the study area
Pleuronectes platessa	Plaice	E/B	Occasional*
Platichthys flesus	Flounder	E	Rare*
Scomber scombrus	Mackerel	B	Occasional*
Gadus morhua	Cod	E	Rare*
Homarus gammarus	European Lobster	B	Rare*
Crangon allmani	Shrimp	Potentially B**	Common*
Nephrops norvegicus	Norwegian lobster	Potentially B**	Rare*
Pandalus montagui	Pink shrimp	Potentially B**	Frequent*
Galathea dispersa	Squat lobster	Potentially B**	Rare*
Galathea strigosa	Squat lobster	Potentially B**	Rare*
Munida rugosa	Rugose squat lobster	Potentially B**	Occasional*
Cancer pagurus	Brown crab	Potentially B**	Rare*
Pagurus bernhardus	Hermit crabs	Potentially B**	Occasional*
Pagurus prideaux	Cloaked crab	Potentially B**	Rare*
Liocarcinus depurator	Harbour crab	Potentially B**	Occasional*
Atelecyclus rotundatus	Circular crab	Potentially B**	Rare*
Portumnus latipes	Spotted crab	Potentially B**	Rare*
Macropodia tenuirostris	Spider crab	Potentially B**	Rare*
Macropodia rostrata	Spider crab	Potentially B**	Rare*
Hyas araneus	Giant spider crab	Potentially B**	Rare*
Pisidia longicornis	Porcelain crab	Potentially B**	Rare*
*Based upon Inch Cape benthic, epibenthic and otter trawl surveys (Appendix 12A and Appendix 13A)			
** No evidence of sensitivity directly relating to these species was found, however lobsters, crabs and shrimps were identified as being sensitive to B fields by COWRIE (CMACS, 2005)			
$^+$ Not identified during the benthic, epibenthic and otter trawl surveys (Appendix 12A and Appendix 13A) . Recorded in the vicinity of or close to the development area during North Sea groundfish surveys conducted by Cefas and Marine Scotland (Ellis *et al.*, 2012).			

The demersal otter trawl gear deployed during site specific survey work at the Development Area has been developed for surveying species on or just above the seabed. As a result, migratory fish species such as salmonids, agnathans and European eel that are known to utilise a variety of depths in the water column are less likely to be recorded during survey work. It cannot be concluded from the survey data that these species are not present in the Development Area and so further consideration of these species will be necessary.

13C.4.2 Sensitive Receptors at Inch Cape Offshore Wind Farm and Development Area

Gill *et al.* (2005) produced a comprehensive review of research to identify those species in UK waters that are sensitive to electric and magnetic fields. A number of those species have the potential to interact with offshore subsea cables associated with the Development Area and Offshore Export Cable Corridor. Based on the site specific survey work and knowledge of species present in shallow coastal waters along the east coast of Scotland there are a number of electrosensitive and magnetosensitive species that have the potential to be affected by the proposed development.

Table 13C.3: Electrosensitive Species that may Interact with the Project

Common Name	Possible interaction with Wind Farm and OfTW
Lesser spotted dogfish (*Scyliorhinus canicula*)	Recorded in low numbers during summer trawl survey.
Cuckoo ray (*Raja naevus*)	Recorded in low numbers during winter trawl survey.
Spurdog (*Squalus acanthias*)	Not recorded during site-specific survey work. Recorded regionally during North Sea groundfish surveys. Nursery areas identified in the vicinity of the development area (Ellis *et al.*, 2012).
Tope (*Galeorhinus galeus*)	Not recorded during site-specific survey work. Recorded regionally during North Sea groundfish surveys. Nursery areas identified in the vicinity of the development area (Ellis *et al.*, 2012).
Common skate (*Dipturus batis* – complex)	Not recorded during site-specific survey work. Recorded regionally during North Sea groundfish surveys. Nursery areas identified in the vicinity of the development area (Ellis *et al.*, 2012).
Cod (*Gadus morhua*)	Recorded in low numbers during all winter, spring and summer trawl surveys. Ellis *et al*. (2012) reported potential low intensity spawning and high intensity nursery grounds in the vicinity of the development area.
Plaice (*Pleuronectes platessa*)	Recorded in low numbers during all winter, spring and summer trawl surveys. Ellis *et al*. (2012) reported potential low intensity spawning and low intensity nursery grounds in the vicinity of the development area.
Flounder (*Platichthys flesus)*	Recorded in low numbers during all trawl surveys.
European river lamprey (*Lampetra fluviatilis*)	Although not recorded in the surveys, this is an anadromous species that migrates to estuaries during adulthood. The distribution of this species is limited to estuarine and outer estuary habitats and is therefore unlikely to interact with the site; however, there may be some level of interaction along the Offshore Export Cable within the Firth of Forth.
Sea lamprey (*Petromyzon marinus*)	Although not recorded in the surveys, this is an anadromous species that migrates to sea during adulthood. The distribution of this species at seas is unknown but may have a wide range. Could potentially be present at the site but not recorded during site specific surveys.
European eel (*Anguilla anguilla*)	Although not recorded in the surveys, this is a diadromous species that migrates from breeding ground in the Sargasso Sea to freshwater habitats around the UK and northern Europe. Migration routes are not well known but have the potential to pass the site during migrations to and from breeding grounds.

Common Name	Possible interaction with Wind Farm and OfTW
Atlantic salmon (*Salmo salar*)	Although not recorded in the surveys, this is an anadromous species that migrates between freshwater spawning grounds and feeding grounds in the northern Atlantic. Migration routes are not well known but have the potential to cross the Development Area and Offshore Export Cable. It is worth noting that research is currently being carried out by Marine Scotland on the effect of EMF on Atlantic salmon. The results are expected in 2013.

Table 13C.4: Magnetosensitive Species that may Interact with the Project

Species	Possible interaction with Wind Farm and OfTW
Mackerel (*Scomber scombrus*)	Mackerel were recorded in the trawl catches during spring and summer. There is a possibility that mackerel were present in higher numbers than recorded as they are a pelagic species and unlikely to be recorded representatively during demersal trawling.
Plaice (*Pleuronectes platessa*)	Recorded in low numbers during all winter, spring and summer trawl surveys. Ellis *et al.* (2012) reported potential low intensity spawning and low intensity nursery grounds in the vicinity of the development area.
Cuckoo ray (*Raja naevus*)	Recorded in low numbers during winter trawl survey.
Lesser spotted dogfish (*Scyliorhinus canicula*)	Recorded in low numbers during summer trawl survey.
European eel (*Anguilla anguilla*)	Although not recorded in the surveys, this is a diadromous species that migrates from breeding ground in the Sargasso Sea to freshwater habitats around the UK and northern Europe. Migration routes are not well known but have the potential to pass the Development Area and Offshore Export Cable during migrations to and from breeding grounds.
Atlantic salmon (*Salmo salar*)	Although not recorded in the surveys, this is an anadromous species that migrates between freshwater spawning grounds and feeding grounds in the northern Atlantic. Migration routes are not well known but have the potential to cross the Development Area and Offshore Export Cable.
European river lamprey (*Lampetra fluviatilis*)	Although not recorded in the surveys, this is an anadromous species that migrates to estuaries during adulthood. Unlikely to interact with site but may be exposed to the export cable in the Firth of Forth.
Sea lamprey (*Petromyzon marinus*)	Although not recorded in the surveys, this is an anadromous species that migrates to sea during adulthood. The distribution of this species at seas is unknown but may have a wide range. Could potentially be present at the site but not recorded during site specific surveys.
Lobsters (*Homarus gammarus*)	Recorded in low numbers in the trawl surveys.

13C.5 Discussion

Despite continuing research attempting to address the effects of offshore electrical cabling there are still knowledge gaps resulting in large uncertainty in risk determinations of marine species in response to EMF’s generated from subsea infrastructure. Inherent difficulties exist in designing experimental or field studies to determine the effect of EMF’s on the population of a species.

Experimental laboratory studies indicating an animal’s ability to detect EMF’s does not necessarily mean that this is an animal’s primary sensory mechanism in the wild. Conversely, where animals are observed in natural habitats it is difficult to isolate and measure all aspects of directional and positional information in the sea to determine the level of influence of a single factor. This could partially explain field studies that concluded no significant effect on migrating fish when magnetic fields were interrupted (Yano *et al.*, 1997). Lohman *et al.* (2008) conducted a review on studies investigating the sensory ecology of marine species and concluded that EMF’s are unlikely to be the sole means of navigation for marine species. The review concluded that species may use a suite of sensory mechanisms such as olfaction, hearing and hydrodynamic movements that may be used sequentially at varying spatial scales. Attempts to determine the magnitude of an effect as a result of the introduction into the marine environment of EMF’s is therefore extremely difficult.

Furthermore, detecting the effects on a population from observations of individuals at a single stage in a species lifecycle makes determining the overall effect on a population’s ability to function difficult. For example, what is the ecological consequence of a reduction in swimming speed in European eel in the Baltic Sea when embarking on long distance migrations back to spawning grounds thousands of kilometres away? And what will the overall effect on energy consumption of an elasmobranch that is attracted or repelled by weak electric fields? There remains great difficulty in extrapolating these effects to determine any risk to a population and as a result there will be great uncertainty when assessing the environmental impacts of electrical cabling associated with offshore wind farms.

Gill *et al.* (2005) suggest that investigations into EMF effects on benthic invertebrate receptors are likely to be easier to study. Due to the smaller natural range of the species, the relative ease of keeping these species in aquaculture and the comparison of fishing data from static gear catch. However, since COWRIE published the review of available information research continues to focus on effects on fish species; this is perhaps a reflection on the relative importance of the species. Nonetheless, there remains a need to robustly assess potential impacts on invertebrate species at a population level.

Ohman *et al.* (2007) recommend assessing environmental impacts based on the likelihood of interaction between a receptor and any offshore cabling infrastructure. This provides a pragmatic approach to making risk determinations in the absence of conclusive scientific evidence. For example, a species such as salmon is known to undertake long distance migrations over a broad front from East coast Scottish rivers to the Northern Atlantic and has a broad natural range (Malcolm *et al.*, 2010). Furthermore, they are reported to swim predominately near the sea surface, particularly in coastal waters (Malcolm *et al.*, 2010). Modelling conducted relating to the Moray Firth Round 3 offshore wind farms suggests that B-fields will dissipate within 5 m both vertically and horizontally. As a result interactions with project-related EMF emissions are likely to be extremely limited, and the cabling footprint is likely to represent a very small area within the species natural range. This is particularly pertinent in relation to migrating salmon, which predominately swim in the upper 10 m of the water column. This approach is recommended for addressing effects on a both fish and invertebrate populations in the absence of a robust knowledge as to the species and population effects of EMF exposure.

The stage of a species lifecycle and the use of an area will affect the magnitude of any potential effect. For example, if an EMF was to affect a species at an ecological bottleneck where there is a greater proportion of that species exposed then any resultant effect is likely to be greater. Further, electrosensitive species are more likely to be affected in areas where a species is resident during feeding behaviour. In contrast magnetosensitive species are more likely to be affected where EMF’s cross important migratory paths. This is likely to result in varying degrees of effect and will need to be discussed accordingly. Therefore an understanding of a species lifecycle and natural range will be essential to ensure a robust and reliable EIA is completed.

13C.6 Conclusion

This report has presented the effects of electric E-fields associated with subsea electrical transmission cabling, presented the potential effects of magnetic B-fields associated with subsea electrical transmission cabling and identified the potentially sensitive receptor species that may be present within the Inch Cape Offshore Wind Farm Development Area and along the Offshore Export Cable Corridor.

Despite the inherent difficult in determining the effect on a species or population there is a large number of published scientific studies that have identified detection capabilities of a range of receptors to electric and magnetic fields associated with renewable infrastructure. Admittedly not all species that are able to detect EMF’s have been the focus of experimental or field based studies, however, through conjecture based on a species ecology and physiology all potentially sensitive species can be identified and incorporated into the EIA in accordance with the ‘precautionary principle’ (Table 13C.2).

Using this approach the species relevant to the Project have been identified using site specific survey data and North Sea groundfish survey data as reported by Ellis *et al.* (2012) (Table 13C.3 And 13C.4). These species are considered within the EIA Chapter 13 to determine effects as a result of electric and magnetic fields from the Project.

13C.7 References

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Annex 13 C.1 Electro and Magneto Sensitive Marine Species found in the UK

Annex Table 13C.1.1: List of Electro-Sensitive Species in the UK (from CMACS, 2005)

Species	Common name	Relative occurrence in UK waters	Evidence of response to E fields
Elasmobranchii	Sharks		
Cetorhinus maximus	Basking shark	Common	
Galeorhinus galeus	Tope	Common	
Lamna nasus	Porbeagle	Common	
Mustelus asterias	Starry smooth-hound	Common	
Scyliorhinus canicula	Lesser spotted dogfish	Common	✓
Squalus acanthias	Spurdog	Common	
Alopias vulpinus	Thintail thresher	Occasional	
Chlamydoselachus anguineus	Frilled shark	Occasional	
Dalatias licha	Kitefin shark	Occasional	
Isurus oxyrinchus	Shortfin mako	Occasional	
Mustelus mustelus	Smooth-hound	Occasional	
Prionace glauca	Blue shark	Occasional	✓
Scyliorhinus stellaris	Nursehound	Occasional	
Centrophorus squamosus	Leafscale gulper shark	Rare	
Centroscyllium fabricii	Black dogfish	Rare	
Deania calcea	Birdbeak dogfish	Rare	
Echinorhinus brucus	Bramble shark	Rare	
Etmopterus spinax	Velvet belly lantern shark	Rare	
Galeus melastomus	Blackmouth catshark	Rare	
Heptranchias perlo	Sharpnose sevengill shark	Rare	
Hexanchus griseus	Bluntnose sixgill shark	Rare	

Species	Common name	Relative occurrence in UK waters	Evidence of response to E fields
Oxynotus centrina	Angular rough-shark	Rare	
Scymnodon obscurus	Smallmouth velvet dogfish	Rare	
Scymnodon squamulosus	Velvet dogfish	Rare	
Somniosus microcephalus	Greenland shark	Rare	
Sphyrna zygaena	Smooth hammerhead	Rare	
Squatina squatina	Angelshark	Rare	
Elasmobranchii	Skates & Rays		
Amblyraja radiata	Starry ray	Common	
Raja clavata	Thornback ray	Common	✓
Dipturus nidarosiensis	Norwegian skate	Occasional	
Leucoraja circularis	Sandy ray	Occasional	
Leucoraja fullonica	Shagreen ray	Occasional	
Leucoraja naevus	Cuckoo ray	Occasional	
Raja brachyura	Blonde ray	Occasional	
Raja microocellata	Small-eyed ray	Occasional	
Raja montagui	Spotted ray	Occasional	
Raja undulata	Undulate ray	Occasional	
Amblyraja hyperborea	Arctic skate	Rare	
Bathyraja spinicauda	Spinetail ray	Rare	
Dasyatis pastinaca	Common stingray	Rare	
Dipturus batis	Common skate	Rare	
Dipturus oxyrinchus	Long-nose skate	Rare	
Mobula mobular	Devil fish	Rare	
Myliobatis aquila	Common eagle ray	Rare	
Rajella fyllae	Round ray	Rare	✓
Rostroraja alba	White skate	Rare	

Species	Common name	Relative occurrence in UK waters	Evidence of response to E fields
Torpedo marmorata	Marbled torpedo ray	Rare	
Torpedo nobiliana	Atlantic torpedo ray	Rare	
Holocephali	Chimaeras		
Chimaera monstrosa	Rabbit fish	Rare	✓
Agnatha	Jawless fish		
Lampetra fluviatilis	European river lamprey	Common	✓
Petromyzon marinus	Sea lamprey	Occasional	✓
Teleostei	Bony fish		
Anguilla anguilla	European eel	Common	✓
Gadus morhua	Cod	Common	✓
Pleuronectes platessa	Plaice	Common	✓
Salmo salar	Atlantic salmon	Common	✓

Annex Table 13C.1.2: List of Magneto-Sensitive Species in UK Coastal Waters (from CMACS, 2005)

Species	Common name	Relative occurrence in UK waters	Evidence of response to B fields
Cetacea	Whales, dolphins & porpoises		
Phocoena phocoena	Harbour porpoise	Common	✓
Tursiops truncatus	Bottlenose dolphin	Common	✓
Lagenorhynchus albirostris	White-beaked dolphin	Common	
Globicephala melas	Long-finned pilot whale	Occasional	✓
Lagenorhynchus acutus	Atlantic white-sided dolphin	Occasional	✓
Orcinus orca	Killer whale	Occasional	
Balaenoptera acutorostrata	Minke whale		

Species	Common name	Relative occurrence in UK waters	Evidence of response to B fields
Delphinus delphis	Short-beaked common dolphin	Occasional	✓
Grampus griseus	Risso's dolphin	Occasional	✓
Physeter macrocephalus	Sperm whale	Occasional	✓
Megaptera novaengliae	Humpback whale	Occasional	✓
Balaenoptera physalus	Fin whale	Occasional	✓
Stenella coeruleoalba	Striped dolphin	Rare	✓
Monodon monoceros	Narwhal	Rare	
Delphinapterus leucas	Beluga	Rare	
Pseudorca crassidens	False killer whale	Rare	
Hyperdoon ampullatus	Northern bottlenose whale	Rare	
Ziphius cavirostris	Cuvier's beaked whale	Rare	
Mesoplodon bidens	Sowerby's beaked whale	Rare	
Balaenoptera borealis	Sei whale	Rare	
Balaenoptera musculus	Blue whale	Rare	
Eubalaena glacialis	Northern right whale	Rare	
Kogia breviceps	Pygmy sperm whale	Rare	✓
Lagenodelphis hosei	Fraser’s dolphin	Rare	
Peponocephala electra	Melon-headed whale	Rare	
Chelonia	Turtles		
Caretta caretta	Loggerhead	Common	✓
Dermochelys coriacea	Leatherback	Common	
Chelonia mydas	Green	Occasional	✓
Eretmochelys imbricata	Hawksbill	Rare	
Lepidochelys kempi	Kemp’s Ridley	Rare	
Teleostei	Bony fish		
Anguilla anguilla	European eel	Common	✓

Species	Common name	Relative occurrence in UK waters	Evidence of response to B fields
Salmo salar	Atlantic salmon	Common	✓
*Scombridae**	Tunas & mackerels	Common	✓
Pleuronectes platessa	Plaice	Common	✓
Salmo trutta	Sea trout	Occasional	✓
Thunnus albacares	Yellowfin tuna	Occasional	✓
Elasmobranchii	All Elasmobranchii, Holocephali and Agnathans possess the ability to detect magnetic fields (for species list see Table 4.1)	Common	✓
Holocephali	As above		✓
Agnatha	As above		
Crustacea*	Specific cases, some non UK Decapoda: *Crangon crangon* (ICES, 2003) Isopoda: *Idotea baltica* (Ugolini & Pezzani, 1995) Amphipoda: *Talorchestia martensii* (Ugolini, 1993) *Talitrus saltator* (Ugolini & Macchi, 1988)	Common Common Common	✓
Mollusca*	Specific case, non UK Nudibranchia: *Tritonia diomedia* (Willows, 1999)	Does not occur	Mollusca*
* Evidence of magnetic response in species outside UK waters			