8 ELECTROMAGNETIC FIELDS (EMF)

8.1 INTRODUCTION

The following has been undertaken to comply with Section 5, Annex 1 of the Food and Environmental Protection Act (FEPA) 1985: Part II (as amended), licence 31579/05/0 (as amended).

Information on the cables and their shielding implemented at North Hoyle Offshore Wind Farm was provided in Appendix A of the 2003 FEPA report (NWPO, 2003).

The COWRIE EMF studies have been undertaken by CMACS Ltd to investigate the modelling and measurement of the E (electric) and B (magnetic) emission from a typical offshore subsea cable. A desk and laboratory study was completed in 2003 and more recently a review of existing information on the impacts of EM-Fields has taken place including proposals for strategies on future research and monitoring. The key findings of the COWRIE Stage 1 and Stage 1.5 reports are provided in Sections 8.2.1 and 8.2.2. Selected information from other studies is also summarised in Section 8.2.3.

8.2 SUPPORTING STUDIES

8.2.1 COWRIE Stage 1 EMF Study

Notable outputs of the study are that a preliminary model has been developed and results have been verified against the analytical solution. Furthermore, transducers to measure the B and E field of a cable in-situ have been constructed and tested.

The salient findings from the COWRIE EMF study “Baseline Assessment of Electromagnetic Fields Generated by Offshore Wind farm Cables”, dated July 2003[1] are reproduced below:

For a cable modelled with perfect shielding/earthing:

- The model showed that the cable did not directly generate an electrical field (E-field) outside the cable.
- However, magnetic fields (B-fields) generated by the cable created 'induced' E-fields outside the cable, irrespective of shielding.
- Maxwell's Eddy Current Field Solver model showed that B-fields are present in close proximity to the cable and that the sediment type in which a cable is buried has no effect on the magnitude of B-field generated.
- The magnitude of the B-field on the ‘skin’ of the cable (i.e. within millimetres) is approximately 1.6μT which will be superimposed on any other B-fields (e.g. earth’s geomagnetic field which is at 50μT).
- The magnitude of the B-field associated with the cable falls to background levels within 20m.

[1] CMACS (2003) A baseline assessment of electromagnetic fields generated by offshore wind farm cables. COWRIE Report EMF-01-2002 66.

The potential significance of modelled results on electrosensitive fish are as follows:

- EMF emitted by an industry standard three-core power cable will induce E-fields.

- In the case modelled this resulted in a predicted E-field of approximately 91µV/m (=0.9 µV/cm) at the seabed adjacent to a cable buried to 1m. This level of E-field is on the boundary of E-field emissions that are expected to attract and those that repel elasmobranches (any of numerous fishes of the class Chondrichthyes, characterised by a cartilaginous skeleton and placoid scales and including the sharks, rays, and skates. See Section 8.2.3 below for a summary of elasmobranch sensitivities to EMF).

- In addition, the induced E-fields calculated from the B-fields measured *in-situ* were also within the lower range of detection by an elasmobranch.

- The options for mitigation using either changes in permeability or conductivity indicate that the induced E-fields can be effectively reduced, however, unless very high permeability materials are used in the cable these E-fields are still within the lower range of detection of elasmobranchs. Hence any reduction in E-field emission would minimise the potential for an avoidance reaction by a fish if it encountered the field but may still result in an attraction response.

- Another important consideration is the relationship between the amount of cable, either buried or on the seabed surface, producing induced E-fields and the available habitat of electrosensitive species.

- There is also a need to determine if the power cable operating frequency (50Hz) and associated subharmonic frequencies have any effect on the EMFs that are detectable by UK elasmobranchs (i.e. the scientific evidence does not yet show whether electrosensitive fish actually detect at 50Hz).

8.2.2 COWRIE Stage 1.5 Electromagnetic Fields Review

A draft COWRIE stage 1.5 report has been drafted titled “The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms – a review”. (Draft - CMACS, 2005. COWRIE report: COWRIE-EM-FIELD 2-06-2004).

The report provides a comprehensive review and analysis of all information currently available. The aim of the review was to allow COWRIE to prioritise Stage 2 research relating to EM-Fields associated with offshore wind farms and EM- Field sensitive species. Once information had been collated the data was reviewed to assess the potential significance of impacts and to identify further research priorities and suggest monitoring strategies at individual sites.

8.2.2.1 Electric Field Detection

Electric fields in the marine environment are directly emitted either as a result of biochemical, physiological and neurological processes within an organism or via anthropogenic sources. Induced E-fields can also occur as a result of the organism itself or oceanic waters interacting with geomagnetic flux lines (CMACS, 2005 in prep).

Species that have specialised electroreceptors naturally detect bioelectric emissions from prey, predators and competitors. The E-sense is only used in close proximity to the source and other senses (such as hearing or smell) are used at distances of more than approximately 30cm. This means that the E-sense is highly tuned for the final stages of feeding or detecting others (CMACS, 2005 in prep).

The comprehensive search of information in the public domain revealed that there are very few studies that have considered the interactions between electrosensitive fish and *anthropogenic sources of E-field.*

8.2.2.2 Magnetic Field Detection

Organisms that are known (or presumed) to be able to detect magnetic fields can be categorised into two groups based on their mode of B-field detection: 1- induced electric field detection and 2- magnetite based detection.

Induced E-field Detection

The first mode relates to species that are electroreceptive, the majority of which are the Elasmobranchs (Table 2). It is generally assumed that the induced E-field mode of detection is used for navigation. The species that utilise this mode are considered to be either:

(a) *passive* - when the animal estimates its drift from the electrical fields produced by the interaction between tidal and wind-driven currents, and the vertical component of the Earth's magnetic field; or

(b) *active* - when the animal derives its magnetic compass heading from the electrical field it generates by its own interaction with the horizontal component of the Earth's magnetic field.

Magnetite Based Detection

Magnetite deposits play an important role in geomagnetic field detection in a relatively large variety of organisms. For many of these species of organism sensitivity to the geomagnetic field is associated with a direction finding ability.

The table below shows the prioritised species that are most likely to interact with offshore wind farm generated EM-Fields. The prioritisation is based on the review of existing knowledge, ecological importance, importance for other human activities (e.g. fishing; recreation), the distribution and occurrence of the species within the areas of round 1 and 2 offshore wind farm developments. In addition, the existing conservation status of species at national and international levels has been taken into consideration (CMACS, 2005 in prep).

Species	E- or B- Sensitive	Priority Criteria
Angel shark[2]	E B	Annex III Barcelona Convention; Annex III Bern Convention; biological and habitat vulnerability; Extirpated from some areas
Tope	E B	UK BAP species; globally seriously depleted; biologically vulnerable
Spurdog	E B	Endangered in NE Atlantic; biologically vulnerable
Basking shark	E B	Appendix II CITES; BAP species; biologically vulnerable
Thresher shark	E B	Severe population decline; biologically vulnerable
Porbeagle shark	E B	UK biodiversity priority list; biologically vulnerable
Common skate	E B	Endemic to NE Atlantic; biologically highly vulnerable; UK BAP species
White skate	E B	Annex III Barcelona Convention; Annex III Bern Convention; biologically highly vulnerable
Long-nose skate	E B	Biologically highly vulnerable; no conservation protection
Thornback ray	E B	Severely depleted; heavy pressure from fishing;
Anguillidae (eels)	E B	Severely depleted; biologically vulnerable
Plaice	E B	Fisheries species
Tuna	B	Fisheries species: Apex predator
Codling	E	Fisheries species
Decapod crustacea (lobster, crab, prawns)	B	Fisheries species

Table 8.1 Priority species for further investigation of significance of electromagnetic fields[3]. All species are known to utilise near-shore waters.

8.2.2.3 Assessment of Existing Sub-sea Cables and Electromagnetic Sensitive Species

Data from early in the 20th century compared with catch data from the 1980's onwards show that elasmobranch populations have drastically declined. These data are limited and the only areas fished which also have cable routes running through them are in the Irish Sea. COWRIE has no information on when the cables were installed but assumed that for most it was post-1910. Whilst the data show a decline in the elasmobranchs the main cause of this is attributed to fishing and habitat degradation. It is not possible to determine whether EM-Fields played any part in this decline (CMACS, 2005 in prep).

The most recent fisheries data show that significant proportions of the English and Welsh ray population inhabit the eastern Irish Sea, the Bristol Channel and the Thames Estuary. These are areas that have major cables running through them. The same data show that there are

[2] Many species, particularly the elasmobranchs, are suffering serious population declines hence the list will need to be up dated as more information is obtained (CMACS, 2005 in prep).
[3] All species of Cetacea (Whales, dolphins and porpoises), Chelonia (Turtles), Lampreys and salmonids are protected under EU Species and Habitats Directive and other conservation protection legislation.

also significant proportions of the ray population in Cardigan Bay where there are no cables (CMACS, 2005 in prep).

8.2.2.4 Summary and Information Gaps

Following the review of industry information COWRIE has identified a number of significant gaps in knowledge regarding sources of electrical and magnetic fields in the marine environment.

This is significant not only because there is a need to understand the extent of anthropogenic B and E fields before attempting to plan and interpret studies to assess their ecological effects but because all anthropogenic sources of B and E fields should be considered as part of cumulative impact assessments for proposed offshore developments that may have electric and/or magnetic field effects (CMACS, 2005 in prep):

- likely electric and magnetic field strengths associated with each existing source (i.e. telecommunication cables, non-wind farm power cables and pipelines);
- frequency and duration of electrical heating of oil and gas pipelines;
- precise location of telecommunication cables;
- precise location of other submarine power cables.

The COWRIE review suggests these information gaps need to be filled so that investment in direct studies of E and B field effects may be fully interpreted in relation not only to offshore wind farm cabling but other sources of such fields.

The potential significance for electrosensitive species of anthropogenic electrical fields is uncertain. The following needs to be considered:

- *whether electrosensitive species can detect the induced fields emitted by the cables;*
- *the consequences, if any, for the species of concern;*
- *if the effects are similar for individuals (e.g. of different age or sex) within a species population;*
- *if attraction to iE-fields from the cables was demonstrated then we would predict indirect impacts for individual animals investigating the induced electric fields assuming that they are associated with food and actually wasting time and energy doing so. A repulsive field could have a direct impact by actively repelling animals, thereby interrupting normal behaviour and potentially excluding habitat from use. It should be noted, however, that there is currently no evidence that either attraction or repulsion due to anthropogenic electric fields will have an effect on fish or other receptor species.*

Benthic species such as skates/rays and catsharks/dogfish use electroreception as their principal sense for locating food. More open water (pelagic) species, such as tope and spurdog, may encounter E fields near the seabed but spend significant time hunting in the water column. The potential for an impact is considered highest for species that depend on electric cues to detect benthic prey (CMACS, 2005 in prep).

For magnetic fields, certain teleost (bony) fish species, including salmonids and eels, are understood to use the earth's magnetic field to provide orientation during migrations. If they perceive a different magnetic field to the earth's there is potential for them to become disorientated. Depending on the magnitude and persistence of the confounding magnetic field the impact could be a trivial temporary change in swimming direction or a more serious delay to the migration (CMACS, 2005 in prep).

As with electric fields, the relative significance of the (relatively) narrow cable route compared to the network of cables within the array is not known.

A number of research priorities are reported in the draft COWRIE review. Future research and monitoring strategies will be reported in the 2005 FEPA report.

8.2.3 Other Studies

The following is summarised from the CMACS 2003 and draft 2005 (COWRIE EMF) reports:

> Westerberg & Begout-Anras (2000)[4] investigated the orientation of silver eels (*Anguilla anguilla*) in a disturbed geomagnetic field created by the presence of a submarine high voltage direct current (HVDC) power cable. HVDC power cables pass a current in a single-conductor cable with the return current via the water. It should be noted that this type of cable is not characteristic of the AC cables currently proposed by UK offshore wind farms.
>
> In the Westerberg & Begout-Anras study, the B-field generated by the cable was of the same order of magnitude as the Earth's geomagnetic field at a distance of 10m. Of twenty-five female eels tracked, approximately 60% crossed the cable. Westerberg & Begout-Anras concluded that the cable did not act as a barrier to the eel's migration path in any major way, but concede that further investigation is required. In a more recent publication, Westerberg (2000)[5] reported similar results after investigating elver (a young stage in the eel life cycle) movement under laboratory conditions.
>
> In 2001, an investigation of the effect of noise, vibration and electromagnetic fields on fisheries related species was carried out at the Vindeby wind farm, Denmark[6]. The aim of this investigation was to determine whether noise and vibration and/or EMF have affected fisheries species in the area of the wind farm and cable route. However, poor weather conditions prevented survey work and so the question at Vindeby remains unanswered. SEAS, Denmark intend to repeat this investigation at the Rødsand wind farm site. To date, baseline data have been collected on migratory and electro-sensitive fish species in the general area of the cable route. Monitoring of fish migration over the cable and any changes in electro-sensitive species number and abundance will be carried out between 2003 and 2005.
>
> Bio/consult has also conducted a study of fish response to the presence of the main power cable to shore at Nysted offshore wind farm in the southern Baltic Sea. The study only considered the magnetic component of the EM-Field. The electrical component was assumed to be contained within the cable shielding and there was no consideration of induced E-fields. The common eel was highlighted as being particularly sensitive to electro-magnetic fields (CMACS, 2005).
>
> For submarine cables, the influence of electromagnetic fields on marine organisms must be closely examined as EMFs outside the cables may have positive or negative implications for the organisms. Some literature shows that the sensitivity threshold of electrosensitive fish species could be much lower than the electromagnetic field level in close proximity to a cable[7]. Existing studies show that elasmobranchs can detect artificial bioelectric fields down to 0.5 µV/m and avoid fields of 100 µV/m or greater (Gill

[5] Westerberg H & Begout-Anras ML (2000) Orientation of silver eel (*Anguilla anguilla*) in a disturbed geomagnetic field. Advances in Fish Telemetry. Proceedings of the Third Conference on Fish Telemetry in Europe, Norwich, England, June 1999. Eds Moore A & Russel I. CEFAS Lowestoft.

[5] Westerberg, H (2000) Effect of HVDC cables on eel orientation. In Merck T & vo Nordheim, H (eds). *Technische Eingriffe in marine Lebensraume*. Published by Bundesamt fur Naturschutz.

[6] Bio/consult (2002) Possible effects of the offshore wind farm at Vindeby on the outcome of fishing. Report to SEAS, Denmark. 23 pages.

[7] Voitovich RA & Kadomskaya KP (1997) Influence of the design parameters of high voltage underwater power cables on the electromagnetic field intensity in an aqueous medium. Electrical Technology, No 2, pp 11-21.

& Taylor 2002[8]). Gill & Taylor also demonstrated that the dogfish, a species of elasmobranch, was sensitive to E-fields equivalent to those estimated to be emitted by power cables.

Magnetic field experiments
The brown shrimp *Crangon crangon* has been recorded as being attracted to the B fields of the magnitude expected around wind farms by ICES in 2003 (CMACS, 2005).

Through controlled experiments it has been shown that EM-Fields appear to disrupt the transport of calcium ions in cells, which may be of importance to developing embryos. B-fields of 1-100 µT have found to delay embryonic development in sea urchins and fish (CMACS, 2005 in prep).

8.3 CONCLUSIONS AND FURTHER WORK

The COWRIE report concluded that the current state of knowledge regarding the EMF emitted by undersea power cables is too variable and inconclusive to make an informed assessment of any possible environmental impact of EMF in the range of values likely to be detected by organisms sensitive to electric and magnetic fields.

As stated above, the COWRIE report did attempt to define the likely range of sensitivity of elasmobranchs to E-fields, based on a literature review by Gill & Taylor (2002). The following summarises the present state of knowledge; however, it must be stressed that there is very little rigorous, experimentally based evidence to support such generalisations at present.

Elasmobranch sensitivity:	0.5 – 1000 µV/m
Potential range of attraction:	0.5 – 100 µV/m
Potential range of repulsion:	> 100 µV/m

In relation to North Hoyle, the modelling undertaken for the COWRIE EMF report is relevant. This predicted that the E-field on the sea bed adjacent to a 1m buried industry standard three-core power cable would be 91 µV/m. This value therefore lies on the boundary of emissions that are expected to attract and those that repel elasmobranchs.

A further COWRIE study (Stage 2) is expected to be commissioned that will investigate the specific biological significance for electrosensitive fish species of EMF. This study should comprise experimental behavioural investigations of fish response to underwater power cables. Findings of this study will be related to the North Hoyle site as they become available. In addition, results of the SEAS study at Rødsand, Denmark should become available within the period of FEPA monitoring for North Hoyle.

NWP Offshore Ltd proposes that the findings of this continued COWRIE research and any subsequent monitoring protocol forms the basis of any future monitoring strategy imposed under the conditions of the FEPA License, if such research suggesting deleterious impacts may result on electro-sensitive species transpires.

[8] Gill AB & Taylor H (2002) The potential effects of electromagnetic field generated by cabling between offshore wind turbines upon elasmobranch fishes. Report to the Countryside Council for Wales (CCW Contract Science Report No 488) 60 pages.