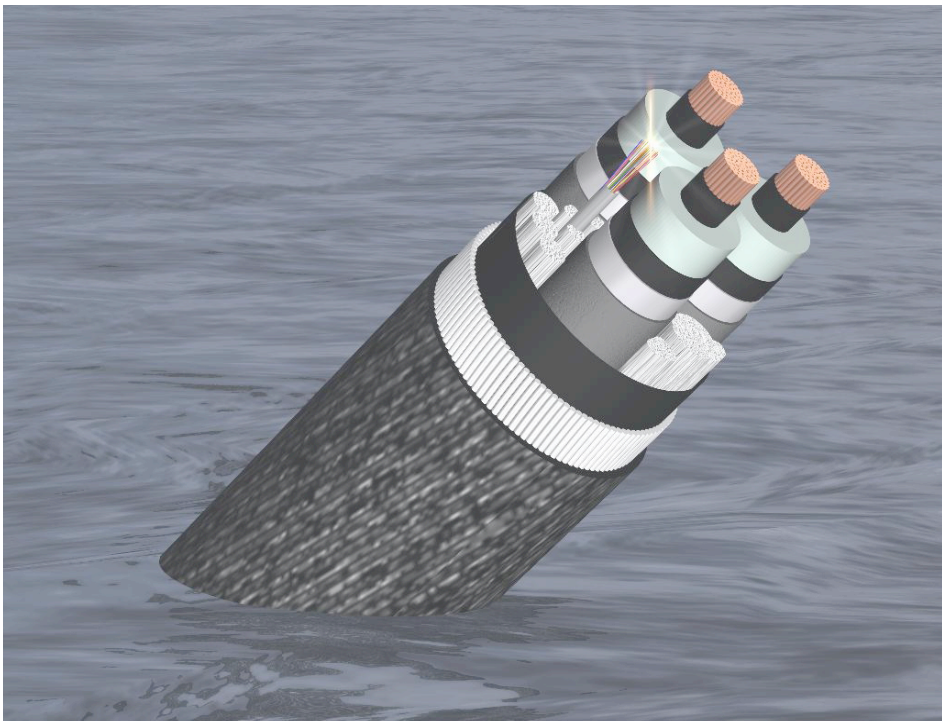
Assessment of Potential Ecosystem Effects from Electromagnetic Fields (EMF) Associated with Subsea Power Cables and TISEC Devices in Minas Channel



Prepared for: Fundy Ocean Resource Centre for Energy

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EXECUTIVE SUMMARY

A demonstration tidal energy project has been established in Minas Channel west of Black Rock near Parrsboro, Nova Scotia. Development of the project is being coordinated by the Fundy Ocean Resource Centre for Energy (FORCE), a not-for-profit corporation, which collaborates with developers, regulators and researchers to study the interaction between tidal turbines and the Bay of Fundy environment. Four different designs of Tidal In Stream Energy Conversion (TISEC) devices are to be installed within a 1.6 km^2 crown lease area with mid-tide depths of approximately 40 to 60 m, and will be connected to shore via four individual undersea cables.

This report discusses concerns regarding the potential effects of electromagnetic fields (EMF) in the context of other potential environmental impacts associated with generation of electrical power from tidal energy in general and the local environment of Minas Channel in particular. Available literature on the potential effects of electromagnetic fields (EMF) is summarized for a broad audience, drawing upon a number of recent major reviews in the US and Europe. The most relevant information on the biological effects of EMF is recent, and on-going studies are being carried out to fill regional data gaps. The assessment of impacts can be partially based on field evaluations of the effects of EMF from the recent installations of offshore wind farms.

The potential magnitude of EMF associated with subsea cables is estimated from reports describing other installed or planned systems. In most cases EM fields are derived from models with little reference to field measurement. Burial of the cable in the seabed has little if any effect on magnitude of magnetic (B) field, but the induced electric field (iE) is reduced by passage through seabed sediment. Burial does, however, in all cases restrict the magnitude of exposure of organisms to EMF by restricting access to the cable.

Biological effects are primarily associated with organisms that use the Earth's magnetic field for navigation and others that use the electrical field produced by biological activity to locate prey. Detection of magnetic fields, incorporating molecular magnetite, appears in organisms ranging from bacteria to vertebrates, such as marine mammals (Kirschvink et al. 2001). While the ability to detect magnetic fields is present in a wide variety of organisms, the magnitude of magnetic fields from subsea power cables has not been documented to cause adverse effects, such as disruption of migration. In relation to organisms sensitive to electrical fields, such as sharks and rays, the sensory systems appear to primarily operate over short distances, e.g. 30 cm. Thus impacts appear to be limited to attraction or repulsion close to the EMF source.

The sensitivity to EMF and the potential effects are sufficiently well understood that vulnerability of many species can be determined based on sensitivity and behavior. For example, sessile benthic species are more likely to be exposed to higher levels of EMF because they can be in close proximity to the source for extended periods. Most pelagic species or species migrating in the mid or upper part of the water column are unlikely to

be exposed to detectable levels of EMF from subsea cables except briefly with only minor transient effects.

For the FORCE project, a network of standard cables is to be constructed connecting each of the TISEC platforms to a common shore-based substation. The subsea cable proposed for installation within the lease area is nominally a 34.5 kV cable with three power cores cabled together with one fiber optic unit and one pilot cable. Each cable is rated to carry a maximum continuous current of 300 amperes for a power output of 10.4 MW per unit. These cables will support either AC or DC operation – design of the generating unit will determine which is required.

When subsea cables carry DC power, EMF are greater and the potential for biological impacts higher than when AC power is used at the same power level. Because details of the TISEC devices are unknown, the magnitude of EMF levels cannot be accurately predicted, particularly when cables run close together near shore. Based on review of the impacts of a range of similar cables and cables handling more power, levels of EMF are expected to be detectable by sensitive organisms within a maximum distance of 30 m. Behavioural effects are anticipated to be much more localized and, for example, effects on feeding would be expected to occur no further than one metre from the cable. Burial of the cables would reduce the potential exposure of organisms to EMF, but duration of exposure in the high currents of the area is still expected to be minimal.

The importance of potential effects from EMF need to be considered in light of the overall operation of tidal energy systems and the environment involved. Tidal energy power generation devices will increase turbulence in the water column, which in turn will alter mixing properties, sediment transport and, potentially, wave properties; in addition, effects of noise and electromagnetic fields need to be considered during installation, operation and abandonment (Frid et al. 2012). While EMF has been shown to result in biological effects, the survival and reproduction of benthic organisms has not been documented, and identified effects on fish are restricted to those species that are particularly sensitive. Overall, tidal power generating devices are unlikely to affect reproduction and recruitment processes unless multiple devices are very closely packed. Within the overall context of effects, responses to EMF tend to be localized and of short duration (Frid et al. 2012).

With respect to EMF, a number of priority species of interest are identified, along with data gaps in our knowledge base, related to their potential vulnerability to EMF and their recreational, commercial, and/or ecological importance or their conservation status. The specific species of interest in the Minas Passage from an EMF perspective are:

- American lobster (*Homarus americanus*),
- Atlantic salmon (*Salmo salar*),
- American eel (*Anguilla rostrata*),
- Spiny dogfish (*Squalus acanthias*), and
- Atlantic sturgeon (*Acipenser oxyrinchus*).

Research conducted to date has not indicated population effects on any species associated with even large offshore wind projects. Effects on even these species of interest are expected to be of short duration and localized.

Given the low potential for population effects even on sensitive species and the difficulty of conducting appropriate types of study in the high current and turbulent environment of Minas Channel, no specific monitoring is recommended. However, the sensitivity of American lobster to EMF was identified as a knowledge gap for the Minas Passage area because of its commercial importance and the potential for transient exposure to subsea cables. Laboratory studies to determine the degree of sensitivity of this species to EMF are being carried out by researchers in United States and results of these studies should be tracked by FORCE.

Contents

GLOSSARY

AC	Alternating Current or time varying current. For example, in North American AC current oscillates at 60 times per second.
B field	Magnetic field outside of a material.
DC	Direct Current or current at a steady flow.
ELF	extremely low frequency (ELF) electromagnetic fields are between 3 - 3000 Hz, such as those associated with generators and electrical cables.
EM	Electromagnetic (EM)
EMF	Electromagnetic Field (EMF)
HVDC	High Voltage Direct Current
iE	induced electric field, which is generated, or "induced", in any conductor moving through a magnetic field.
magnetic field	The flow of electricity in a conductor (i.e., the movement of electric charges or current) creates a magnetic field.
magnetic flux density	the amount of magnetic flux or magnetic induction in a unit area perpendicular to the direction of magnetic flow measured in micro teslas (μT).
MHK	marine and hydrokinetic energy devices, which would include tidal energy systems as considered in this report.
MRE	marine renewable energy, which includes wind farms and both instream and wave power-generating devices.
shielding	Braided strands of copper (or other metal, such as aluminium), a non-braided spiral winding of copper tape, or a layer of conducting polymer may be used as shielding around a conductor.
S	seimens (S) is the SI unit for conducdtivity. Mho is an alternative name of the same unit, the reciprocal of one ohm.
TISEC devices	Tidal In Stream Energy Conversion devices, which include a range of designs to generate electricity but which do not include wave energy conversion.

μT	micro tesla, a unit of magnetic induction.
μV	micro volt (100 μV/m = 0.000001 V/cm)
μV/m	micro volt per metre (1 V/m = 0.01 V/cm)
μV/cm	micro volt per centimeter (1 V/cm = 100 V/m)

1 INTRODUCTION

1.1 FORCE and Minas Channel Tidal Development

A demonstration tidal energy project has been established in Minas Channel west of Black Rock near Parrsboro, Nova Scotia. Development of the project is being coordinated by the Fundy Ocean Resource Centre for Energy (FORCE), a not-for-profit corporation, which collaborates with developers, regulators and researchers to study the interaction between tidal turbines and the Bay of Fundy environment. Four different designs of Tidal In Stream Energy Conversion (TISEC) devices are to be installed within a 1.6 km^2 crown lease area with mid-tide depths of approximately 40 to 60 m, and will be connected to shore via four individual undersea cables (Figure 1-1).

Nova Scotia Power Inc. (NSPI) installed the first prototype tidal generator on November 12, 2009. This unit was subsequently removed in December 2010, and three additional units by other developers are planned for installation within the same lease area in 2013 or 2014.

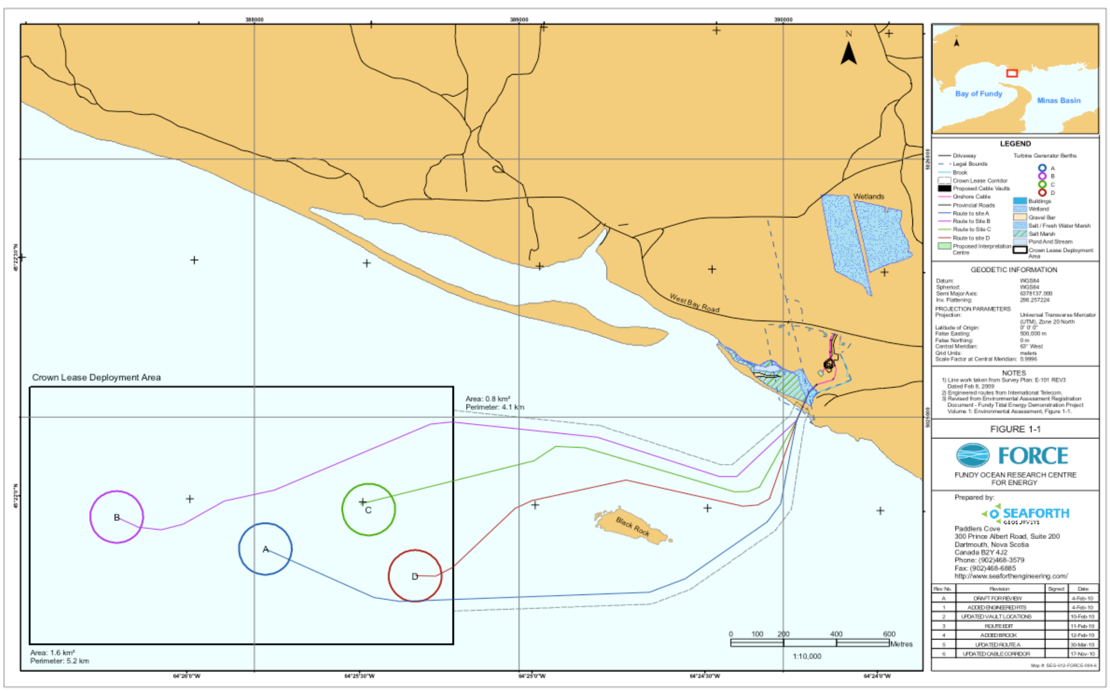


Figure 1-1: FORCE Lease Area, Develop Sites and Subsea Cable Routing as of November, 2010

1.1.1 Subsea Cable Design

The subsea cable proposed for installation within the lease area is nominally a 34.5 kV cable with three power cores cabled together with one fiber optic unit and one pilot cable. Overall cable dimension is designed to be 143 mm and weigh 39.2 kg/m in air (27 kg/m in water). A maximum continuous current of 300 amperes is anticipated. The cable will be relatively flexible with a bending radius of 2.8 m (static).

The three power cable design supports AC power generation, but the cable can also be used for DC power flow depending on the specifications of a particular developer. The overall cable is shielded and bonded, and when used as a balanced, three-phase power cable, no electrical field will exist external to the submarine cable as a result of current flow through the three power cores (conductors). A small magnetic field will be produced by the current flow through the power cores, but will exist only in close proximity to each submarine cable. If used as to conduct DC power, only two of the three cables will be used and a larger magnetic field will be generated.

The cable cannot be buried in offshore areas because of bedrock conditions, but the cable is planned to be buried at shore approaches to avoid ice damage. Thus, the cable will lay directly on the sea bottom over most of its length. As illustrated in Figure 1-2, between the two yellow layers, the cable is protected by two layers of heavy steel armouring.

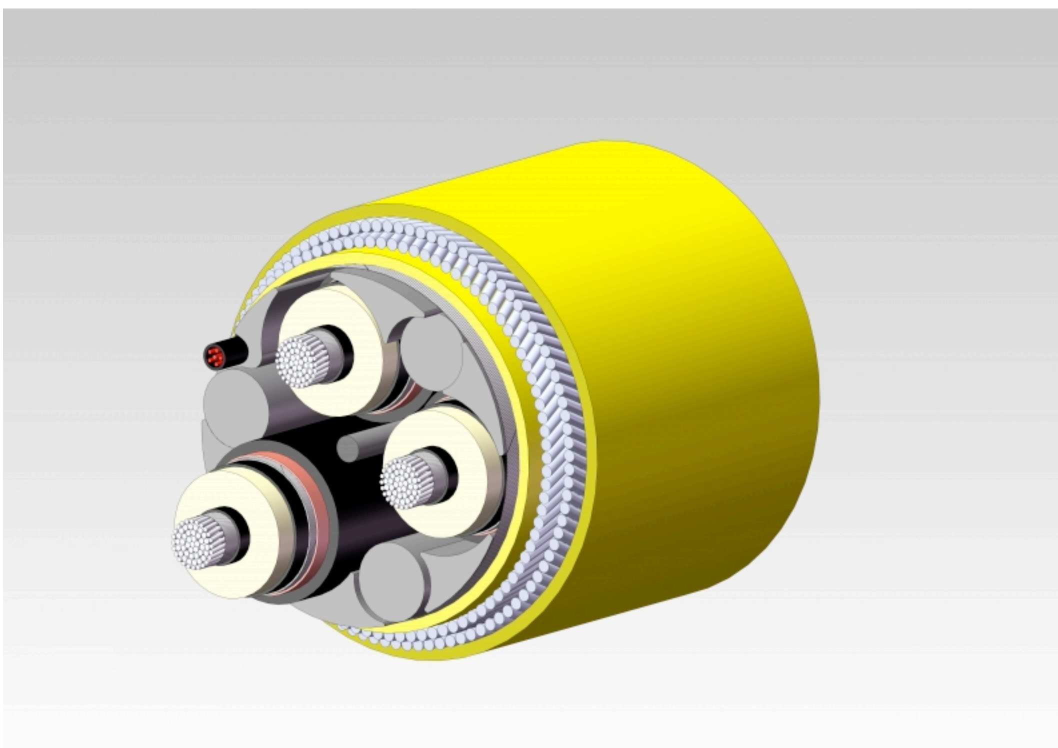


Figure 1-2: Typical Submarine Composite Cable Cross-section

In Figure 1-2, components include the three internal power cables, a fiber optic cable, and a pilot cable.

1.1.2 Environmental Background

The Upper Bay of Fundy is an important rearing, feeding and reproduction area for many fish and shellfish species. Commercial species of importance include lobster, herring, dogfish, and flounder. Recreational species include striped bass, shad and in very limited numbers salmon. Marine mammals are also occasionally seen in the area. Most of these animals move in and out of the bay seasonally and potentially migrate past tidal power generating units and interconnecting subsea power cables in Minas Channel. Animal behaviour, including migration, could be affected by exposure to electromagnetic fields (EMF) from generating units or subsea cables. Other species, like lobster, are resident for extended periods in the Minas Channel and could be exposed to EMF fields from subsea cables for longer periods of time. This report assesses the potential for impacts on animals from EMF associated with the FORCE demonstration tidal power project and identifies potential areas for research.

1.2 Terms of Reference

The purpose of this report was defined to:

Summarize available literature on the potential effects of EM fields for a broad audience as it related to subsea power cables (and the potential around TISEC devices) installed in the FORCE lease area within Minas Channel. FORCE may use this to prepare environmental assessments or to develop monitoring/mitigation plans.

The specific services to be performed included:

1. Review and describe natural and anthropogenic sources of EM fields;

2. Provide a measure of EM sensitivities for marine organisms, including use in migration and sensing organs in animals like Elasmobranchs, with an emphasis on potentially effected species in the Minas Passage of the Bay of Fundy;

3. Assess potential effects of EM activities on marine organisms, their habitat and commercial fisheries.

The report was to summarize background information necessary to provide a basic understanding of naturally-occurring electromagnetic fields, EM fields around power cables, EM technologies used in the marine environment, and the potential use of these fields by a variety of animal groups. Relevant marine species or groups were to be described with emphasis on elasmobranch fishes, the group potentially most affected by electromagnetic emissions. The report was also to describe differences in design of power systems and subsequent effects on subsea cabling systems and EM fields to reflect differences, such as AC and DC transmission.

Any existing information on EMF around TISEC devices and potential issues was also to be reviewed (background from FORCE developers to be requested by client).

Overall, the report was to provide a risk assessment and gap analysis on the impacts of EMF on marine organisms in the Minas Passage, particularly within the FORCE lease area.

1.3 Methodology

This report discusses concerns regarding the potential effects of electromagnetic fields (EMF) in the context of other potential environmental impacts associated with generation of electrical power from tidal energy in general and the local environment of Minas Channel in particular. Available literature on the potential effects of electromagnetic fields (EMF) is summarized for a broad audience, drawing upon a number of recent major reviews in the US and Europe. The most relevant information on the biological effects of EMF is recent, and on-going studies are being carried out to fill regional data gaps. The assessment of impacts can be partially based on field evaluations of the effects of EMF from the recent installations of offshore wind farms.

1.3.1 Information Sources

Two of the major assessments of EMF effects on marine organisms were completed in 2011. These include:

- Normandeau et al. (2011) – an assessment and gap analysis of the effects of EMF from subsea cables on marine organisms prepared for the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), U.S. Department of the Interior, Washington, DC; and,
- Buchanan et al. (2011) – an assessment of the effects of electromagnetic techniques used for oil & gas exploration & production on marine organisms prepared for the International Association of Geophysical Contractors, Houston, Texas.

In addition, a Scottish literature review on the effects of EMF and offshore noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel (Gill and Barlett 2010) provided a helpful summary of the role of EMF in behaviour and bionavigation. Gill et al. (2005) was also an invaluable summary of relevant literature carried out for the Collaborative Offshore Wind Energy Research into the Environment (COWRIE) in UK. In the US, the Oregon Wave Energy Trust funded a literature review of the effects of electromagnetic fields on marine species (Fisher and Slater 2010).

Our understanding of the biological effects of EMF are relatively recent. A major review of fish migration in 1960 stressed the possible importance of olfactory and celestial cues but did not mention a role for magnetism in migration (Hasler 1960). Most research and advances in understanding has occurred since 1970 (Marino and Becker 1977). Kirschvink et al. (2001) proposed that magnetoreception based on tiny crystals of single-domain magnetite (Fe_3O_4) has resulted in a high evolved, finely-tuned system used by a wide range of species from bacteria through higher vertebrates.

2 EM FIELDS – NATURAL AND ANTHROPOGENIC SOURCES

Electromagnetic fields (EMF) include electromagnetic energy across a wide frequency spectrum ranging from radio waves at the low frequency end (e.g., the AM radio band starts at 750 kHz) and gamma rays at the high frequency end where frequencies can range up to 10^{20} Hz.

EM fields can be considered vectors, that is, they are directional. A compass needle pointing in a north–south direction is a directional attribute of the earth's magnetic field. Vector fields from different sources can cancel as well as add to each other, depending on their relative orientation. So, for example, the magnetic field at a point near one conductor can be reduced or increased by placing another conductor nearby, depending upon the orientation of the field vectors.

EM fields, such as radio waves, were long felt to be benign but since the late 1970s questions have been raised about whether some types of fields produce adverse human health effects when exposure is frequent and in close proximity to sensitive body areas, such as in the use of cell phones.

2.1 Electromagnetic Fields

Electric and magnetic fields (EMF) exist wherever electric current flows - in power lines and cables, residential wiring and electrical appliances. The types of EMF fields generated by electrical generators and cables are classified as extremely low frequency (ELF) electric and magnetic fields. The principal sources of electromagnetic energy in the marine environment are static and also extremely low frequency fields (0-3000 Hz).

For energized power cables, the difference in electric potential (voltage) between the conductors creates an electric field. The strength of the electric field is usually expressed in units of volts per meter (V/m) or V/cm (where 1 V/cm = 0.01 V/m). Mean values of the electric field in the home are up to several tens of volts per metre.

Time-varying fields are referred to as alternating current (AC) fields. In North America, the fields from the power system oscillate 60 times per second, i.e., at a frequency of 60 Hz. In Europe and Asia the frequency of these fields is 50 Hz. Electricity flowing at a steady current in conductors is referred to as DC power. AC and DC fields are generated by organisms (i.e., biogenic), environmental sources, and man-made power systems.

Magnetic fields surround magnetic materials and electric currents. The magnitude of the magnetic field is usually expressed as magnetic flux density (or magnetic field) in units of gauss (G) or tesla (T). Publications in North America most often report magnetic flux density in G while in scientific publications and in Europe, T is more commonly used. The units are interconvertable by the expression 0.001 G = 1 milligauss (mG) = 0.1 microTesla (μT).

Underneath power lines, magnetic fields can be about 20 μT and electric fields can be several thousand volts per metre. However, average residential power-frequency magnetic fields in homes are much lower - about 0.07 μT in Europe and 0.11 μT in North America.

Both types of fields are strongest close to the source and diminish rapidly with distance. The electric and magnetic components travel together at the speed of light, but signal strength dissipates proportionally to r^2 (where r is the distance from the source). Unlike sound, EM fields behave similarly in water and air.

Electric fields arise from electric charges and are shielded by common materials, such as wood and metal. Conversely, magnetic fields arising from the motion of electric charges (i.e., a current) are not shielded by most common materials and pass through them with no attenuation.

2.2 Electrical Induction

According to Faraday's Law, an electrical current is generated, or "induced", in any conductor moving through a magnetic field. A current may also be induced in a stationary conductor if the surrounding magnetic field is in motion. Either way, electrical induction depends upon movement of electrical charges (Buchanan et al. 2011).

An electric current also creates a magnetic field in the space surrounding a conductor. A magnetic field expands around the conductor when current flow begins. When current flow stabilizes, the surrounding magnetic field stops expanding and becomes a static magnetic field. If the current is shut off, the magnetic field collapses. The polarity of the magnetic field depends upon the direction of current flow. When current flow reverses in a conductor, the polarity of the surrounding magnetic field reverses. When an AC current is applied the surrounding magnetic field continually expands and collapses at the frequency of the current (Buchanan et al. 2011).

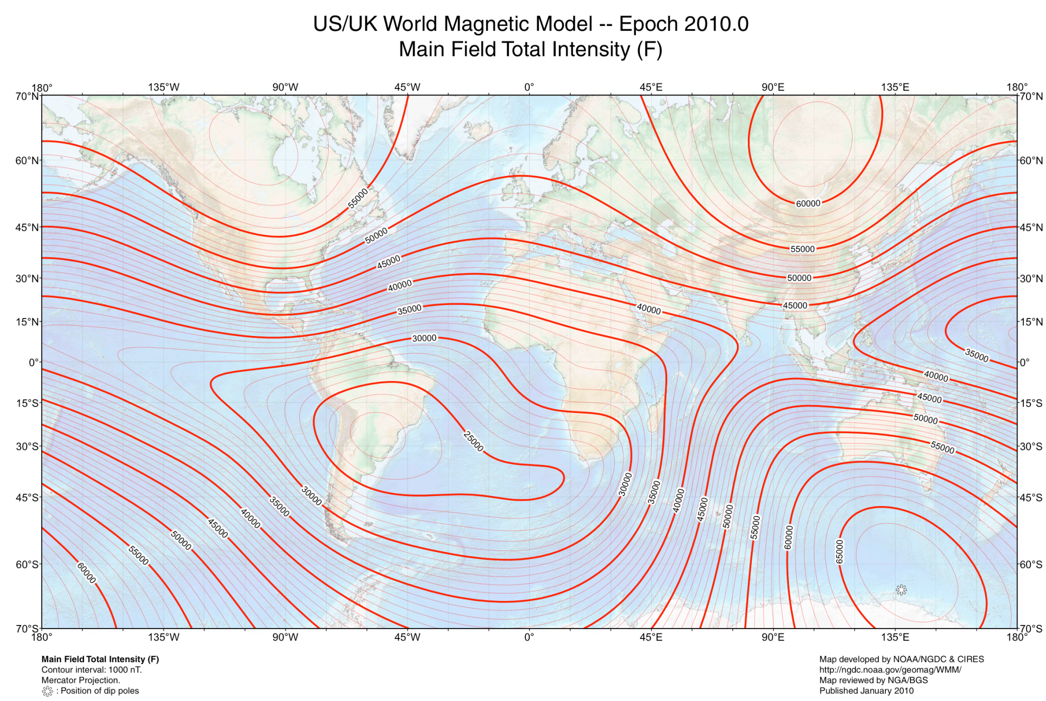
All animals are electrical conductors. Biological organisms continually generate internal voltage gradients and electrical currents including those associated with the nervous system, all types of biochemical reactions, reproductive processes, and membrane integrity. Electromagnetic fields of sufficient strength have the ability to induce microcurrents within an organism and possibly disrupt these normal electrical functions. However, the effects of ELF electromagnetic fields have limited direct effects in most animals, although some, such as elasmobranches are especially sensitive.

2.3 Geomagnetism

Understanding the biological effects of EM fields needs to consider how animals use geomagnetism. Many animals use the earth's magnetic field as an aid to navigation and anthropogenic EMF may interfere with an animal's ability to navigate.

The Earth's magnetic field has a geographic north-south pole the axis of which is 11 degrees off alignment from the Earth's rotational axis. Two principal features of the Earth's geomagnetic field are inclination and intensity. At any point on the Earth, magnetic field lines intersect the planet's surface at a specific angle (inclination) relative to the horizontal. Because the geomagnetic field is roughly symmetrical around the Earth's surface, lines of equal inclination exist as equivalent rough lines of latitude around the geomagnetic axis. Figure 2-1 illustrates the main magnetic field based on modeling by the NOAA National Geophysical Data Centre; contour lines of equal flux density are shown in nT (0.001 μT).

As Figure 2-1 illustrates, the intensity of the geomagnetic field varies. It is highest near the magnetic poles at 60 to 70 µT), is about 40 to 50 µT at mid latitudes, and decreases to about 30 µT at the geomagnetic equator (Buchanan et al. 2011; Normandeau et al. 2011).



Source: NOAA (2010)

Figure 2-1: Map of Total Intensity of Main Geomagnetic Field (Contour interval 1,000 nT)

Local magnetic deviations, distortions, and anomalies that vary irregularly over the Earth's surface have effects on this field. In northeastern North America, field intensity changes at about 3.4 nT/km (0.0034 µT/km), whereas the regional gradient across central Europe is 2.5 nT/km. The Earth's magnetic field is also subject to short- and long-term variations ranging from daily fluctuations in the order of 30 nT to extremes as high as about one µT.

Evidence that many animals use this global magnetic field for navigation is increasing (see Section 3.2).

2.4 EMF in Electrical Cables

Anthropogenic sources of EMFs such as those associated with subsea cables are becoming increasingly common in the marine environment.

EMFs emitted from cables (and devices) can be altered by using shielding material. In industry standard High Voltage DC (HVDC) cables, the materials are sufficient to contain the directly emitted electric (E) field, but the magnetic (B) field cannot be fully shielded regardless of the materials used[1]. Where there is water (tidal) movement or the movement of an organism (e.g., a swimming fish) through the B field, an induced electric field can also be generated; this separate electric field is referred to as an iE field.

This is not the only iE field that is associated with electricity production. In High Voltage AC (HVAC) cables, the B field produced rotates with the alternating movement of the electrical current through the three cores within the cable. This magnetic rotation is not contained within the cable shielding, hence it is emitted into the adjacent sea water and induces an E field. So for an AC cable, there is the directly emitted B field, similar to the DC cable and an induced E field associated with the electricity production. A swimming organism, and/or tidal movement, will also induce other E fields, similar to the DC cable.

Normally, the maximum magnitude of the EMF at any given point is inversely proportional to the distance from the power cable. In addition, Faber Maunsell & Metoc (2007) summarized the power cable features, which may influence the EMF fields produced:

- Utility connection voltage
- Sub-sea cable technology
- Distance from shore and use of substations
- Cable voltage
- Cable sizing
- Cable orientation and separation
- Cable burial
- Cable armouring

In the case of the FORCE demonstration project, the utility connection, cable technology, size, burial and armouring will be consistent between all cables. None of the cables will be buried, but the orientation and separation of the cables will vary and they will get closer together as they approach the shoreline. The voltage and the type of substation equipment required will also vary depending on the TISEC device to which the cable is connected.

[1] The subsea FORCE cable incorporates a metallic shield over the insulted core of two tinned copper tapes (Prysmain PowerLink, MV Submarine Composite Cable Design, Document PPL.-09-097-SES-TP(1).2). When the cable is operated as a balance, three-phase power cable, no electrical field will exist external to the cable, but a small magnetic field will be produced by the current flow.

Cables in close proximity to each other (e.g., where cable may be less than 10 m apart) may need site specific analysis due to the interaction of the EMF fields as a single system (Faber Maunsell and Metoc 2007). These variations make it impractical to predict the likely EMF precisely but magnitude of fields can be reasonably predicted in relation to the sensitivity of marine organisms and the probable kind of effects.

2.4.1 Example Cables

Recent reports and industry consultations indicate that widespread standardization is increasing in cabling strategies across the wind farm industry (Gill et al. 2005; Gill and Bartlett 2010). Developers commonly select three-core, AC 33 kV cables for intra-array connections and 132 kV (or possibly 245kV) cables for grid connection to land. Physically larger cables are capable of carrying greater currents.

Research modeling EMFs from cables with contrasting conductor sizes and current loads at the Kentish Flats offshore wind farm site has been undertaken by the University of Liverpool (Table 2-1). The simulations indicated that a higher current within a cable means that the maximum size of the EMF in the sea and seabed is increased. A previous study modeled a single 132 kV AC, three-core subsea cable carrying 350 A in each conductor (CMACS 2003). Analysis methods were broadly similar between these studies.

Table 2-1: EMF Output Parameters for Industry Standard Cables (buried 1.5 m in seabed)

Cable Parameter	Cable A	Cable B
Conductor size[2] (mm^2)	500	185
Maximum voltage (kV)	33	33
Maximum current (A)	530	265
Maximum B field in seabed (μT)	1.5	0.9
Maximum B field in sea (μT)	0.03	0.02
Maximum current density in seabed ($\mu A/m^2$)	40	25
Maximum current density in sea ($\mu A/m^2$)	10	6
Maximum iE field in seabed (μV/m)	40	25
Maximum iE field in sea (μV/m)	2.5	1.4

Source: Gill and Bartlett 2010, page 21, from Gill et al. 2005.

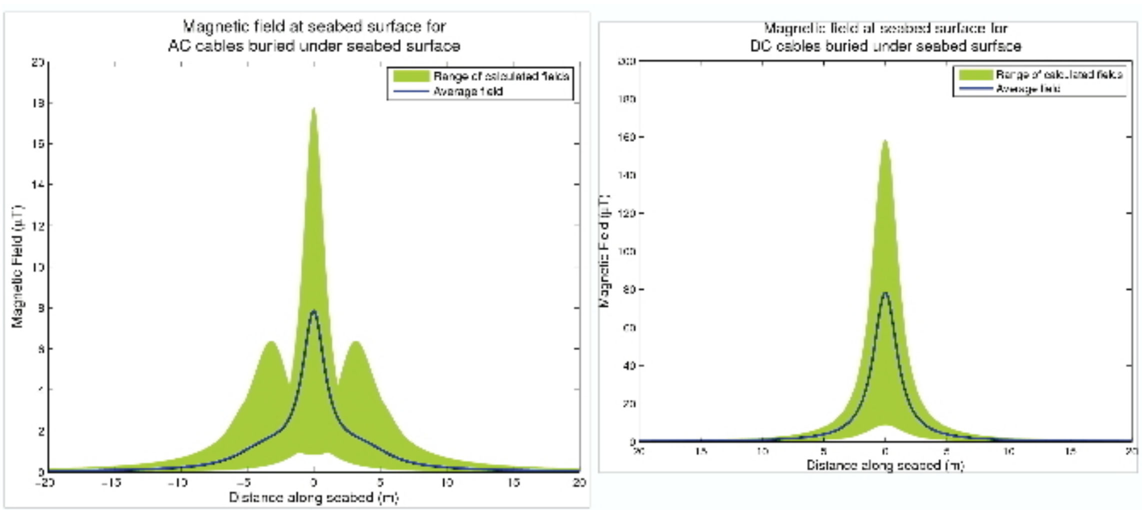
These models predicted that the B field on both the surface of a 33kV cable (i.e., within millimetres of the source) and the seabed directly above the cable was of the order of

[2] For comparison, the cable proposed for use within the FORCE lease area has a similar voltage and current capacity but a conductor diameter of 120 mm^2.

40 µA/m^2 or 1.5 µT. Assuming the seabed has a conductivity of 1 S/m, the resultant E field would have a likely strength of 40 µV/m. Furthermore, the E field in the seabed was modeled to dissipate rapidly to only 1 or 2 µV/m within a distance of approximately 10 m from the cable. The maximum magnitude of the modeled B field at the interface between the seabed and seawater was approximately 10 µ/m^2 or 0.33 µT. This means that the maximum E field strength induced in the seawater would be about 2.5 µV/m.

Normandeau et al. (2011) reviewed the design characteristics of 24 undersea cable projects and modeled expected magnetic fields from both AC and DC cables. These cables generally carried more power than anticipated in the case of FORCE and resulting levels of EM fields are higher. The comparison, however, provides relevant information on attenuation, differences associated with AC and DC power flow, and the effect of cables being routed in close proximity.

For eight of the ten AC cables modeled, the intensity of the field was roughly a direct function of the voltage (ranging from 33 to 345 kV) on the cables, although separation between the cables and burial depth also influenced field strength. The predicted magnetic field for these cables was strongest directly over the cables and decreased rapidly with vertical and horizontal distance from the cables. In projects where the current was delivered along two sets of cable that were separated by at least several meters, the magnetic field appeared as a bimodal peak (see Figure 2-1).



Source: Normandeau et al. (2011) page 2 and 3.

Figure 2-1: Variations in Magnetic Field from Twenty Four AC (left) and DC (right) Cables

Similar to AC cables, the strength of the magnetic field around DC cables was a function of voltage (ranging from 75 to 500 kV) and cable configuration. Proximity of the outflow and return cables to one another affected the field intensity because fields from opposing currents are subtractive. Figure 2-1 illustrates the range in magnetic field for the various cables modeled. The bimodal field shown for AC cables was partly a result of the separation distance between two cables. The magnetic field at the seabed for AC cables ranged up to 18 µT, whereas the magnetic field at the seabed for DC cables ranged up to 160 µT.

Table 2-2 summarizes the average magnetic fields over 18 AC and DC cables modeled assuming a one metre burial depth.

Table 2-2: Magnetic Fields (µT) Averaged from Different Subsea Cable Assuming a Burial Depth of 1 m

Type of Power	Sample Size	Distance Above the Seabed (m)	Horizontal Distance (0 m)	Horizontal Distance (10 m)
AC	10	0	7.85	0.22
		5	0.35	0.14
		10	0.13	0.08
DC	8	0	78.27	1.02
		5	2.73	0.75
		10	0.83	0.46

Source: Normandeau et al. (2011) page 4.

Unlike the magnetic field from AC cables, the magnetic field from DC cables can influence the intensity of the local geomagnetic field, as well as its inclination and declination. Thus the orientation of the cable relative to the geomagnetic field should be accounted for when considering the effects of DC cables (Normandeau et al. 2011). The DC magnetic field from cables running perpendicular to magnetic north will affect the intensity and inclination angle of the geomagnetic field, but not the declination angle. In contrast, the DC magnetic field from cables running parallel to magnetic north will affect the declination angle of the geomagnetic field as well as its intensity and inclination angle. As an example, the expected magnetic field from the proposed NaiKun 200 kV cable was modeled with and without the influence of the local geomagnetic field. In this case, the combined magnetic field would be about 30 percent lower than modeling that does not account for the geomagnetic field would suggest because the magnetic field from the proposed cable is oriented opposite to that of the geomagnetic field.

2.4.2 Example Induced Electric Fields

Movement through a magnetic field or the rotation of a magnetic field creates induced electric fields. This can occur from water current movement or from an organism swimming through the field or from the asymmetric rotation of the AC field within the industry standard 3-phase cable. The speed and orientation of the current or the organism relative to the field determine the strength of the induced field. A water current or organism moving parallel to the cable magnetic field will not generate an induced electric field. A water current or organism moving perpendicular to the cable magnetic field will generate the maximum induced electric field and that field strength will be a function of the current's or organism's speed, its exact orientation relative to the cable magnetic field, and the strength of the magnetic field (Normandeau et al. 2011).

The induced electric field strength generated by a 5 knot current running perpendicular to a DC cable is shown in Table 2-3. While magnetic fields from AC cables can also induce electric currents, the polarity of the induced current would reverse at the same frequency as that of the AC magnetic field, potentially reducing the likelihood that the induced field from AC rotation would be detectable by organisms.

Table 2-3: Modeled Average Induced Electric Field from DC Subsea Cables (V/m) Assuming a Burial Depth of 1 m

Distance Above the Seabed (m)	Horizontal Distance (0 m)	Horizontal Distance (4 m)	Horizontal Distance (10 m)
0	1.94×10^{-4}	3.15×10^{-5}	7.85×10^{-5}
5	1.75×10^{-5}	1.62×10^{-5}	1.39×10^{-5}
10	8.80×10^{-6}	8.52×10^{-6}	7.13×10^{-6}

Source: Normandeau et al. (2011) page 4.

It is important to note that maximum current will be flowing through the subsea cables when tidal current flows are highest. The orientation of the subsea cables with respect to the direction of high current flows will affect the interaction between the two sources of EMF. Turbulence may result in these effects varying to different degrees in different areas along the cable.

2.4.3 Summary

The Talisman Environmental Statement for the Beatrice Wind Farm Demonstrator Project off the Scottish coast (Talisman Energy 2005) provides a good summary of the anticipated magnitude of EMF from typical subsea Marine Renewable Energy (MRE) electrical cables:

> *In a typical industry-standard cable conducting 132kV and an AC current of 350A, the size of the B field produced would be 1.6μT (micro Tesla)(CMACS, 2003). This B field would be present only directly adjacent to the cable, and although it would be additive with the earth's natural geomagnetic field (approximately 50μT), it was shown that the magnitude of B field associated with the cable would fall to background levels within 20m of the cable. Furthermore, the modeling conducted by CMACS showed that the magnitude of a B field is not affected by any non-magnetic sediment in which a cable may be buried.*
>
> *In the same study CMACS showed that for a cable buried 1m below the seabed the magnitude of the iE field at the seabed would be approximately 91μV/m. Although the magnitude of the B field was not affected by the fact that the cable was buried, the iE field dissipated more quickly in sediment than in seawater. At a distance of approximately 8m from the cable the iE field in the sediment was only 1 or 2μV/m, whereas in seawater the iE field at this distance was still approximately 10μV/m.*

In the case of the subsea cables employed within the FORCE demonstration area, variations in EMF will occur as a result of difference in cable orientation to currents and to other cables in close proximity, as well as the electrical currents induced by the strong water currents. Review of EMF associated with other similar power cables indicates anticipated magnetic fields of approximately 1.5 µT and iE fields of 40 µV/m at the cable laying on the seafloor (Gill et al. 2005). Where cables are not buried or fields otherwise dampened when cables come together at substations, iE fields of several hundred µV/m could be reached (CMACS 2005).

2.5 EFM in TISEC devices

EMF may be associated with both subsea power cables and the TISEC devices themselves. Electrical generation will only occur approximately 60-65% when the tide provides sufficient current flow through the generator. EMF in the TISEC devices and cables will ramp up and down 4 times a day and only produce peak levels of power and thus EMF for relatively short period of time.

In the context of TISEC devices, there are some designs of devices that may emit EMF, such as those that use permanent magnet driven turbines. Hence the design of the device may need to be considered with regards to EMF. A 2010 Scottish review found no current information on EMF from wave or tidal devices (Gill and Bartlett 2010). That particular review took the view that any effects apparent will be similar to those associated with offshore wind subsea cable EMF.

3 Detection and Use of EMF by Organisms

This section describes the ability of marine animals to detect EMF, the sensitivity of various animal groups, and the roles of EMF in their behaviour. Some animals have specialized sensory organs that are used to detect EMF, while other species have less obvious mechanisms for detection. Many animals that migrate over large distances use EMF detection and the Earth's geomagnetic field for global positioning. Some animals, such as elasmobranchs, use EMF to locate prey in addition to navigation.

EM-sensitive marine organisms can detect both localised polar and larger-scale uniform EMFs; these are the predominant type of fields associated with subsea cables.

3.1 Electroreceptive Fishes (Elasmobranchs)

The best current understanding of the interaction between fish and the electric field component of the EMF comes from studies of elasmobranchs and their related species that are known to be electroreceptive (Gill and Bartlett 2010). Specific marine species where electrodetection thresholds have been studied include (Peters et al. 2007):

- the lesser spotted dogfish or catfish (*Scyliorhinus canicular*);
- the smooth (Atlantic) dogfish (*Mustelus canis*);

- the nurse shark (*Ginglymostoma cirratum*);
- the sandbar shark (*Carcharhinus plumbeus*);
- the hammerhead shark (*Sphyrna tiburo*),;
- the thornback skate (*Raja clavata*);
- other skates (*Raja sp*.);
- the round stingray (*Urobatis halleri*); and,
- common stingray *(Trigon pastinaca*).

In addition to elasmobranchs, Peters et al. (2007) reviewed studies of electrodetection in the spotted ratfish[3] (*Hydrolagus colliei*) and the sea lamprey (*Petromyzon marinus*).

3.1.1 Sensitivity

Elasmobranchs and agnathans possess ampullae of Lorenzini (AoL) that consist of a series of pores on the surface of the skin, leading to canals approximately 1 mm in diameter and up to 20 mm in length. These canals are filled with a conductive mucopolysaccharide jelly, which has a low resistance similar in magnitude to that of seawater (~20 S/cm). At the end of the canals are clusters of ampullae, which enable elasmobranchs to detect very weak voltage gradients (down to 0.5 μV/m) in the environment around them (Kalmijn, 1971; Murray, 1974).

An elasmobranch can locate the source of a polar E field based on differential voltage potential at the pores with reference to the internal potential of the body. In a uniform E field, the different length and orientation of the AoL canals allows an elasmobranch to compare voltage gradient change (Gill et al. 2005). The system tends to become more sensitive with growth because the distance between the pores becomes wider and the canal longer.

In most sharks the pores are evenly distributed between the dorsal and ventral surface of the head. In the dorso-ventrally flattened rays and skates the pore pattern is concentrated on the ventral surface particularly in association with the mouth. This permits accurate location of polar bioelectric fields of buried prey and ensures the mouth of the ray is brought close to the prey (Gill et al. 2005). Based upon the interaction of multiple electric fields, Haine et al. (2001) calculated that the distance at which the source potential dropped below the detection level of the shark and ray was 250 cm.

A review of cited behaviour thresholds to EMFs for marine organisms with ampullary or mucous gland electroreceptor organs was recently carried out by Peters et al. (2007) They summarized study methodologies and thresholds for freshwater and saltwater species, including various sharks, rays, ratfish, and sea lamprey. Thresholds for limnic species ranged

[3] Deep water chimeras, also a member of the class Chondrichthyes as are sharks and rays, are also electroreceptive (Buchanan et al. 2011). One of the best-known species is the spotted ratfish (*Hydrolagus colliei*) of the west coast of North America.

between 10^{-4} to 10^{-6} V/cm, while thresholds for marine species ranged between 10^{-8} to 10^{-6} V/cm (Peters et al. 2007). Reports by Haine et al. (2001) of threshold responses at about 4 nV/cm in the blacktip reef shark and whitetail stingray are at the more sensitive end of this spectrum.

3.1.2 Navigation in Elasmobranchs

DC voltage gradients resulting from currents in the Atlantic typically range from 0.05 to 0.5 10µV/cm, and the voltage gradient associated with the strong tidal currents in the English Channel reach 0.25 10µV/cm (as cited in Kalmijn 1971). These voltages are detectable by animals with AoL, but navigation by these signals directly would likely be impossible due to confounding factors, such as changes with depth.

However, elasmobranchs can also sense voltage gradients in their own body that inductively generates as the fish swims through the Earth's geomagnetic field. The horizontal velocity of the animal interacts with the horizontal component of the geomagnetic field producing a vertical electrical field. Induced voltage is a function of the speed at which the conductor moves through a magnetic field and the angle that it cuts the lines of magnetic flux. A sinusoidal path through the water would provide a stream of stimuli providing potential 360° navigation.

Thus, the same electroreceptive organs can be used for food detection and navigation, but using different mechanisms.

3.2 General Orientation and Navigation Models

Prior to the 1970s the existence of magnetoreception was difficult to reproduce and virtually all laboratory-based attempts to train animals to discriminate magnetic cues had failed (Kirschvink et al. 2001). Hasler (1960) in a state of the art review of fish migration guidance reported that solid evidence had been obtained for the role of visual (primarily sun position) and olfactory cues in migration guidance. Today substantial evidence has been obtained to support the use of EMF in orientation and navigation in a wide range of organisms, with demonstrated magnetoreception in organisms from bacteria through to higher vertebrates (Kirschvink et al. 2001). The specific mechanism used for magnetoreception in most animals remains unclear.

Organisms that respond to magnetic fields can be categorised into two groups:

- species that have a response based on magnetite or chemical mediated detection.
- those that respond to an induced electric (iE) field.

Some species, such as American eel, have significant magnetically sensitive material (i.e., magnetite) within their skeletal structure (Berge 1979). This mechanism of magnetic field detection occurs in a relatively large variety of organisms (such as birds, insects, turtles, fish and cetaceans; Kirshvink 1997) and is now commonly thought to be used for direction finding using the Earth's geomagnetic field.

Responses to iE fields are generally assumed to be a mode of navigation and may either be passive or active on the part of the animal. In active navigation the organism generates its own EMF to interact with the horizontal component of the Earth's magnetic field (Paulin 1995). Passive detection is derived from the interaction of the tide or wind driven currents and the vertical component of the Earth's geomagnetic field.

3.2.1 Magnetoreception

The most widely documented model for explaining magnetic orientation behavior in animals is compass orientation. Compass orientation requires the ability to detect some parameter (e.g., total field intensity, polarity, or inclination angle) of the Earth's magnetic field. For a magnetoreceptor to be functional it needs to be sufficiently sensitive to accurately measure small differences (as small as 2–3 nT, corresponding to less than 1 km in geomagnetic field strength). Two main functional modes of the magnetic compass have been identified from bird studies (Buchanan et al. 2011).

.1 Magnetite-based Mechanisms

Permanently magnetized magnetite crystals have been identified in a number of widely diverse taxa including insects, chitons, crustaceans, amphibians, reptiles, fish, birds, and mammals (Wiltschko and Wiltschko 1995).

Early studies demonstrated that the rotational energy of magnetite in the typical magnetotactic bacteria exceeded thermal background energy by 20 fold, thereby allowing for stable magnetic alignment. Later studies discovered that within these microscopic organisms, magnetite crystals actually form long chains such that their magnetic moments sum linearly (Kirschvink 1997). This additive effect of the magnetite chains provides sufficient stimuli to overcome randomizing effects.

.2 Radical Pairs Model

Schulten (1982) proposed a model in which a radical-pair mechanism can act as a sensor for magnetic compass orientation. Magnetically sensitive reactions almost always involve radicals—molecules that have an odd number of electrons and consequently an unpaired electron spin. The direction of spin can be affected by outside magnetic fields, and the relative change between a pair of radicals can provide a stimulus. The radical pair model forwarded by Ritz et al. (2000) suggested that magneto-reception in birds was mediated by radical pair processes in specialized photo-pigments of the eye.

.3 Bird Migration

Bird migration is reviewed because much of the current understanding of the use of geomagnetism came from research with birds. Magnetic orientation was first demonstrated in the European robin in 1966 (Wiltschko and Wiltschko 1995). With the advent of the magnetite hypothesis, and later the radial pairs hypothesis, researchers first considered them to be mutually exclusive mechanisms. Subsequent tests with passerine migrants yielded evidence that supported both hypotheses. Birds use a suite of navigational systems that may work independently of or in concert with magnetoreceptors: celestial information including stars, sun azimuth position, olfaction, visual landmarks over short distances, and the associated skylight polarization at sunrise and sunset to determine and maintain migratory direction (Buchanan et al. 2011).

Study of homing pigeons has revealed that multiple navigation systems can exist and involve a hierarchy of preferences. Homing pigeons can use elements of a magnetic compass, sun compass and a star compass with different systems being dominant in various situations, and providing feedback to the accuracy of other systems (Buchanan et al. 2011). The different mechanisms that may provide stimuli for navigation in birds and the complex ways different navigation systems can interact may be present in marine organisms as well; research in this area is in its infancy.

4 RELEVANT MARINE ANIMALS IN MINAS CHANNEL

This section reviews the information available on EMF effects on species groups and specific marine animals that are known to occur within the Minas Channel. This information is used to identify particularly sensitive animals, evaluate the types of impacts that may occur, and assess the overall vulnerability of these animals to adverse effects.

4.1 Invertebrates

Invertebrates that have so far been found to be EMF sensitive have sensitivity thresholds above the modeled level of induced electric fields from undersea cables. Recent investigation of the magnetic sense in molluscs has focused on the nudibranch, *Tritonia diomedea*; it was shown that this marine species could detect Earth-strength magnetic fields (Normandeau et al., 2011, pages 110-112). Woodruff et al. (2011) found that Dungeness crab did not indicate any response to EMF levels of 1-3 mT when tested using behavioral end points including detection, detection of a food odor, and avoidance/attraction to EMF. Normandeau et al. (2011) concluded that while some marine invertebrates could detect Earth-strength magnetic fields, the sensitivity threshold was above those likely encountered from subsea cables.

The western Atlantic spiny lobster (*Panulirus argus*) undertakes mass migrations in which thousands of lobsters walk across the seafloor in head-to-tail procession. Laboratory and field behavioral studies have demonstrated that individuals can detect Earth-strength shifts in surrounding magnetic fields and can orient in the field along specific geomagnetic compass bearings (Buchanan et al. 2011). Boles and Lohmann (2003) concluded that *P. argus* is capable of true navigation based on a magnetic map sense (in Normandeau et al., 2011).

However, European lobster (*Homarus vulgaris*), which is genetically quite similar to American lobster[4], showed no neural response to magnetic fields at 500 Hz 0.2 T or 50 Hz 0.8 T measured at an isolated gigantic axon (Ueno et al. 1986). This level of exposure represents a field strength about five orders of magnitude higher than expected directly over an "average" buried power cable (Normandeau et al. 2011). Laboratory behaviour response tests to determine EMF detection thresholds using American lobster (*Homarus americanus*) are planned at the Pacific Northwest Laboratory in 2012.

EMF in relation to invertebrates may be important in terms of detection as prey by more EMF sensitive predators, such as skates and rays. Angular swimming movements generate AC stimuli, which act like the noise in a stochastic resonance system, and result in a detection threshold in marine organisms such as skates and rays as low as 1 nV/cm (Peters et al. 2007). The electric fields generated by invertebrates were found to be size dependent with large specimens giving off stronger fields (Buchanan et al. 2011).

4.2 Fishes

Most teleosts (the largest group of bony fishes) do not have a highly advanced electrosensory system. A Scottish assessment concluded that most teleosts do not react to electric fields of less than 6V/m (Faber Maunsell & Metoc 2007), orders of magnitude greater than levels produced by the type of power cables being considered here. However, chondrichthyes (sharks, skates, rays and ratfish), agnathans (sturgeon and lampreys), many salmonids (salmon and trout), and eels are much more sensitive (Normandeau et al. 2011). Information on these sensitive species is summarized below in relation to species frequenting Minas Channel, including salmonids, eels, sturgeon, and sharks and rays.

4.2.1 Salmonids

A detailed literature review by Scottish researchers came to the following conclusions (Gill and Bartlett 2010). Atlantic salmon (*Salmo salar*) and American eel (*Anguilla anguilla*) can use the earth's magnetic field for orientation and direction finding during migrations. Brown trout (*Salmo trutta*) juveniles and close relatives respond to both the earth's magnetic field and artificial magnetic fields.

The most comprehensive study of the magnetic sense in any vertebrate to date showed that rainbow trout (*Oncorhynchus myskiss*) have a behavioural and electrophysiological response to magnetic fields based on magnetite-magnetoreceptor cells in the nose of the fish (Walker et al. 1997).

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[4] American and European lobster are genetically much more similar to each other than to spiny lobster. The lack of EMF sensitivity in European lobster strongly suggests it does not exist in American lobster either, however, behavioural response tests may be more appropriate than the methods used by Ueno et al. (1986).

Lohmann et al. (2008) present the hypothesis that some populations of sockeye salmon (*Oncorhynchus nerka*) that undergo long distance migrations imprint on the magnetic signature of their birth place, but that non-magnetic local cues are more important in pinpointing spawning areas. It is uncertain whether salmon could detect the time-varying magnetic field from an AC cable. The rate of change of the field may be too rapid for a magnetite-based mechanism to respond to weak fields. Modeling suggested a salmon would need to be within several meters of a cable to detect a 60-Hz magnetic field from a cable carrying 1,000 Amps AC. However, a similar cable carrying DC current could likely be detected over a larger distance, possibly 20 m (Normandeau et al. 2011).

4.2.2 Eels

European eel (*Anguilla anguilla*) has magnetic material in the skull, vertebral column and lateral line (Moore and Riley 2009), and the lateral line of European eel shows an electrophysiological response to changes in EMF. More recent work has shown that European eels have a strong direction-finding component in swimming and orienting themselves relative to magnetic north (Moore and Riley 2009). However, the American eel (*A. rostrata*) demonstrated no physiological or behavioural responses to EMFs at ten times more than geomagnetic levels in controlled laboratory experiments (Richardson et al. 1976).

Research carried out in controlled-condition swimming tunnels in the laboratory using European eel has shown they can respond to changes in an EMF over and above the ambient background levels (Tesch et al. 1992). The speed and timing of migration of European eels were shown to change in the short-term (tens of minutes) with exposure to AC electric subsea cables in the Baltic Sea, even though overall direction remained unaffected (Öhman et al. 2007).

The reproduction strategy of *Anguilla sp.* with elvers returning to natal freshwater streams from spawning in the Sargasso Sea requires some ability to navigate and use of the Earth's magnetic field is the most likely mechanism. This ability could be present in elvers and not apparent in older eels.

4.2.3 Sharks, Skates and Rays

In the laboratory, both avoidance and attraction responses have been observed on elasmobranchs. For example, in a European species of dogfish[5] avoidance was observed at high power electrical fields whereas the fish was attracted to low power electric fields comparable to potential live prey (Gill and Taylor 2001).

The only documented example of an emission from a subsea cable having an effect on marine fish in the wild was a study by Marra (1989), who showed evidence of shark bites on submarine optical telecommunications cables. The cables were associated with two forms of

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[5] Spiny dogfish (*Squalus acanthias*) are concentrated in the Bay of Fundy and are discussed in more detail in Section 5.4.4.

induced electric fields: a 50 Hz E field of 6.3 μV/m at 1 m which was caused by the power feed to the cable, and another of 1 μV/m at 0.1 m resulting from the sharks crossing the B field emitted by the cable. Follow up laboratory behavioural tests and trials carried out at sea were inconclusive in determining cause and effect for this species.

Electrodetection in elasmobranches is well accepted for detection of prey. Peters et al. (2007) document sensitivity thresholds of various elasmobranches, but evidence of the use of the Earth's magnetic field for navigation remains mostly theoretical.

4.2.4 Sturgeon

Similar to the behavior seen during studies on dogfish, Basov (1999) found that sterlet (*A. ruthenus*) and Russian sturgeon (*A. gueldenstaedrii*) were attracted or repelled at different levels of E-fields (1 to 50 Hz, 0.2 to 3.0 µV/cm).

The only example found of the effect of EMF on a migrating fish (Gill and Bartlett 2010) was through observations of sturgeon (*Acipenser gueldenstaedtii*) moving away from high voltage (100 kV) overhead power cables (Poddubny 1967). The fish swam slowly in proximity to the cables and accelerated when past them. Whilst these cables were not in the water, overhead cables are not well shielded. This means that the EMFs that they emit will have most probably entered the water where sections of cable crossed near to the surface. It was stated that the behavioural responses were a result of the effect of the EMF penetrating the shallow waters at this point in the lake (Poddubny 1967). Sturgeon (*Acipenser sp.*) are generally considered EMF sensitive in the literature, but thresholds of detection have not been determined.

4.2.5 Fish Summary

Studies of potential EMF effects on fish were conducted at a Danish windfarm. One bi-directional and two quadri- directional pound nets were placed on each side of the subsea power cable, making it possible to detect the migration direction of the fish and estimate the number of fish crossing the cable (Dong et al. 2006). Based on data from 2003 and 2004, effects on migration of Baltic herring, common eel, Atlantic cod and flounder were found to be significant but no cause and effect relationship was determined. No field measurements of EMF were undertaken and these results were considered preliminary.

Laboratory research on EMF effects on coho salmon (*Oncorhynchus kisutch*) and two species of halibut (*Hippoglossus hippoglossus* and *Paralichthys californicus*) was conducted at the Pacific Northwest National Laboratory in Washington State in 2010 and 2011 (Woodruff et al. 2011). Researchers concluded that there was no reason to believe that EMFs associated with MHK[6] devices or cables will result in adverse impacts at individual, community, or population levels for the species evaluated in this study.

In relation to EMF sensitive species, the detection limit of freshwater (limnic) vertebrates with ampullary organs is 1 μV/cm, and of marine fish is 20 nV/cm. Angular movements are essential for stimulation of the ampullary system in uniform DC fields. Angular movements in the geomagnetic field also generate induction voltages, which exceed the 20 nV/cm limit in marine fish. As a result, marine electrosensitive fish are sensitive to motion in the geomagnetic field, whereas limnic fish are not. The difference between freshwater and marine thresholds corresponds roughly with the different conductivities of fresh and seawater suggesting that it is the displacement of electrical charges that is the effective stimulus of the receptor cells (Peters et al. 2007).

Fish in the benthic space are exposed to stronger electric stimuli than fish in the pelagic space. Benthic fish scan the orientation plane for the maximum potential difference with their raster of electroreceptor organs to locate bioelectric prey. This behaviour explains why the detection threshold does not depend on fish size. Pelagic marine fish are mainly exposed to electric fields caused by movements in the geomagnetic field. The straight orientation courses found in certain shark species might indicate that the electric sense functions as a simple bisensor system. Symmetrical stimulation of the sensory raster would provide an easy way to keep a straight course with respect to a far-field stimulus. The same neural mechanism would be effective in the location of a bioelectric prey generating a nearfield stimulus (Peters et al. 2007).

A recent experimental study showed that in semi-realistic circumstances benthic elasmobranchs are able to respond to the EMF emitted by subsea cables (Gill et al. 2009). This experimental study was the first of its kind in relation to any EM-sensitive species and power subsea cables. Responses by the fish were variable and dependent on the individual fish and the species. Evidence of whether the response is biologically significant for populations and communities within the coastal ecosystem remains unclear.

4.3 Sea Turtles

Sea turtles are uncommon in the upper Bay of Fundy but could occur[7]. Studies have shown that juvenile loggerheads and leatherbacks can detect changes in their surrounding geomagnetic field, but there is little evidence that adult sea turtles use geomagnetics for primary navigation cues (Buchanan et al. 2011).

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[6] MHK refers to marine and hydrokinetic energy devices, which would include tidal energy systems as considered in this report.

[7] In 2009, a Kemp's Ridley sea turtle was found on a beach at Morden, Nova Scotia, not far from the entrance to Minas Channel (CCWHC 2009)

4.4 Marine Mammals

Evidence of geomagnetic detection and orientation in cetaceans is limited and mostly theoretical (Buchanan et al. 2011). However, comparison of mass stranding locations and times to geomagnetic anomalies suggests marine mammals use geomagnetic cues for navigation.

Klinowska (1985) analyzed 3,000 cetacean strandings that occurred over a 70- year period in the United Kingdom and found that live strandings tended to occur in areas where geomagnetic contour lines ran perpendicular to, or cut across, the coastline, potentially funneling animals unfamiliar with the coastal area into shore. Further research indicated that live strandings were correlated with geomagnetic disturbances and that strandings generally occurred 1-2 days after major geomagnetic storms (Klinowska 1986). Total intensity variations of as little as 50 nT (0.1% of the total field) were sufficient to influence stranding location (Kirschvink et al. 1986).

The static fields from DC cables are unlikely to harm marine mammals, however, the time-varying EMF (mainly the magnetic fields) associated with AC cables may be of concern (Michel et al. 2007).

4.5 Seabirds

Although geomagnetic navigation has been demonstrated in several species of terrestrial birds, few seabirds have been studied and with conflicting results (Buchanan et al. 2011).

5 POTENTIAL IMPACTS

5.1 Overview of the Effects of Tidal Power Generation

Frid et al. (2012) reviewed the types of environmental impacts associated with offshore tidal stream energy and wave energy collectors. These types of devices have only been deployed on an experimental scale and thus the authors point out that prediction of their impacts is based on limited empirical data. More empirical data are available on the effects of subsea power cables but this initial overview focuses on tidal power systems to provide context to the subsequent discussion.

Tidal energy power generation devices will increase turbulence in the water column, which in turn will alter mixing properties, sediment transport and, potentially, wave properties. In both the near field and far field, tidal amplitude, current velocities, and water exchange will be reduced in a region proportional to the number of units installed, potentially altering hydrography and sediment transport. Benthic habitat is affected by altering water flows, wave structures, or substrate composition and sediment dynamics. Large bottom structures may result in localized scour and/or deposition. Levels of direct mortality of organisms passing through turbines could be high and disorientation might reduce species viability.

However, these devices are unlikely to affect reproduction and recruitment processes unless multiple devices are very closely packed (Frid et al. 2012).

Potential impacts from tidal and wave energy devices include effects from noise and electromagnetic fields (Fried et al. 2012). If installation involves pile driving, explosive or seismic work, even intermittent, short duration activities may affect cetaceans, but noise during operation of any of these installations is unlikely to be ecologically significant. In terms of EMF, the survival and reproduction of several benthic organisms are not affected by long-term exposure to static magnetic fields (Bochert and Zettler 2004). Effects on fish are restricted to those species that are particularly sensitive, which include sharks, skates, sturgeon and eels. Some species of shark have been shown to respond to localized magnetic fields of 25-199 μT (Meyer et al. 2004). Migrating European eels appeared to detect EMF from an unburied cable but their migration was not disrupted (Westerberg and Lagenfelt 2008). Responses tend to be localized and of short duration.

5.2 Impacts from Tidal Power in Minas Channel

Evaluation of the impacts of EMF associated with tidal power development must consider the low frequency of the emissions, the rapid attenuation of the field from the source, and the other environmental factors of influence, especially the high currents and frequent turbidity of the waters. The magnitude of EMF emissions also varies with the tidal cycle and power generation, remaining at peak levels for relatively short periods of time. In addition, the high-current environment of the area limits the number of species likely to be exposed to any effects.

This section reviews the general thresholds of sensitivity of marine organisms found in the area in relation to the potential levels of EMF emissions from subsea cables and TISEC devices. Since the cable is relatively small and trenching is only being conducted at the shoreline, habitat impacts from cable construction are likely minimal. Thus, EMF emissions associated with the subsea cable may be a primary concern in relation to potential impacts associated with operations.

Potential impacts associated with TISEC devices include physical injury, pressure injury and noise, in addition to possible EMF emissions. The other potential sources of impact appear likely greater than those associated with EMF because of the location of the generators in the middle of the water column where survey evidence says a relatively lower percent of fish and other organisms pass in and out of the channel. Most evaluations suggest that EMF impacts are likely greater on the bottom where organisms are likely more exposed for longer periods of time.

5.3 Evaluating Severity of Exposures

The summary of typical emissions of EMF from subsea power cables provided by Frid et al. (2012) is consistent with the review in this study. The power cables that are the most similar to those proposed for the FORCE demonstration area, for which there are estimates of EMF emissions, are those from Gill and Barlett (2010) referenced in Table 2-1. The maximum iE field in the seabed was estimated to be 40 µV/m and the maximum B field was 1.5 µT. These values are most likely realistic estimates of EMF associated with the FORCE subsea cables. Burial could reduce the magnitude of potential emissions by 10 or 20%, but as mentioned previously, burial is not possible given the bedrock in the area.

EMF emissions in a typical high-power, industry-standard cable are considerably greater than the values cited above. The higher emissions associated with much larger power cables provide an upper boundary limit to possible EMF from FORCE facilities. Even with much higher power flows, studies have reported that EMF would fall to background levels (ca. 50 µT) within 20 m of the cable (CMACS, 2003). Marra (1989) showed that induced iE fields of up to 91 µV/m were emitted from cables buried to 1 m in sediment. Cables carrying high voltage DC cables may produce fields of up to 5 µT at up to 60 m (Westerberg and Begout-Anras 2000). Biological effects have not been documented at even these larger power flows.

5.3.1 Natural Ranges of Exposure

Overall, most aquatic animals are surrounded by an electric field the strength and polarity of which is determined by a number of factors including their activity level. Electric fields are induced by the movement of charged objects (e.g., currents or organisms) through a magnetic field, and bioelectric fields are produced internally by organisms. The beating of a heart, nerve impulses within an organism, and the uneven distribution of charged ions are examples of AC and DC electric fields of biological origin. Particularly strong fields emanate from wounded crustaceans (Kalmijn 1971).

High background values of electric fields in the oceans were reported to range from about 0.5 µV/cm to 0.75 µV/cm measured over muddy seabeds; during geomagnetic storms EMF may reach 1.25 µV/cm (Normandeau et al. 2011). Specific background measurements are not available, but similar high levels of background EMF would be expected in Minas Channel during peak tidal flows.

A geomagnetic storm is a disturbance in the Earth's magnetic field caused by solar activity. These storms disturb the earth's magnetic field and would necessarily affect an animal's ability to navigate by a biological magnetic compass. Minor geomagnetic storms of 70-120 nT intensity would occur between 9.7 and 19.3 times per year; moderate storms (120-200 nT) from 3.4 to 6.8 times; strong storms (200-330 nT) from 1.1 to 2.3; and severe storms (330-500 nT) every one to two years (Buchanan et al. 2011).

5.3.2 Detection and Background Levels

Table 5-1 provides a summary of background levels of EMF, detection limits for sensitive and typical marine species, and an indication of the range of natural variations in EMF based as a summary of the information presented thus far. Marine organisms have detection thresholds as low as 1 nV/cm (0.001 µV/cm), which is about a million times less than what is considered potentially dangerous in long-term exposure for humans (WHO 2007)[8]. Sensitive marine species will unquestionably be able to detect EMF near the cable at times, but the field strength attenuates rapidly with distance according to the inverse square law. The ability to detect the cable will depend on numerous conditions including tidal currents, power flow through the cable, orientation of the cable to flows and other cables.

Table 5-1: Comparison of EMF Background and Detection Levels in the Marine Environment

Environmental Parameter	Induced Electrical Field	Magnetic Field
Likely EMF at cable (Table 2-1)	40 μV/m	1.5 μT
Natural background levels		30 to 70 μT 2.5 to 3.4 nT/km
High natural variations	125 μV/m	70 to 500 nT in geomagnetic storms
Detection limits for sensitive marine species	0.1 μV/m	2 to 3 nT (postulated)
Detection limits for typical bony fishes (Teleosts)	> 6V/m	

5.4 Priority Species

The available information suggests that most organisms will remain unaffected by EMF from TISEC devices or subsea cables. Thus, emphasis has been placed on identifying priority species that are the most likely to be affected. The identification of priority species for assessment of risks considers the sensitivity of the species, the likelihood of exposure depending on behaviour patterns and habitat preferences, and the conservation status of the species or population (Buchanan et al. 2011; Normandeau et al. 2011).

Recent assessments of the effects of EMF on marine organisms have focused on subsea cables, although Buchanan et al. (2011) examined potential effects of electromagnetic survey techniques used in oil and gas exploration and thus looked more broadly at the entire water column. Available evidence suggests that EMF from subsea cables connecting TISEC devices have a higher potential for impact on marine organisms than midwater sources of EMF because benthic organisms near the cable are likely exposed for longer periods of time and may be largely constrained in terms of location by habit conditions.

A key factor in the selection of priority species in the Minas Channel is the physical environment. The extreme currents, rough and variable bottom, and turbidity have a high probability of affecting species behaviour in response to stimuli, including EMF. Thus, the

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[8] The threshold for detection of a stimulus such as EMF does not imply an impact occurs at this field strength.

unique conditions of the Minas Channel need to be considered when applying information from other areas.

In this assessment the following factors have been used to select priority species for assessment:

- Intermittent nature of EMF emissions associated with TISECs and subsea cables over tidal cycles;
- Potential sensitivity of the species or species group to EMF;
- Potential exposure (general short duration in high current) to EMF from subsea cables or TISEC devices;
- Importance of the species commercially, recreationally and ecologically; and,
- Conservation Status of the species or population.

Most species passing through Minas Channel are pelagic, such as herring (*Clupea harengus*), mackerel (*Scomber scombrus*), shad (*Alosa sapidissima*), gaspereau (*Alosa pseudoharengus*), striped bass (*Morone saxatilis*) or juveniles of species including gadoids (cod-like fishes). Most of these species[9] are not known to be sensitive to EMF and are unlikely to be exposed to EMF except for brief periods as they pass near TISEC generators. Fish migration surveys also found that relatively lower densities of fish were found at the mid-water depths where the TISEC generators will be located (CEF 2011). The potential for changes in behaviour as a result of the minimal exposure to EMF is considered inconsequential in comparison to the impact of other environmental factors, such as currents. The demonstration nature of the FORCE project further lessens these concerns because long-term exposure is not an issue.

In contrast, exposure of demersal species is much greater because they are generally less mobile and thus in closer, prolonged exposure to the source. Benthic species known to be especially sensitive to EMF include spiny dogfish and Atlantic sturgeon. American lobster may also be sensitive although information is inconclusive. In addition, some species that frequent the area and use Minas Channel as a migration path are known to be especially sensitive to EMF. These species include Atlantic salmon and American eel.

Based on these factors, the species considered of highest priority are:

- American lobster (*Homarus americanus*),
- Atlantic salmon (*Salmo salar*),
- American eel (*Anguilla rostrata*),
- Spiny dogfish (*Squalus acanthias*), and
- Atlantic sturgeon (*Acipenser oxyrinchus*).

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[9] Some studies have suggested possible effects of EMF on cod and herring (e.g., Dong et al. 2006), but the sensitivity of these species is considered relatively low in comparison to salmonids, eels, sturgeon, and sharks and rays.

The sensitivity of these species to EMF is distinctly higher than other species typically found in the Minas Channel and their potential exposure is also potentially higher. Concern for some other species of interest, such as marine mammals, is comparatively low because they are uncommon in the high currents of Minas Channel. The low exposure levels and the brief period of potential exposure suggest that marine mammals are not a priority concern in relation to EMF in Minas Channel.

5.4.1 American Lobster

Normandeau et al. (2011) completed a detailed assessment of potential effects of subsea power cables, both AC and DC, on spiny lobster[10]. Their analysis suggested that magnetic fields from AC power flow would not likely be detected by lobster (assuming a magnetite-based detection mechanism) at typical power levels up to a 60-Hz magnetic field from a cable carrying 1,000 A beyond several metres. The magnetic field from a DC cable could be more easily detected by spiny lobster, but effects would still be limited to close to the cable. It should be noted, however, that total DC field is highly specific to project configurations – a maximum effect range of 20 metres on either side of the centerline of the SwePol link was referenced (Normandeau et al. 2011). As stated previously, American lobster appear less sensitive to magnetic fields than spiny lobster, if sensitive at all. However, the data on EMF sensitivity for American lobster are limited and lobster's high potential for exposure to the subsea cable networks as well as their major commercial importance in the area, suggests they must be viewed as a high priority species.

5.4.2 Atlantic salmon

The inner Bay of Fundy population of Atlantic salmon is classified as *Endangered* under *Canada's Species at Risk Act* (*SARA*). A growing body of evidence suggests that the rapid decline in numbers of Inner Bay of Fundy Atlantic salmon is due to low marine survival rather than an inability to spawn and live successfully in freshwater rivers and streams. The reasons for the salmon's low marine-survival rates are unknown, but may be due to ecological changes in the Bay of Fundy. Tidal barriers placed at the mouths of rivers and streams may also be a factor, as might commercial salmon farms, which can attract predators, alter habitat, obstruct migration and harbor disease (DFO 2010).

Atlantic salmon are known to be sensitive to EMF and use the Earth's magnetic field for navigation back to natal rivers. The extent to which magnetic fields are relevant to a salmon's

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[10] The types of behaviours potentially affected include major seasonal migrations but also daily foraging patterns. During mass migrations of spiny lobster that occur each autumn, thousands of lobsters have been reported moving in single-file lines at consistent compass headings from inshore areas to deeper waters (Lohmann et al. 1995). Lobsters foraging at night have also been reported to follow straight-line paths from their foraging areas several hundred meters to their specific den locations in rock or coral reefs where they hide out by day (Lohmann et al. 1995).

navigation in proximity to natal rivers is uncertain, but it is no doubt of lesser importance that it would be in the outer Bay of Fundy or even more distant from natal rivers. If a salmon is native to an inner Bay of Fundy river, olfactory cues likely begin to play a dominant role in homing behaviour by the time the fish reaches Minas Channel. However, the effect of EMF in shallow coastal areas remains uncertain. The numbers of salmon potentially affected are quite low and thus the potential for interaction is low, but possibly significant if it does occur.

5.4.3 American Eel

The American eel was listed as a species of concern by COSEWIC in 2006, primarily because of large declines in population in Ontario and Quebec (COSEWIC 2006). The eel is known to be sensitive to EMF and elvers potentially use magnetic fields to navigate back to natal streams. The mix of stimuli relevant to homing in elvers is unknown and thus the effect of EMF remains uncertain. However, a relatively small proportion of the elvers population would be exposed to measurable EMF from subsea cables and TISEC devices because elvers are likely widely dispersed by the strong tidal currents and overall numbers are large.

5.4.4 Spiny Dogfish

The Atlantic Canada population of spiny dogfish is thought to consist of both resident and migrating components. In Atlantic Canada and eastern U.S. waters there are several more or less well-defined *groups* with one group associated with the Bay of Fundy and southern Scotian Shelf (COSEWIC 2010). Dogfish, particularly females, move into the inner Bay of Fundy in summer. Globally, low population levels are thought to be primarily due to over fishing. The Canadian population has been assessed as of Special Concern by COSEWIC. The dogfish is known to be sensitive to EMF and is found at times on the bottom in the FORCE lease area[11].

Exposure to EMF is more likely to affect prey detection and thus feeding than migratory behaviour. Study on a different species of dogfish (*Scyliorhinus canicula*) showed an E field of 1000μV/m elicited an avoidance (variable) response, whereas an E field of 10μV/m elicited an attraction response (Gill and Taylor 2001).

It is possible that EMF from TISEC devices or subsea cables could act as an attractant or as a repellant, affecting local distributions, but the extreme tides in the area are likely to limit potential impacts.

5.4.5 Atlantic Sturgeon

In summer, adults and juveniles are found in Minas Basin with records of catch from the Avon and Shubenacadie Rivers. Spawning is known to occur within the Saint John River, but there is also some mixing with sturgeon from US waters. Recent mark-recapture studies of

[11] Dogfish were occasionally found in lobster traps fished as part of an effects monitoring assessment within the FORCE lease area (CEF 2011).

tagged individuals (juveniles and sub-adults) in the Minas Basin suggest that they occur in the thousands in the Bay of Fundy. The Maritimes population was designated as Threatened in May of 2011 (COSEWIC 2011).

The sturgeon is known to be sensitive to EMF and is a demersal fish likely feeding on the bottom within the FORCE lease area. Exposure to EMF is more likely to affect prey detection and thus feeding than migratory behaviour. It is possible that EMF from TISEC devices or subea cables could act as an attractant or as a repellant, affecting local distributions, but the extreme tides in the area are likely to limit exposure and therefore likely potential impacts.

5.5 Cumulative Effects

Gill et al. (2005) summarized cumulative effects by saying that we need to improve our understanding of the actual significance of existing anthropogenic sources of E and B fields for receptor species. Until we can do this, the assessment of cumulative impacts will only be possible by means of educated assumptions.

Depending upon location, the marine environment can be a “noisy” place in terms of electromagnetic emissions. A number of man-make sources add to natural background EMF signals from the Earth’s core, earthquakes, sunspots, lightning, radiation, and water currents. These include a variety of ELF sources, AC and DC and covering a range of amperages (Buchanan et al. 2011). Some primary examples include:

- Underwater pumps and pipelines,
- Communication lines, and
- Electricity transmission lines.

Depending upon specific siting, underwater transmission lines have the greatest potential to affect the environment from an electromagnetic perspective. Such lines may be AC or DC and are becoming more common, especially in Europe as the number of offshore wind farms increase. Transmission lines are in fixed positions for many years and have the potential to affect fish migration and prey detection, especially for elasmobranchs (Buchanan et al. 2011).

In some areas, the marine environment already has many electrical cables used for power transmission, communications and other uses. However, tidal energy facilities in the upper Bay of Fundy will add a new source of EMF to an area where EMF was previously absent.

Shielded submarine cables generally emit very low levels of EMF. Cables that become damaged and emissions from tidal turbines and other components will contribute additional sources of EMF. Evidence suggests there will be no direct consequences to the health of populations with the Minas Channel as a result of increase EMF emissions. EMF could add a small additional stress to the ecological system, but at this time cumulative impacts do not appear to be a significant concern.

6 FINDINGS

6.1 Adequacy of the Information Base

One of the key findings of this review is that the information base on EMF generated by energy facilities and the biological effects of EMF are adequate to develop an understanding of the risk of tidal energy developments within the FORCE demonstration area. In terms of EMF, experience from offshore wind farms can be applied to tidal power generation particularly because power cables are commonly run along the seafloor. Information is also available on the sensitivity of various species to EMF and the way in which EMF emissions may change behaviour or affect long term survival through behaviours like prey detection. The available information was also considered adequate to identify priority species of concern and to determine whether additional research or monitoring was required.

6.2 Likely Residual Impacts

Information from literature reviews and assessments of impacts from power cables similar and much larger than those proposed for use by FORCE suggest:

- Induced electrical fields and magnetic fields associated with subsea power cables will be detectable by sensitive marine animals;
- EMF will fluctuate with electrical power loads on the cables and cannot be totally shielded even with burial;
- Exposure will fluctuate due to the cyclic nature of power generation and high current flows in the Minas Cannel;
- EMF from cables proposed for use by FORCE will dissipate rapidly with distance from the cable; and,
- Impacts have not been observed at power cables with much larger power flows than those proposed for use by FORCE.

Because a wide range of factors influence the magnitude of EMF associated with the subsea cables, specific values have not been estimated for set distances from the cable.

Review of available information has suggested that EMF from subsea cables or TISEC devices have no realistic potential for causing direct injury to marine organisms because of the low frequency and power levels of these fields. However, indirect effects, primarily impacts on behaviour, may occur in a wide range of marine organisms from single celled organisms to higher vertebrates. These effects are most likely to be concentrated on sensitive benthic species because exposure to EMF is highest near the cable and the duration of exposure likely the longest. Cables where DC power is carried have a higher potential for effect than when AC power is used. Burial of the cables would reduce the EMF, particularly the exposure to the strongest fields close to the cable, because the substrate would provide a barrier to exposure. However, regardless of burial, effects are quite localized and unlikely to occur beyond 30 m of the cables[12].

Current knowledge suggests that EMFs from subsea cables and orientation of cabling may interact with migrating sensitive species, such as Atlantic salmon or American eel if their migration or movement routes take them over the cables, particularly in shallow waters (<20 m). Species sensitive to induced electrical fields, particularly Atlantic sturgeon and dogfish, will likely be able to detect the cables when they are conducting power. However, the reaction of either species to the cables, in terms of attraction of repulsion at specific power levels, is uncertain.

Behavioural effects, if any, could be a relatively minor temporary change in swimming direction, or potentially a more serious avoidance response or delay in migration. Based on available information, significant impacts are not anticipated. However, further research to determine sensitivity thresholds to EMF, especially on American lobster, should be tracked to address potential concerns.

6.3 Uncertainties

Information on the relative importance of EMF to various species and the likelihood of exposure to significant levels of EMF from subsea cables and TISEC devices is relatively well understood. The likelihood of direct injury of adverse physiological effect in marine organisms is very low. However, the behavioural response of sensitive organisms is largely unknown.

Uncertainty exists around the magnitude of EMF from operating subsea cables within the FORCE lease area because the type of power, AC or DC, will be determined by the individual developers. If DC power is transmitted through the cables, the potential for higher level iE fields exists and directionality of magnetic fields would increase. The degree to which this is a concern remains uncertain because power levels and other aspects of operation remain unknown.

Uncertainty also exists in relation to the magnitude of EMF associated with TISEC devices. While devices with permanent magnets may produce higher levels of EMF, the degree to which this increases concern is uncertain without more information about the specific devices.

An identified uncertainty relates to the sensitivity of American lobster, an important species to the commercial fishery in the Minas Channel. For other priority species, the precise

[12] Almost all available literature and modeling was based on cables buried one to 1.5 metres below the surface. Normandeau et al. (2011) estimated the maximum distance for detection by sensitive marine organisms at approximately 20 m based on the high-power DC twinned cables used in the SwePol link. This was extended to 30 m in this report to compensate for the cables being directly on the sea floor.

behavioural response to EMF exposure is uncertain, but the likelihood of significant impacts is low because the effects are expected to be of short duration and the potential for exposure of a large portion of the population is low.

6.4 Data and Knowledge Gaps

In order to properly understand the effects of tidal energy generation installations on marine animals, it is important to determine the basic behavioural responses of each species. Identifying whether there are any effects such as attraction or avoidance (short or long term) of EMFs in each species is critical. Such research should determine if the effects are similar for individuals within a species population (i.e. are there age, morphological stage or sex differences). It would also be important to determine any physical exclusion effects on fish, where the introduction of submarine structures alone causes disturbance in each receptor species' ecology. Cumulative effects from arrays of devices may also affect the types of impacts or their magnitude (Gill and Bartlett 2010).

The sensitivity of American lobster to EMF represents a knowledge gap identified in the study. However, laboratory research is being carried out at the Pacific Northwest Laboratory in Washington State in 2012 to fill this data gap.

6.5 Effects Monitoring

Specific studies identified in relation to coastal tidal power developments and EMF can be designed to:

- Determine whether these species will respond to the likely electric and magnetic field strengths associated with each subsea cables and TISEC devices, and assess the potential significance of any effects for each of the critical life cycle stages identified. This could include studies of how exposure to EMF causes effects (e.g. physiological and biochemical stress resulting from EMF).
- Identify how each of the species interacts with the EMFs when free swimming and during the migration phases of their life cycles. This is likely to vary between species according to their habits, and needs to consider different life stages of each species.
- Specifically consider the cumulative impacts of adjacent developments, and determine the effects of constructive and destructive interference patterns and interactions between EMFs and noise from cables or marine renewable devices associated with whole developments.

Both laboratory and field studies would be required to answer questions surrounding the potential responses of organisms, thresholds of effect, and the potential for impact of these effects on species and/or populations. To assess impacts it may be necessary to evaluate the synergistic effects of noise, and other potential stressors, and EMF. The first step, however, is to determine if further study is warranted given the suggested low magnitude of potential risks. A second step is to determine if conditions within Minas Channel are an appropriate place to do this type of field work.

Normandeau et al. (2011) suggest laboratory studies on particular high priority species to determine basic sensitivities to EMF. They state that the ability of American lobsters, Dungeness crabs, or horseshoe crabs to sense electric or magnetic fields has not been determined so conducting field studies with these species may be premature. Instead, these species could be exposed to fields of a similar intensity to those predicted for relevant cables projects in the laboratory where it is easier to control other variables and make direct observations. If exposure to these fields elicits no or limited responses, then no further research would be required.

In other cases, the sensitivity of species to EMF has been established and the questions focus more on the types of behavioural response and the impacts associated with those responses. While exposure for most species may be limited because of high currents, little information exists on the behavior of priority species under the various current regimes.

It is unlikely EMF from a subsea cable could be a barrier to movements in the high current environment of the Minas Channel. Still, the effect on behavior from exposure is largely unknown. Different arrangements of pound nets anchored to the seafloor have been used in some Danish studies (Dong et al. 2006), however, the high currents in Minas Channel make use of such monitoring methods impossible. In other areas, mesocosm[13] studies have been used to obtain some basic information on the potential magnitude of effects of EMF. These types of studies are based on changes in spatial distribution over time following exposure to real conditions in the field. However, construction of an experimental mesocosm in the environmental conditions present within the FORCE development area is also not likely to be technically feasible or justified based on the anticipated low potential risk from EMF associated with the FORCE facilities.

6.6 Conclusions

The importance of potential effects from EMF need to be considered in light of the overall operation of tidal energy systems and the environment involved. Tidal energy power generation devices will increase turbulence in the water column, which in turn will alter mixing properties, sediment transport and, potentially, wave properties; in addition, effects of noise and electromagnetic fields need to be considered during installation, operation and abandonment (Frid et al. 2012). While EMF has been shown to result in biological effects, impairment of the survival and reproduction of benthic organisms has not been documented, and effects on fish are restricted to those species that are particularly sensitive. Overall, tidal power generating devices are unlikely to affect reproduction and recruitment processes particularly at the demonstration phase, unless multiple devices are very closely packed. Within the overall context of effects, responses to EMF tend to be localized and of short

[13] A mesocosm is a caged area of natural habitat that is instrumented with monitoring equipment. For studying the effects of cables, mesocosms are placed both over operational cables and an appropriate control site located outside the predicted magnetic field of that cable (Normandeau et al. 2011).

duration (Frid et al. 2012). The potential for adverse effects is further limited by reduced exposure resulting from the high currents in this area.

A variety of marine species use acoustic, magnetic, chemical, and hydrodynamic cues for navigation or communication. An operational tidal power generation installation could have negative impacts on some or all of these mechanisms, which in turn could impact local movements or long-distance migrations of these animals. Research conducted to date has not indicated population effects on any species associated with even large offshore wind projects. Effects on even sensitive species are expected to be of short duration and localized.

EMF fields vary over time as the current and voltage change. The electrical fields are highly attenuated by the metal shielding around the cables. The magnetic fields, however, penetrate most materials, but their strength decreases rapidly with increasing distance from the cable.

Indirect effects, primarily impacts on behaviour, may occur in a wide range of marine organisms from single celled organisms to higher vertebrates. These effects are most likely to be concentrated on sensitive benthic species where the duration of exposure is longest. Cables where DC power is carried have a higher potential for effect than when AC power is used. Burial of the cables would reduce the EMF, but regardless of burial, effects are quite localized and unlikely to occur beyond 30 m of the cables.

Given the low potential for population effects even on sensitive species and the difficulty of conducting appropriate types of study in the high current and turbulent environment of Minas Channel, specific monitoring is not recommended. However, the sensitivity of American lobster to EMF was identified as a knowledge gap for the Minas Passage area because of its commercial importance and potential for exposure to subsea cables. Laboratory studies to determine the degree of sensitivity of this species to EMF are being carried out by researchers in United States and results of these studies should be tracked by FORCE.

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