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Environmental Impact Assessment of Electromagnetic Techniques Used for Oil & Gas Exploration & Production

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Environmental Impact Assessment of Electromagnetic Techniques Used for Oil & Gas Exploration & Production

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EXECUTIVE SUMMARY

Introduction

In October 2010, LGL Limited environmental research associates (LGL) of St. John's, Newfoundland and Labrador, Canada was contracted by the International Association of Geophysical Contractors (IAGC) to prepare an Environmental Impact Assessment (EIA) of electromagnetic (EM) techniques used for oil and gas exploration and production in the marine environment. The goal of the EIA is to provide a comprehensive resource summarizing available literature and potential effects of EM technologies for a broad audience. IAGC members may also use the EIA to optimize environmental protection plans (EPPs) associated with their EM activities.

The EIA focuses on EM technologies that are currently being used to search for resistivity anomalies around the world: Controlled-Source Electromagnetics (CSEM) and Multi-Transient Electromagnetics (MTEM). As such, this EIA is geographically generic in scope. Site-specific EIAs and EPPs will still be needed to address issues associated with local fauna.

The document provides a basic description of EM technologies, naturally-occurring electromagnetic fields, and the potential use of these fields by diverse animal groups. Relevant marine species or groups are described with emphasis on elasmobranch (sharks, rays and skates), the group potentially most affected by electromagnetic emissions. Over 400 reports and publications were reviewed during the course of this EIA. The generic effects assessment focuses on those survey activities with at least some potential to affect marine animals such as EM, noise, light emissions, and accidental events.

Electromagnetics and Biology

Electromagnetic fields are generated by anything that carries or produces electricity. EM fields consist of an electric field component (E) and a magnetic field component (H) that travel together in space at the speed of light. The electromagnetic wave is characterized by a frequency and a wavelength. Frequency is the number of cycles of a wave per unit time and is measured in hertz Hz (1 Hz = 1 cycle per second). Wavelength is the distance traveled by the wave in one cycle.

EM technologies use extremely low frequencies (ELF). ELF fields are defined as those less than 300 Hz and include common household electrical systems that operate on 60 and 50 Hz standards for North America and internationally. These low frequencies and long wavelengths carry very little energy and are insufficient to break molecular bonds.

As defined by Faraday's Law, an electrical current is generated, or "induced", in any conductor moving through a magnetic field. Magnetic fields have polarity (north and south poles) and the direction of current flow within a conductor is a function of the direction in which the conductor moves relative to the north-south orientation of the magnetic field. If a conductor moves from left to right relative to the north-south orientation, direct current (DC) will flow in one direction, and if it moves from the right to the left current will flow in the opposite direction. If a conductor is moved back and forth within the magnetic field, the current will alternately flow in opposite directions; an alternating current (AC) is generated. 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. Either a conductor must move within a magnetic field, or a magnetic field must move past a stationary conductor. If both elements are motionless, no electric current is induced.

Just as a magnetic field induces an electric current in a conductor, an electric current creates a magnetic field in the space surrounding the conductor. When current flow is initiated a magnetic field expands around the conductor. When current flow eventually 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.

The relevance of electrical induction to EM surveys is that 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 ranging from digestion to higher brain functions, sensory and motor mechanisms, reproductive processes, and membrane integrity. Elecromagnetic fields of sufficient strength have the ability to induce micro-currents within an organism and possibly disrupt these normal electrical functions.

Geomagnetic Navigation

Many scientists believe that the planet’s geomagnetic field is the primary template that many forms of life use as a navigation coordinate system. It is the dominant feature that underlies the theory of geomagnetic navigation in animals. As such, any disruption to this field could have adverse affects on marine fauna.

The Earth's geomagnetic field potentially provides a reliable global positioning system for any organism that can detect and interpret the magnetic landscape in terms of relative position and/or directional orientation. Indeed, over the past 50 years a considerable amount of evidence has been amassed showing that an astounding variety of organisms respond to geomagnetic cues: magnetotactic bacteria, protists, gastropods, crustaceans, insects, bony fish, amphibians, sea turtles, birds, and migratory whales.

For a magnetic map to work the animal must overcome four distinct challenges:

1. Global gradients typically vary in total intensity by 5-10 nano-tesla/kilometer (nT km^{-1}) and in inclination by about 0.01°/km. This is a weak signal. Also, since magnetic gradients cannot be detected directly the animal must make a series of point samples that have a known spatial relationship to each other. This requires that an animal memorize precise measurements from different sites.
2. Local irregularities caused by spatial anomalies in underlying rock can disrupt smoother large scale geomagnetic gradient, and thus the navigational system.
3. Interactions between the Earth's magnetosphere and solar wind cause daily fluctuations in total intensity of about 30-100 nT and in inclination of about 0.33°. Daily fluctuations could result in significant errors in fine-scale map estimates. Further, solar storms can cause fluctuations as high as 800 nT.
4. Geomagnetic drift over an individual's life time could cause errors in position determination.

Even though the idea of geomagnetic navigation has grown into a major field of scientific study and there is much support for its theory, the mechanisms by which animals might implement a bi-coordinate mapping system and overcome its many challenges remain unknown. Adding to the complexity is the role that other environmental cues such as olfaction, celestial navigation, visual landmarks, currents, and temperature/salinity gradients may play, either interactively with geomagnetic navigation or at times dominating the navigation process.

Bird Migration

There is a large volume of research on bird navigation. Migratory birds undoubtedly 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. Polarized light studies show that migratory songbirds use cues from the region of the sky near the horizon to recalibrate their magnetic compass at sunrise and sunset (Muheim et al. 2006). Clock-shifting experiments show that experienced pigeons use the sun as a preferred compass and when it is not available they rely on magnetic cues (Walcott 2005). Walcott (2005) contends that pigeons use multiple and redundant cues to find their way home. There is even some evidence that pigeons may use several cues and that pigeons raised in different lofts under different environmental conditions may prefer to use one cue over another.

Valued Ecosystem Components

This EIA focuses on those high profile marine animal groups that are of most interest socially, culturally and economically, have at least some potential to be affected by EM surveys, and where information exists on the animals' behavior and electromagnetic fields. These groups also contain many rare and endangered species and include fish, sea turtles, marine birds, and marine mammals. Some consideration is also given to sensitive habitats.

Marine Mammals

Some species of cetaceans migrate long distances and appear able to use geomagnetic cues for navigation. Several studies have correlated mass strandings with geomagnetic contours perpendicular to the coast and anomalies originating from solar storms. Total intensity variations of as little as 50 nT (0.1% of the total field) were sufficient to influence stranding location in the data (Kirschvink et al. 1986). Other studies in areas of no consistent pattern in geomagnetic anomalies have found no such correlations (Brabyn and Frew 1994; Hui 1994). In addition to potential effects from electromagnetic fields, cetaceans are known to be able to detect and react to sound from vessel propulsion systems such as thrusters.

Sea Turtles

Sea turtles undergo extensive migrations during the course of their lifetime. Newly hatched turtles of most species migrate offshore from their natal beaches into open-ocean convergence zones where they occupy driftline assemblages of seaweed and flotsam. These convergence zones are areas of high productivity. This oceanic period of surface foraging may last from 2-20 years depending upon species and long-term oceanic conditions. Little is known about this stage of sea turtle life and it is often referred to as "the lost years". During this pelagic phase, juvenile turtles can be dispersed for thousands of kilometers by major oceanic gyres and currents. Hatchlings appear to use visual cues and wave directions during their initial entry into the water. Studies have shown that juvenile loggerheads and leatherbacks can detect changes in their surrounding geomagnetic field. However, in contrast to the case for young sea turtles, there is little scientific evidence that adult sea turtles use geomagnetic navigation to any large extent.

Fish

Research into geomagnetic orientation in fish has focused primarily on two groups that undergo long migrations: (1) salmon, and (2) eels of the genus *Anguilla*. Salmon hatch from freshwater spawning grounds then migrate out to sea where they can undergo extensive oceanic or coastal feeding migrations for hundreds or even thousands of kilometers. After spending their adult lives foraging and growing at sea, salmon migrate back to their natal rivers to spawn. *Anguilla* species have an opposite life cycle. They inhabit coastal rivers throughout the world but migrate back to oceanic breeding grounds to mate and spawn. In the Atlantic, the European eel (*A. anguilla*) migrates to spawning grounds in the Sargasso Sea off the southeastern coast of the U.S. where they spawn and presumably die (Facey and Van Den Avyle 1987). The American eel (*A. rostrata*) migrates from rivers on the U.S. east coast to the same general locale in the Sargasso Sea. Newly spawned eels are carried in the North

Atlantic Gyre where they disperse back to rivers in the U.S or Europe. The fact that salmon and eels undergo long ocean migrations makes them likely candidates for a geomagnetic guidance system. Few studies have focused on the role of geomagnetic orientation in fish since the late 1980s and researchers appear to have lost interest in this theory of fish migration.

Seabirds

Although geomagnetic navigation has been demonstrated in several species of terrestrial birds, few seabirds have been studied. In experiments with juvenile herring gull and ring-billed gull, orientation to a migratory heading toward the species' usual wintering grounds is disrupted in experiments in which the earth's magnetic field is disturbed by magnetic storms or by the placement of magnets on the birds or in their cages (Moore 1975). In contrast, placing magnets on the heads of procellariiforme seabirds (black-browed albatross, wandering albatross, and white-chinned petrel) did not prevent them from homing to nesting colonies when returning from their typically long foraging trips (Bonadonna et al. 2005).

Elasmobranchs (Electroreceptive Fishes)

The principal group of electroreceptive fishes in the marine environment are the elasmobranchs (sharks, skates, and rays), and chimeras or deep sea ratfish. Very little research has been conducted on chimerids. It is well documented that ampullae of Lorenzini in marine species are capable of detecting weak electric currents in seawater. Kalmijn (1966) showed that swimming sharks and rays exhibited avoidance responses when subjected to voltage gradients of 1-10 µV cm^{-1}. Sedate sharks and rays visibly responded to a square wave field of 5 Hz with a voltage gradient of 0.1 µV cm^{-1}. Changes in the heart rate of a ray were detected down to a voltage gradient of 0.01 µV cm^{-1}. The dogfish displayed behavioral responses to gradients as low as 5 nV/ cm^{-1} (Kalmijn 1982). The blacktip reef shark and whitetail stingray both showed threshold responses at about 4 nV cm^{-1} (Haine et al. 2001).

Despite evidence that elasmobranchs can detect DC electric fields, ampullae of Lorenzini are not DC receptors. Rather, they detect changes in the surrounding electric field, making them AC receptors with an adaptation time constant of about 3-5 seconds (Kalmijn 2003). When a shark, skate, or ray moves in a straight line for more than 3-5 seconds at a constant velocity in a uniform DC field, its sense organs do not register the field. Ampullae can only detect AC changes in the field. The fish must actually explore and probe its surroundings by purposely varying its direction of travel. It is the unequal clustering of ampullae over the surface of the body that enables elasmobranchs to determine, by constant intra-ampullae comparison of microchanges in the surrounding field, the intensity, spatial configuration and direction of the electrical source.

Prey Detection

Despite the extraordinary electrosensory capabilities of elasmobranchs, the effective range for detection of prey in nature is rather short. This is not because ampullae are short-range sensors. But rather the electric fields produced by aquatic organisms are very weak and the elasmobranch must pass close to the source to detect them. Haine et al. (2001) conducted electrosensory studies on the blacktip reef shark and whitetail stingray and found that both exhibited threshold responses at about 4 nV cm^{-1}.

The electric fields generated by invertebrates were size dependant with large specimens giving off stronger fields. For both invertebrates and fish, fields were strongest at their anterior ends presumably because of the closer proximity to physical and neural activity associated with feeding and respiratory processes. 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.

Electroreceptive Navigation

In the "active mode" model of electroreceptive navigation, the elasmobranch senses voltage gradients in its own body that it inductively generates as it 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 electromotive field. Theoretically, the elasmobranch electrosensory system could provide it with 360° navigational ability.

Geomagnetic Navigation

Behavioral responses to shifts in geomagnetic fields have been documented in laboratory studies for leopard sharks, round stingrays, sandbar sharks, and scalloped hammerhead sharks (Kalmijn 1978; Meyer et al. 2004). In field studies, there is evidence that hammerhead sharks in the Gulf of California did exhibit movement patterns consistent with tropotaxis. Telemetry studies indicated that some individuals followed consistent forging routes from their daytime resting area in the vicinity of a seamount to their nocturnal feeding grounds. While the pattern was unrelated to current patterns or bottom topography, more than a random number of routes were associated with sharp gradients in the local geomagnetic landscape.

Effects Assessment

Equipment, materials, and activities with at least some potential to affect key members of the marine ecosystem and that may be characteristic of EM surveys include:

- Underwater noise emissions (from thrusters during extensive manuvering when bottom-mounted antennae are deployed and retrieved)
- Light emissions
- Accidents such as small oil spills (e.g., small scale spills from flotation fluids such as Isopar™, if used)
- Source emissions (the primary focus)
- Electrolysis at the electrodes (chlorine emission)

Fish, seabirds, and sea turtles are all capable of detecting underwater sound and may react to those sounds. In general, these groups are considered to be not nearly as sensitive as marine mammals, especially cetaceans. CSEM survey vessels may use thrusters extensively and intermittently when retrieving bottom-mounted receivers, which could number as many as 200 or so. The underwater noise generated by thrusters may be a source of disturbance to marine mammals, perhaps more so than the steady noise of ship propulsion noise when moving at a constant slow speed. There is no mitigation for this type of disturbance except to select quieter models of thruster if available and to minimize the use of thrusters where feasible. The underwater noise generated by the ship's thrusters has some potential to create some minor behavioral effects on cetaceans.

Light emissions from any work platform at sea have the potential to attract prey that in turn may attract predators such as fish, sea turtles, seabirds, and marine mammals. In the case of an EM survey vessel with work lights illuminated the decks, such attractions can be considered localized and transitory, and any effects are probably negligible. However, it is well documented that light emissions can attract birds at night and in some cases (e.g., on nights with poor visibility) birds may collide with the superstructure and become stranded and/or suffer mortality. Bird handling mitigations are available and effective.

Accidents such as ship strikes of sea turtles and marine mammals are unlikely given the slow speeds used during EM surveys. Accidental petroleum hydrocarbon spills (e.g., fuels, lubricants, hydraulic fluids, and flotation fluids) have the potential to affect all of the animal groups of interest. None of these types of fluids are unique to an EM survey with the possible exception of Isopar™, a floatation fluid used in geophysical cables. Small spills on the order of a few liters to a few hundred are possible when it is used. Such spills are of little concern for most marine animals with the exception of seabirds where even a small amount of oil can cause a loss of insulation and subsequent mortality. Mitigations for this situation include rapid clean-up materials and training, dispersal with ship's props, minimizing attractions, bird handling and release protocols, lighting modifications, and placing of mesh over dangerous areas where birds may become trapped or oiled.

The unique aspects of EM surveys are the electromagnetic emissions from a towed electrical source. The source may be towed near surface or near bottom in shallow (e.g., 30 m) or deep (e.g., off-shelf) water. The source emissions (single or multiple frequencies) have virtually no potential for causing health effects because they are very low frequency and because exposure times are of short duration.

However, some marine animals such as elasmobranchs (sharks, skates and rays) have highly developed electroreceptive organs and most likely can detect EM emissions. Some animals may use naturally occurring electromagnetic information to navigate (e.g., young sea turtles) and others may use the information to detect less visible prey at close range. Elasmobranchs may be the most sensitive group to EM emissions since they have been shown to use them to detect prey at close range particularly in areas of low visibility.

Electromagnetic energy obeys the diffusion equation which means that the signal strength falls off proportionally to r^2 (where r is the distance from the source) unlike seismic energy which obeys the wave equation where the signal strength falls off proportionally to r. Therefore, EM energy attenuates far more rapidly than seismic energy and thus its effect is much more localised. This is beneficial in that the EM source zone of influence is relatively localised and for a given transit speed the duration of any effects will be shorter. Based upon attenuation data provided by the EM industry, studies of the reactions of various animal groups to electric and magnetic fields, and some simple calculations by the authors, it can be concluded that the horizontal “zone of influence” of a typical source would be less than 400 m radius. In addition, the time of exposure would be on the order of minutes between a moving source and a stationary or mobile animal.

As noted above, some animals may use electric or magnetic fields for navigational purposes. However, it is highly likely that these fields would represent only one cue among a suite of navigational cues such as sun angle, olfactory, current strength, and possibly others. A total dependence upon geomagnetic cues likely would render the system useless during times (e.g., solar storms) or locations of anomalies. In addition, the Earth’s electric field is DC whereas most EM surveys emit AC fields.

The marine EM industry companies through IAGC provided attenuation data for their specific gear that were calculated using a standard set of parameters. These data were then compared to sensitivity data derived from published literature on elasmobranchs (electroreceptive sharks, skates and rays) which are likely the most sensitive group of large marine animals to EM fields. Thresholds of effects (primarily behavioral) suggest that any effects would only occur within radii of 400 hundred meters or less and only for a matter of minutes under any realistic scenario.

In terms of electrolysis, the chemistry involved will depend upon the electrode material which may be copper, stainless steel or titanium, and will be site specific and complex. Chlorine gas will be produced by the source electrodes but it will be very quickly hydrolyzed into other forms. In addition, the source’s position underwater, natural water currents, plus the towing at 2-4 knots will rapidly disperse any residual chlorine or any other harmful compounds derived from the electrolytic process to negligible levels. Any effects of electrolysis products from the various types of electrodes presently used are predicted to be low impact.

It was concluded that EM sources as presently used have no potential for significant effects on any of the important animal groups such as fish, seabirds, sea turtles, and marine mammals. In addition, any cumulative effects from EM surveys are negligible compared to natural EM anomalies, induced fields from natural water currents, and other anthropogenic EM sources such as those originating from undersea equipment especially underwater powerlines and associated electrodes.

References Cited

Bonadonna, F., S. Chamaille-Jammes, D. Pinaud, and H. Weimerskirch. 2003. Magnetic cues: are they important in black-browed albatross *Diomedea melanophris* orientation? Ibis 145:152-155.

Brabyn, M., and R. Frew. 1994. New Zealand herd stranding sites do not relate to geomagnetic topography. Marine Mammal Science 10:195-207.

Facey, D.E., and M.J. Van Den Avyle. 1987. American eel. *In*: Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic). USFWS-SEFSC Biological Report 82, TR EL-82-4.

Haine, O.S., P.V. Ridd, and R.J. Rowe. 2001. Range of electrosensory detection of prey by *Carcharhinus melanopterus* and *Himantura granulate*. Marine and Freshwater Research 52:291-296.

Hui, C. 1994. Lack of association between magnetic patterns and the distribution of free-ranging dolphins. Journal of Mammology 75:399-405.

Kalmijn, A.J. 1966. Electro-perception in sharks and rays. Nature (London) 212:1232-1233.

Kalmijn, A.J. 1978. Experimental evidence of geomagnetic orientation in elasmobrach fishes. Pages 347-353 *in* K. Schmidt-Koenig and W.T. Keeton, editors. Animal Migration, Navigation and Homing. Heidelberg: Springer-Verlag.

Kalmijn, A.J. 1982. Electric and magnetic field detection in elasmobranch fishes. Science 218:916-918.

Kalmjin, A.J. 2003. Physical principals of electric, magnetic, and near-field acoustic orientation. Chapter 4. Pages 77-91 *in* S.P. Collins and N.J. Marshall, editors. Sensory Processing in Aquatic Environments. Springer.

Kirschvink, J.L., A.E. Dizon, and J.A. Westphal. 1986. Evidence from strandings for geomagnetic sensitivity in cetaceans. Journal of Experimental Biology 120:1-24.

Klimley, A.P. 1993. Highly directional swimming by scalloped hammerhead sharks, *Sphbyrna lewini*, and subsurface Irradiance, temperature, bathymetry, and geomagnetic field. Marine Biology 117:1-22.

Meyer, C.G., K.N. Holland, and Y.P. Papastamatiou. 2004. Sharks can detect changes in the geomagnetic field. Journal of the Royal Society Interface. Published online.

Moore, F. R. 1975. Influence of solar and geomagnetic stimuli on the migratory orientation of Herring Gull chicks. Auk 92:655-664.

Muheim, R., F.R. Moore, and J.B. Phillips. 2006. Calibration of magnetic and celestial compass cues in migratory birds—a review of cue conflict experiments. Journal of Experimental Biology 209:2-17.

Walcott, C. 2005. Multi-modal orientation cues in homing pigeons. Integrative Comparative Biology 45:574-581.

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ABBREVIATIONS

ABR	Auditory Brainstem Responses
AC	Alternating Current
AM	Amplitude Modulation
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CETAP	Cetacean and Turtle Assessment Program
cm	Centimeter
CME	Coronal Mass Ejection
CSEM	Controlled-Source Electromagnetics
DC	Direct Current
DP	Dynamic Positioning
Dst	Disturbance Storm Time
EIA	Environmental Impact Assessment
ELF	Extremely Low Frequency
EM	Electromagnetic
FAO	U.N. Food and Agriculture Organization
FM	Frequency Modulation
GOM	Gulf of Mexico
HF	High Frequency
Hz	Hertz
IAGC	International Association of Geophysical Contractors
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IOC	International Ornithological Congress
IUCN	International Union for Conservation of Nature
km	kilometer
LF	Low Frequency
LNG	Liquefied Natural Gas
m	meter
MF	Mid Frequency
mV	milli volt
MTEM	Multi-transient Electromagnetics
NGMCS	Northern Gulf of Mexico Continental Slope
NMFS/USFWS	National Marine Fisheries Service and U.S. Fish and Wildlife Service
NOAA	National Oceanic and Atmospheric Administration
nT	nano Tesla
nV	nano volt
OWD	Oil-in-water Dispersion
PAH	Polyaromatic Hydrocarbon
PRBS	Pseudo-random Binary Sequence

T	Tesla
TTS	Temporary Threshold Shift
UV	Ultraviolet
V	Volt
VEC	Valued Ecosystem Component
WSF	Water Soluble Fraction
µT	micro Tesla
µV	mico volt

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1.0 INTRODUCTION

In October 2010, LGL Limited environmental research associates (LGL) of St. John's, Newfoundland and Labrador, Canada was contracted by the International Association of Geophysical Contractors (IAGC) to prepare an Environmental Impact Assessment (EIA) of electromagnetic (EM) techniques used for oil and gas exploration and production in the marine environment. The goal of the EIA is to provide a comprehensive resource summarizing available literature and potential effects of EM technologies for a broad audience. IAGC members may also use the EIA to optimize environmental protection plans (EPPs) associated with their EM activities.

The IAGC outlined several key objectives. Use current literature and previous EIAs to:

- Review and describe natural and anthropogenic sources of EM fields;
- Characterize EM survey activities, including the physical components and gear, methodologies, and parameter variables involved in oil and gas industry active EM sources and acquisition techniques;
- Provide a measure of EM sensitivities for marine organisms; and
- Assess potential effects of EM activities on marine organisms, their habitat and commercial fisheries.

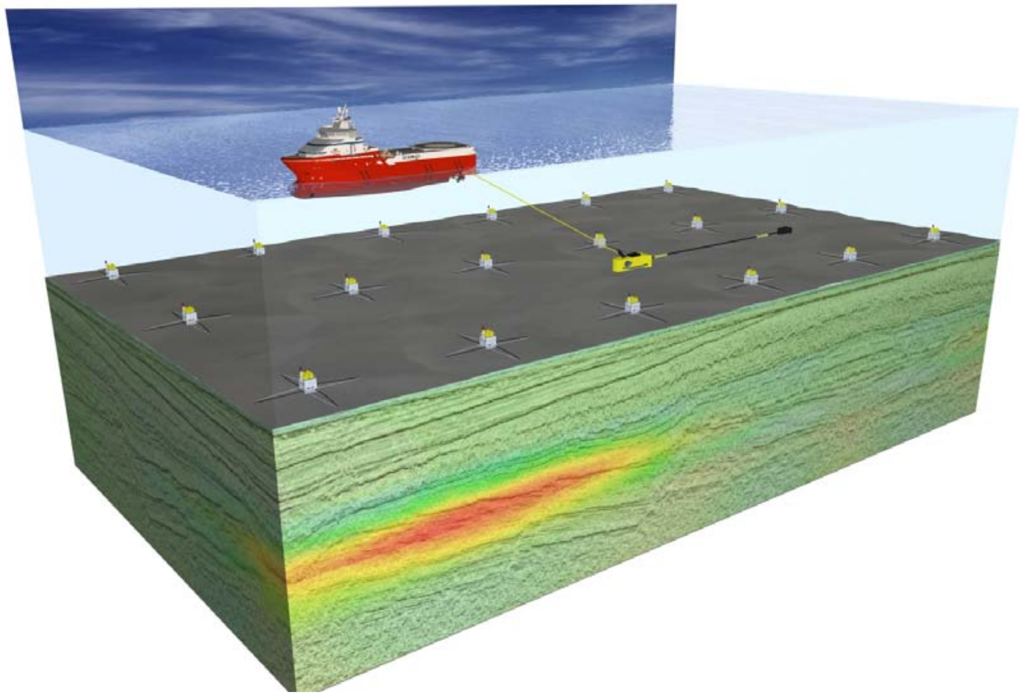
After review and consultation with IAGC, it was decided that the EIA would focus on primary EM technologies that are currently being used to search for undersea resisitivity anomalies around the world, namely: Controlled-Source Electromagnetics (CSEM) and Multi-Transient Electromagnetics (MTEM). As such, this EIA is geographically generic in scope. Users of this EIA as a basis of site-specific EIAs or EPPs will still need to address issues associated with local fauna.

The document first provides background information necessary to provide a basic understanding of EM technologies, naturally-occurring electromagnetic fields, and the potential use of these fields by a variety of animal groups. Relevant marine species or groups are described with emphasis on elasmobranch fishes, a group potentially most affected by electromagnetic emissions. Over 400 reports and publications were reviewed during the course of this EIA. The generic effects assessment then follows with focus on those survey activities with at least some potential to affect marine animals such as EM, noise, light and chemical emissions, and to a lesser extent accidents.

2.0 CSEM AND MTEM TECHNOLOGIES

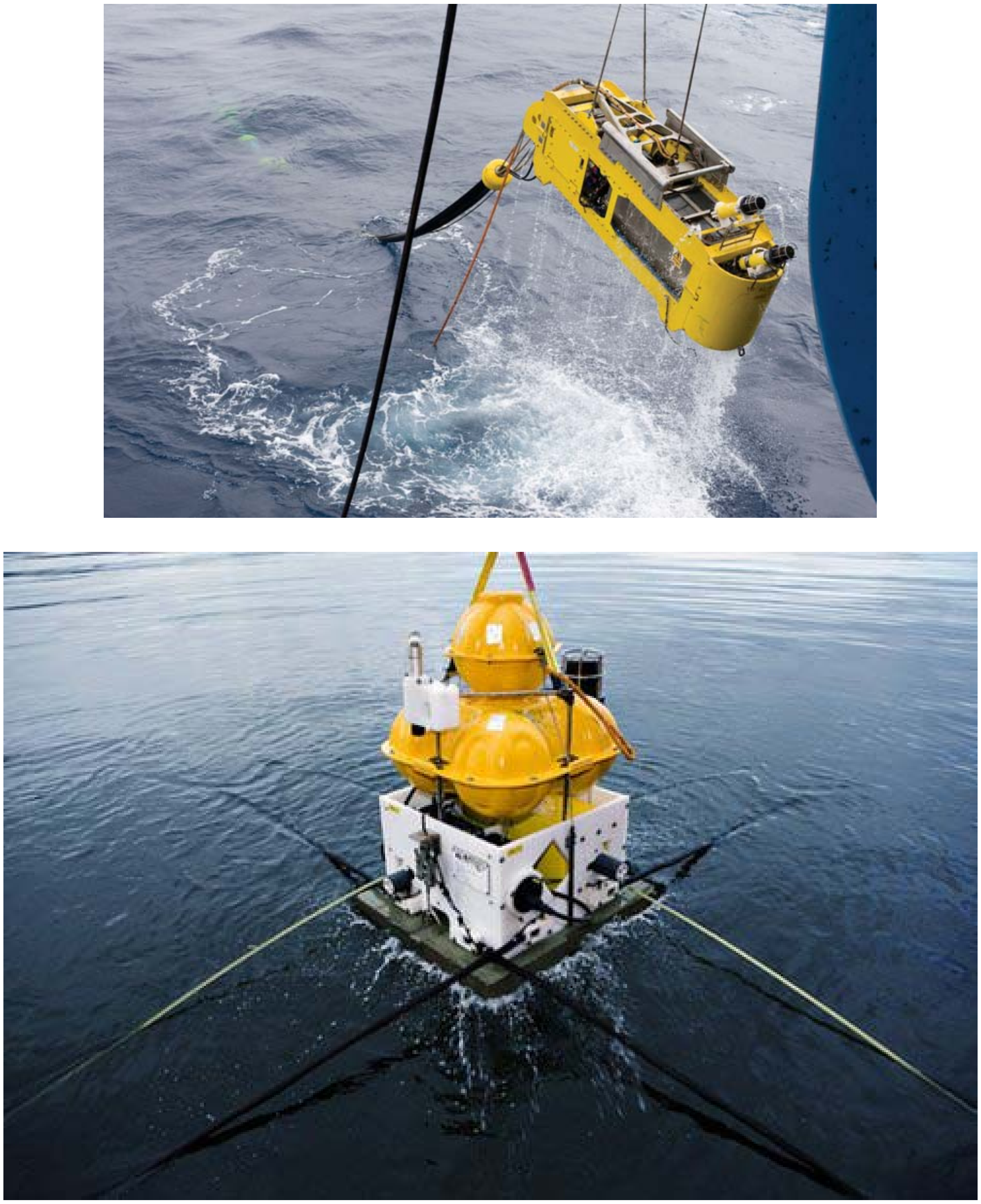
Over the past 30 years, Controlled-Source Electromagnetic (CSEM) technology has been used to search for resisitivity anomalies in deepwater (off-shelf) areas of the ocean (e.g., Edwards et al. 1981; Chave and Cox 1982). More recently, Multi-Transient EM (MTEM) techniques have been developed as a new type of EM geophysical technology. In this EIA, they are often referred to collectively as EM techniques. Due to recent advances in signal and data processing, EM techniques can now be used in shallow water (EMGS 2011).

The CSEM technique uses a mobile horizontal electric dipole source that typically has been towed 30-50 m above the sea-floor, and an array of electric and magnetic dipole field receivers located directly on the seafloor in a grid pattern (Figure 2.1). The source (Figure 2.2) may have a peak output of 1250 amperes (A) at low frequencies potentially ranging from 0.05 to 10.00 Hz. Receivers (up to about 200) (Figure 2.2) can be anchored with compacted sand anchors that break down in 6-9 months. The processed data can determine the resistivity of the underlying rock. Hydrocarbon-bearing rock shows greater resistivity relative to water-bearing rock and thus areas that appear highly resistive may indicate the presence of hydrocarbons (PGS 2007). The CSEM technique has been used globally.



Source: EMGS (2011).

Figure 2.1 Schematic of CSEM near-bottom survey.



Source: EMGS (2011).

Figure 2.2 CSEM source (top) and CSEM receiver (bottom).

There are two main EM approaches: *frequency-domain* and *time-domain.* In the frequency-domain method an oscillating current of a constant low frequency is generated in a transmitter towed above the seafloor. This oscillating current, in turn, sets up an oscillating magnetic field at the same frequency. This primary field penetrates the Earth's seafloor strata where it creates secondary electric current and magnetic fields via induction (PGS 2007). The secondary magnetic field is at the same frequency as the primary, but with a phase difference that depends on the electrical properties of the rock. The primary and secondary fields are detected by the surface receivers and the collective data are used to develop resistivity profiles. Some instruments are designed so that the effect of the primary can be removed and the secondary signal can be analyzed independently. Thus, as the towed dipole source is moved over the survey area, a varying signal will indicate the presence of variations in ground resistivity.

In the time-domain method, a constant primary current is applied then switched off. As the primary field decays it induces secondary electric currents and EM fields in the substrata. The decay rates of the secondary fields are detected by the receivers with the decay rate indicating the resistivity of the underlying rock.

The MTEM system uses a time-domain approach and a broadband transient signal rather than a single frequency (PGS 2007). The source waveform uses a pseudo-random binary sequence (PRBS) consisting of a range of frequencies. The PRBS allows the frequency content to be tuned to the depth of interest with shallow targets employing a higher frequency sequence and deeper targets lower frequencies. The multi-frequency return signal is deconvolved, a process in which individual frequencies are isolated and analyzed.

The MTEM system can be towed near-surface and can be used in both shallow and deep marine waters whereas until recently CSEM has mostly been limited to deep water regions due to surface interference. The air-water interface acts as a highly resistive zone and refracts the CSEM signals. The underwater receivers pick up energy that has diffused through the Earth plus energy that has refracted off the air-water interface at the surface of the water column, the latter often masking or occluding the measured response. Because water attenuates EM signals, the strength of the refracted EM wave declines as depth increases and becomes negligible if depth is great enough. The CSEM was normally restricted to depths exceeding 300 m (PGS 2007). Recent research indicates that CSEM also can be towed near surface (Shantsev et al. 2010) and used in shallow water (Pedersen et al. 2010).

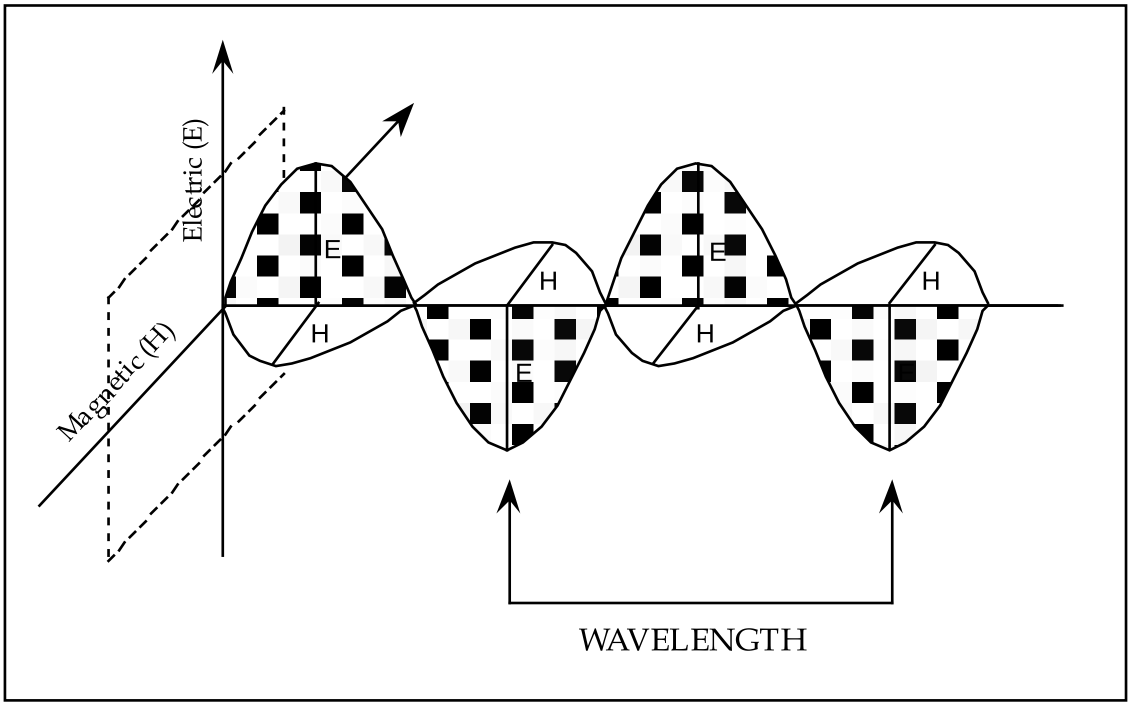
Research is presently being conducted that would allow CSEM and MTEM systems to tow both EM sources and receivers near-surface, similar to a seismic survey. Both technologies generate modulating EM waves that pass through the marine environment with the possibility of affecting biological organisms if they are proximal to the transmission source.

3.0 BACKGROUND ON ELECTROMAGNETICS

In order to assess the potential environmental effects of EM surveys it is first necessary to understand the basics of electromagnetic fields, both natural and anthropogenic. The following sections provide a brief description of these processes.

3.1. Electromagnetic Fields

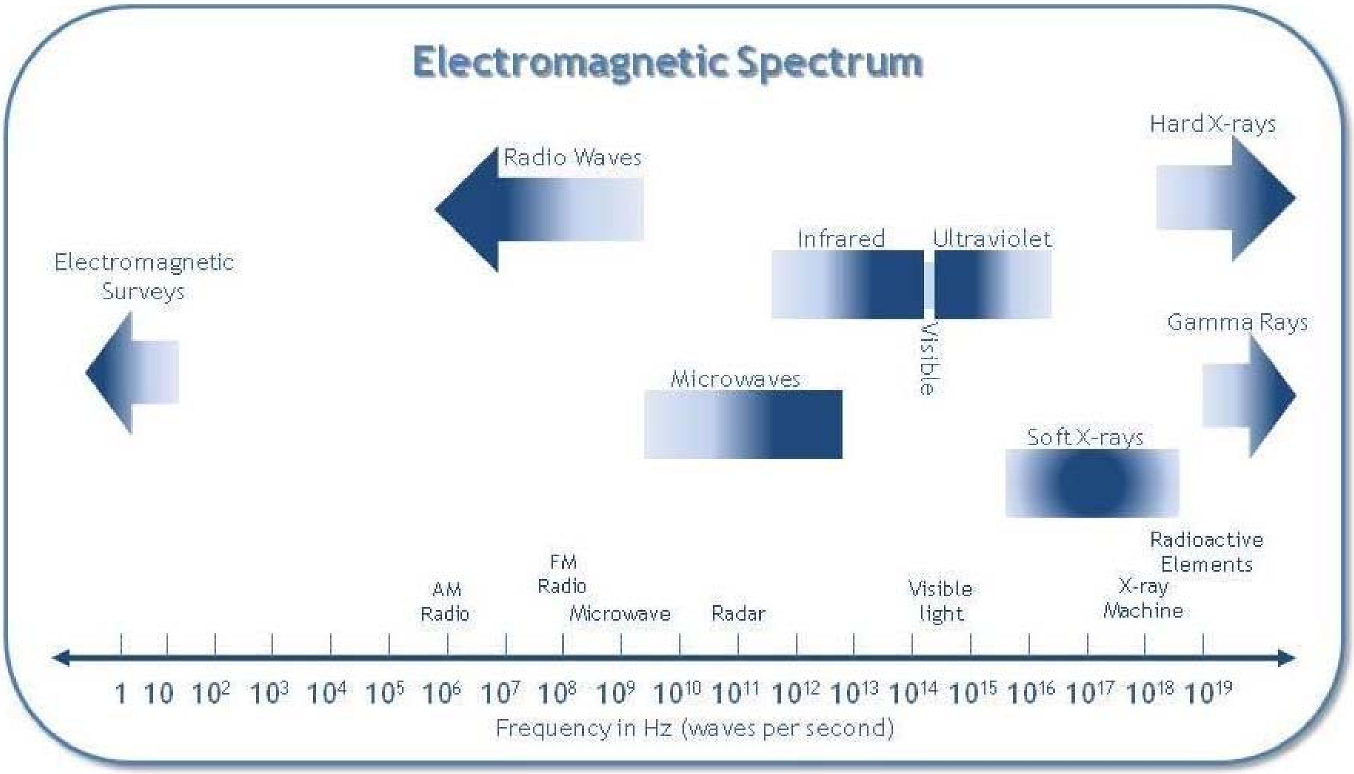
Electromagnetic fields are generated by anything that carries or produces electricity. Electromagnetic fields consist of an electric field component (E) and a magnetic field component (H) that travel together in space at the speed of light, as shown in Figure 3.1. The electromagnetic wave is characterized by a frequency and a wavelength. Frequency is the number of cycles of a wave per unit time and is measured in hertz Hz (1 Hz = 1 cycle per second). Wavelength is the distance traveled by the wave in one cycle (Vitale 1995; World Health Organization 2005).



Source: World Health Organization (2005).

Figure 3.1 Electromagnetic wave.

The electromagnetic spectrum encompasses all possible wavelengths of electromagnetic radiation. At the lower end (low frequency) of the spectrum are radio waves like those used in AM (750-1,000 kilohertz) and FM (80-100 megahertz) radio transmissions (Figure 3.2). Gamma rays from cosmic sources and from radioactive elements are at the high end of the spectrum where frequencies can range from 10^{18} to 10^{20} Hz. The frequency (wavelength) of electromagnetic waves determines their energy content. Electromagnetic waves consist of energy particles called quanta and quanta of higher frequency waves carry more energy than lower frequency waves. High-frequency waves like gamma rays given off by radioactive elements, cosmic rays, and X-rays contain enough energy per quantum to break down molecular bonds and thus are classified as "ionizing radiation". Ionizing radiation can have serious detrimental effects on humans and animals. Lower frequency fields like those associated with radio and microwave frequencies are insufficient to break molecular bonds and are classified as "non-ionizing radiation". Extremely low frequency (ELF) fields are defined as those less than 300 Hz and include common household electrical systems that operate on a 50/60 Hz standard. These low frequencies and long wavelengths carry very little energy (Vitale 1995; National Institute of Environmental Health Sciences/National Institute of Health 2001; World Health Organization 2005).



Source: Modified from University of California (1996).

Figure 3.2 The electromagnetic spectrum.

As described in Section 2.0, EM technologies use non-ionizing ELFs (usually <10 Hz) and thus have essentially no potential for direct effects on the health of marine animals.

3.2. Electrical Induction

The concept of electrical induction is key element for understanding the pathway by which EM transmissions may disrupt nearby marine fauna. As defined under the principles of Faraday's Law, an electrical current is generated, or "induced", in any conductor moving through a magnetic field. Magnetic fields have polarity (north and south poles) and the direction of current flow within a conductor is a function of the direction in which the conductor moves relative to the north-south orientation of the magnetic field. If a conductor moves from left to right relative to the north-south orientation, direct current (DC) will flow in one direction, and if it moves from right to left current will flow in the opposite direction. If a conductor is moved back and forth within the magnetic field, the current will alternately flow in opposite directions; an alternating current (AC) is generated. 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. Either a conductor must move within a magnetic field, or a magnetic field must move past a stationary conductor. If both elements are motionless, no electric current is induced.

Just as a magnetic field induces an electric current in a conductor, an electric current creates a magnetic field in the space surrounding the conductor. When current flow is initiated a magnetic field expands around the conductor. When current flow eventually 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. It is important to note that EM technologies use mostly AC current whereas most natural electrical processes and phenomena involve DC current.

The relevance of electrical induction to EM activities conducted by industry is that 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 ranging from digestion to higher brain functions, sensory and motor mechanisms, 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. Induction of microcurrents can be associated with either the electrical or magnetic component of the EM wave.

3.3. Geomagnetism

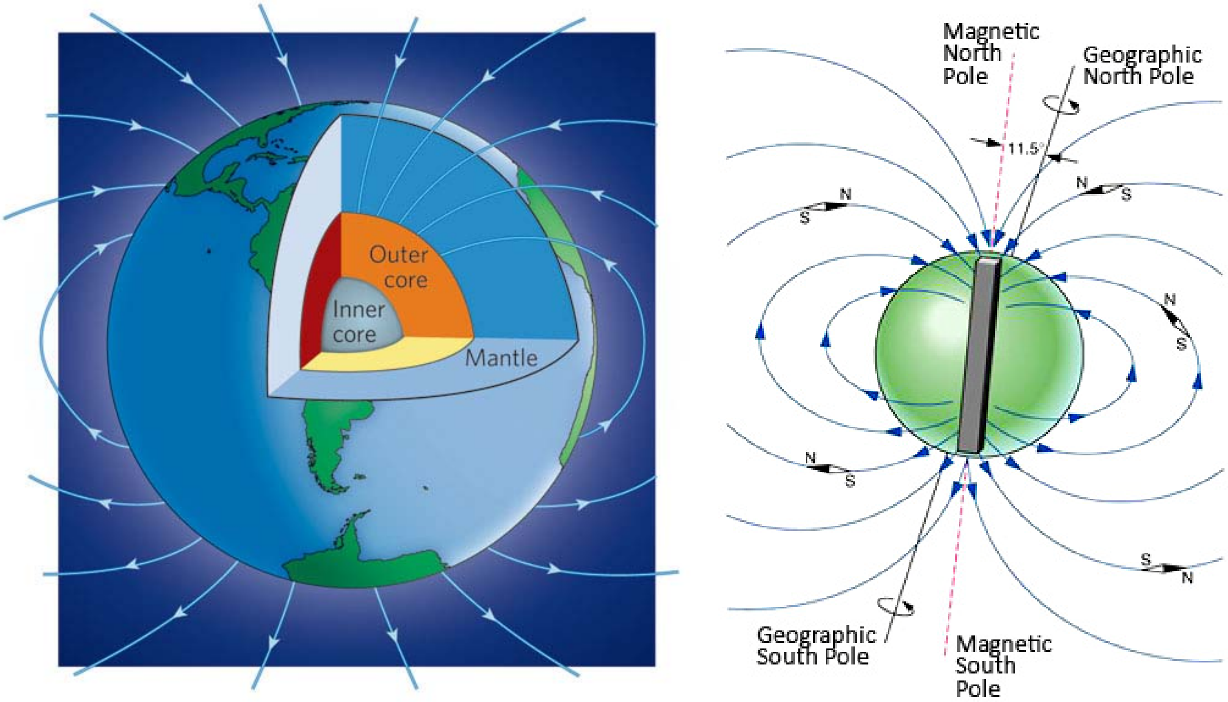
Understanding the basic components of the Earth’s magnetic field is essential for assessing the possible effects of EM transmissions on marine life. Many scientists believe that the planet’s geomagnetic field is the primary template that many forms of life use as a navigation coordinate system. It is the dominant feature that underlies the theory of geomagnetic navigation in animals. It has been theorized that any natural or anthropogenic disruptions of this field may have adverse affects on marine fauna by affecting their navigational abilities.

The Earth's magnetic field is a dipole field with a geographic north-south pole the axis of which is 11 degrees off alignment from the Earth's rotational axis (Figure 3.3). Magnetic field lines leave the geomagnetic South Pole vertical to the planet, curve around the Earth, and re-enter straight downward (90°) at the geomagnetic North Pole. The point where field lines run parallel to the Earth's surface (0°) is the magnetic equator. Magnetic field lines thus point upward and to the north in the southern hemisphere and downward and to the north in the northern hemisphere.

The Earth's magnetic field is caused by the dynamo effect. In this mechanism, fluid motion in the Earth’s outer core moves liquid iron across an already existing, weak magnetic field and generates an electric current. The electric current, in turn, produces a magnetic field that also interacts with the fluid motion to create a secondary magnetic field. A requirement for the induction of the field is the rotating fluid in the outer core, which is powered by the Coriolis Effect caused by the rotation of the Earth. In the case of the Earth, the magnetic field is induced and constantly maintained by the convection of liquid iron in the outer core.

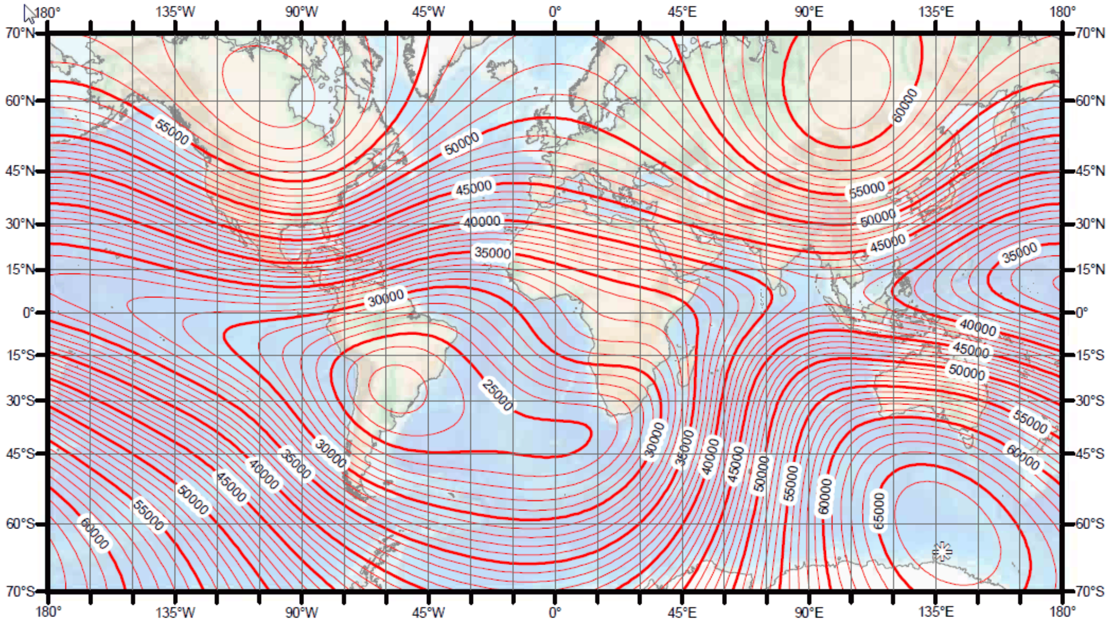
Two principal features of the Earth's geomagnetic field are inclination and intensity. At any point on the Earth, magnetic field lines intersect the planet's surface at a specific angle (inclination) relative to the horizontal, ranging from 0° (parallel to the Earth) at the geomagnetic equator, to 90° at the geomagnetic poles (see Figure 3.3). 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. The intensity of the geomagnetic field also varies (Figure 3.4). It is highest near the magnetic poles at 60,000 nano Tesla (nT,) is about 40,000 to 50,000 nT at mid latitudes, and decreases to about 30,000 nT at the geomagnetic equator (Kirschvink et al. 1986; Wiltschko and Wiltschko 1995a).

Superimposed on this global field are local magnetic deviations, distortions, and anomalies that vary irregularly over the Earth's surface. This geomagnetic topography consists of magnetic hills and valleys of varying size and intensity that are associated with the magnetic nature of underlying rock and localized dynamics in the Earth's iron core. High concentrations of magnetized rock localized in areas of low magnetic concentration create strong magnetic gradients. Regional gradients typically are quite subtle. In northeastern North America, field intensity changes at about 3.4 nT/km, whereas the regional gradient across central Europe is 2.5 nT/km. A most notable geomagnetic anomaly lies 445 km south-southwest of Moscow, Russia, with local intensities 19,000 nT above the underlying global field (Kirschvink et al. 1986; Wiltschko and Wiltschko 1995a).



Source: http://www.glcoherence.org/monitoring-system/earth-rhythms.html
http://www.nature.com/nature/journal/v452/n7184/fig_tab/452165a_F1.html.

Figure 3.3 The Earth's geomagnetic field.



Source: http://ngdc.noaa.gov/geomag/WMM/data/WMM2010/WMM2010_Report.pdf, page 64, based on the US/UK world magnetic model for 2010-2015 by NOAA National Geophysical Data Center and British Geological Survey.

Figure 3.4 Global geomagnetic field lines (total intensity) in nanoTeslas (nT).

Plate tectonics cause magnetic fields in the oceans to be more irregular than on land. New ocean floor is continually created at mid-ocean ridges through the process of seafloor spreading. As the result of complex processes associated with the Earth's geologic history, oceanic crust has developed as long bands of magnetic highs and lows aligned parallel to the axis of the mid-oceanic ridges. Because most oceanic ridges run in a north-south direction in the major ocean basins, the magnetic delineations associated with them also run in a north-south direction. Thus, while broad-scale patterns in inclination and total field intensity vary with latitude, fields associated with oceanic tectonics provide a degree of longitudinal gradation (Kirschvink et al. 1986; Wiltschko and Wiltschko 1995a).

The Earth's magnetic field is also subject to short- and long-term variations. Solar electromagnetic radiation impinging on the Earth's surface can cause daily fluctuations in field intensity of up to 30 nT and shifts in inclination of up to 0.33°. These daily perturbations vary with latitude and season. Magnetic storms associated with sun spot activity also cause fluctuations of 200 nT or more. Fluctuations as high as 800 nT have been recorded at the Tromsø Observatory. The geomagnetic field also undergoes long-term drift with field intensity varying about 0.05% per year with period of several thousand years. There is also a westward drift in the field of about 0.2° longitude per year (Kirschvink et al. 1986; Wiltschko and Wiltschko 1995a).

Lightning strikes can also cause local electromagnetic anomalies. Worldwide these thousands of strikes cause oscillations in the space between the Earth's surface and the ionosphere. This phenomenon known as the Schumann Resonance contributes to the electromagnetic background at extremely low frequencies. The Schumann Resonance provides an extremely weak signal on the order of 10^{-12} T (Cherry 2002; Schlegel and Füllekrug 2002) and thus is unlikely to affect animal orientation or navigation (Section 3.4) (see wiki.encyclopedia, Anyamba et al. 2000; Hayakawa et al. 2005; Yang and Pasko 2006 for further information on this phenomenon).

3.4. Biological Use of Geomagnetics for Orientation and Navigation

The Earth's geomagnetic field potentially provides a reliable global positioning system for any organism that can detect and interpret the magnetic landscape in terms of relative position and/or directional orientation. Indeed, over the past 50 years a considerable amount of evidence has been amassed showing that an astounding variety of organisms respond to geomagnetic cues: magnetotactic bacteria (Blakemore 1975; Kirschvink 1980), protists (Bazylinski et al. 2000), gastropods (Lohmann and Willows 1987), crustaceans (Lohmann 1985; Lohmann et al. 1995b; Arendse 1978; Ugolini and Pezzani 1992), insects (Jacklyn 1992; DeJong 1982; Schmidt and Esch 1993; Gegeer et al. 2008; Riveros and Srygley 2010), bony fish (Quinn and Groot 1983; Taylor 1986; Chew and Brown 1987; Walker 1984), amphibians (Phillips 1986; Diego-Rasilla et al. 2010), sea turtles (Lohmann 1991; Light et al. 1993; Lohmann and Lohmann 1994a, 1994b, 1996b; Goff et al. 1995), birds (Wiltschko and Merkel 1966; Wiltschlko et al. 2010; Wilzeck et al. 2010), and migratory whales (Klinowska 1985; Kirschvink et al. 1986; Walker et al. 1992). In addition, there are many more citations than just those listed above.

These observations led to the development and continued research of the magnetic map hypothesis (Yeagley 1947; Gould 1980; Moore 1980; Wallraff 1991; Phillips 1996). The model proposes that as an animal moves it learns the alignment and steepness of geomagnetic gradients (Freake et al. 2006). Geomagnetic parameters could be total intensity, inclination angle, or a combination of both. Once a home gradient pattern has been learned it may be extrapolated to unfamiliar areas by comparing unfamiliar cues with home cues. A prerequisite for "true navigation" is a bi-coordinate positioning system (Griffin 1952). For an animal to determine its location using magnetic parameters *alone*, it must (1) be able to perceive at least two distinct parameters of the Earth's geomagnetic field, and (2) these parameters must vary relative to each other across the Earth's surface such that a grid is formed from which a position can be fixed. For animals that migrate long distances, such a system would provide not only a source of directional information, but a source of positional information as well (Wiltschko and Wiltschko 1995b; Gould 1998).

For a magnetic map to work the animal must overcome four distinct challenges (Phillips 1996; Phillips et al. 2006):

1. Global gradients typically vary in total intensity by 5-10 nT km^{-1} and in inclination by about 0.01° km^{-1}. This is a weak signal. Also, since magnetic gradients cannot be detected directly the animal must make a series of point samples that have a known spatial relationship to each other (Phillips and Deutschlander 1997). This requires that an animal memorize precise measurements from different sites.
2. Local irregularities caused by spatial anomalies in underlying rock can disrupt smoother large scale geomagnetic gradient, and thus the navigational system.
3. Interactions between the Earth's magnetosphere and solar wind cause daily fluctuations in total intensity of about 30-100 nT and in inclination of about 0.33° (Wiltschko and Wiltschko 1995b). Daily fluctuations could result in significant errors in fine-scale map estimates. Further, solar storms can cause fluctuations of 200 nT or more. During March 1989, solar storm caused the province-wide blackout in Quebec, Canada; the disturbance reached Dst -548 nT in intensity (Cliver and Svalgaard 2004).
4. Geomagnetic drift over an individual's life time could cause errors in position determination (Kirschvink et al. 1986; Wiltschko and Wiltschko 1995b).

Even though the idea of geomagnetic navigation has grown into a major field of scientific study and there is much support for its theory, the mechanisms by which animals might implement a bi-coordinate mapping system and overcome its many challenges remain unknown. Adding to the complexity is the role that other environmental cues such as olfaction, celestial navigation, visual landmarks, currents, and temperature/salinity gradients may play, either interactively with geomagnetic navigation or at times dominating the navigation process.

3.4.1. Orientation and Navigation Models

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.

Two functional modes of the magnetic compass were identified from bird studies (Wiltschko and Wiltschko 1995a). The first is an inclination compass in which the animal is able to detect and interpret the ambient inclination angle of the Earth's geomagnetic field thus giving it the ability to distinguish between *equatorward* and *poleward* direction. The second is a polarity compass that detects the polarity of the ambient magnetic vector allowing the animal to distinguish between magnetic north and south. In their studies of sea turtles, Lohmann and Lohmann (1996b) reported that juvenile loggerhead sea turtles could distinguish changes in total field intensity. Magnetic compasses, based upon inclination angle, polarity, or field intensity, have been identified in at least 38 animal taxa (Wiltschko and Wiltschko 1995a).

Another model for geomagnetic navigation is tropotaxis. It is essentially a fine-scale magnetic mapping system in which animals navigate magnetic gradients amidst the highs and lows of the local geomagnetic landscape. In most areas of the planet, changes in geomagnetic parameters (intensity and inclination angle) with distance are small and the use of tropotaxis would only be useful to highly mobile animals having extended migrations (Wiltschko and Wiltschko 1995a). For a navigational map to be functional, the animal would need to have some sense of its recent geomagnetic history and its geomagnetic goal. While specifics of such a system are currently a matter of debate and conjecture, there is circumstantial evidence (detailed in following sections) that cetaceans and some sharks may be able to detect and navigate in conjunction with small-scale geomagnetic gradients and anomalies.

3.4.2. Magnetoreception

The idea that magnetic fields might be used as an orientation cue in animals was first postulated by von Middendorff (1859) who suggested that migrating birds used magnetic meridians as navigational aides. Viguier (1882) later proposed a navigational map for homing birds based on field intensity and inclination. Little attention was paid to these hypotheses until the first half of the 20th century when studies of behavioral navigation in animals began in earnest. The first signs of acceptance within the scientific community came with the identification of the sun compass in birds and bees in the 1950s. Beginning in 1960, the number of papers on magnetic orientation and navigation within the animal kingdom increased rapidly (Wiltschko and Wiltschko 1995a).

For a magnetoreceptor to be functional it would have 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). The two predominant theories favored in the current discussion of magnetoreception assume processes based on different physical mechanisms. The magnetite hypothesis proposes that the process is mediated by particles of magnetite, a ferrimagnetic mineral (Yorke 1979; Kirschvink and Gould 1981), whereas the radical pair model suggests that magnetic input is mediated by magnetically sensitive chemical processes involving specialized photo pigments (Schulten 1982; Schulten and Windemuth 1986; Ritz et al. 2000).

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 1995a). Research has demonstrated that many of these organisms have the biochemical ability to precipitate ferromagnetic magnetite (Kirschvink and Gould 1981; Frankel et al. 1979; Walcott et al. 1979; Kirschvink et al. 1985; Mann et al. 1988), including humans (Kirschvink et al. 1992). What remains the subject of debate is the exact biophysical mechanism that governs magnetoreception in higher-level animals (Diebel et al. 2000; Ritz et al. 2000).

By themselves, single crystals of magnetite do not interact strongly enough with the Earth's magnetic field to overcome the randomizing effects of thermal buffeting (Kirschvink and Walker 1985). Thermal buffeting is the de-stabilizing effect that thermal background energy has at the molecular level (Kirschvink and Walker 1985). Buffeting agitates single crystals of magnetite to the point where they cannot maintain magnetic alignment. Nevertheless, 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 (Kirschvink 1997). Later studies discovered that within these microscopic organisms, magnetite crystals actually form long chains such that their magnetic moments sum linearly (Kirschvink et al. 1985; Kirschvink 1997; Diebel et al. 2000). The additive effect of the magnetite chains gave them the ability to overcome thermal buffeting.

For a magnetite-based mechanism to function in animals, it would have to exert an effect through some intermediary at the cellular level. Kirschvink (1997) calculated that in higher animals, the equivalent of only a single magnetotactic bacterium connected to a single sensory neuron could give that animal an extraordinarily good magnetic compass sense. When fluctuations in external geomagnetic fields physically alter the alignment of a chain of magnetite, that change in alignment would be converted via a nerve cell attachment into electrophysical neural information. That neural information would then serve as the basis for the organisms' response. Researchers are currently exploring where and how such magnetoreceptor cells might operate in higher-level organisms (Walker et al. 2003).

Radical Pairs Model

Schulten (1982) and Schulten and Windemuth (1986) proposed a model in which a radical-pair mechanism can act as a sensor for magnetic compass orientation. It has been known since the 1970s that certain chemical reactions respond to applied magnetic fields (Rodgers and Hore 2008).

Magnetically sensitive reactions almost always involve radicals—molecules that have an odd number of electrons and consequently an unpaired electron spin. A radical pair is a short-lived reaction intermediary comprising two radicals formed in tandem whose spin can be either parallel or anti parallel. Each spin has a magnetic moment or component that can be affected by outside magnetic fields. An entire chemical reaction can thus be modified magnetically via the radical pair intermediary. Experimental and theoretical studies of radical pair mechanisms over the last 30 years have led to a unique field of study termed *spin chemistry* (Rodgers and Hore 2008).

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. Radical pairs can be formed easily by photo-excitation and therefore photo-receptors in the retina would be a convenient site to host a radical pair mechanism (Winklhofer and Kirschvink 2010). Crypto-chromes, a group of blue-sensitive photo-receptors were suggested as possible magneto-receptor candidates since crypto-chromes have the ability to form long-lived radical pairs (Ritz et al. 2000).

Most of the subsequent and current research into magnetite and radical pair mechanisms has focused on passerine birds (perching birds), which are discussed below.

3.4.3. Bird Migration

Passerine birds are discussed here because, as a group, they have received the greatest amount of scientific study over the past 45 years. Most of the major breakthroughs in identifying and understanding the physiological, biochemical, and neural components that contribute to magnetic orientation and navigation have come from research on passerines.

Magnetic orientation was first demonstrated in the European robin in 1966 (Wiltschko and Wiltschko 1995a). 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. As predicted by the magnetite hypothesis, migratory orientation was affected by a short, strong magnetic pulse designed to alter the magnetization of the magnetite particles (Wiltschko et al. 1994, 1998). As predicted by the radical pair hypothesis, migratory orientation required light and proved to be wave-dependent, being ineffective at long-wavelength light of 590 nano meters (nm) and beyond and most effective at short-wave light ranging from 370 nm to about 565 nm (Wiltschko et al. 1993, 2007, 2010; Muheim et al. 2002). Experiments in high frequency fields directly indicated an underlying radical pair mechanism (Ritz et al. 2004; Thalau et al. 2005; Wiltschko et al. 2005). Together, these findings suggested that migratory birds used receptors based on magnetite as well as radical pair mechanisms.

Under pure white light conditions, birds typically orient in a direction consistent with their seasonal migratory direction. Under higher-wave monochromatic light, birds exhibited a *fixed direction* response. That is, birds preferred certain directions that were different from their migratory direction and that were independent of season (Wiltschko et al. 2007; Stapput et al. 2008). It was further determined that fixed direction responses are polar and they likely originate in magnetite-based receptors discovered in the upper beak (Fleissner et al. 2003; Stapput et al. 2008; Falkenberg et al. 2010). Further work with European robins led Wiltschko et al. (2010) to conclude that (1) compass orientation is based on radical pair processes in the right eye and (2) fixed direction responses originate in magnetite-based receptors in the upper beak. Both responses are light dependant and the mechanisms interact with each other in the magnetic orientation process.

To be sure, birds use a suite of navigational systems that may work independently of or in concert with magnetoreceptors: celestial information including stars (Emlen 1970), sun azimuth position (reviewed by Schmidt-Koenig 1990), olfaction (Papi and Loale 1988), visual landmarks over short distances, and the associated skylight polarization at sunrise and sunset to determine and maintain migratory direction (Able 1982; Muheim et al. 2006). Muheim et al. (2008) refined those polarized light studies to show that migratory songbirds use cues from the region of the sky near the horizon to recalibrate their magnetic compass at sunrise and sunset. Clock-shifting experiments show that experienced pigeons use the sun as a preferred compass and when it is not available they rely on magnetic cues (Walcott 2005). In a review of homing pigeon research, Walcott (2005) contends that birds use multiple and redundant cues to find their way home. There is even some evidence that pigeons may use several cues and that pigeons raised in different lofts under different environmental conditions may prefer to use one cue over another (Walcott 1996).

Navigation is further discussed for the relevant animal groups in the following sections.

4.0 RELEVANT MARINE ANIMALS

The focus in this EIA is on those marine animals that are of prime interest (i.e., commercial, social, cultural, and scientific) to society and have at least some potential to be affected by EM survey emissions (e.g., EM, underwater noise, light, and spills). In general, these include marine mammals, seabirds, sea turtles, and fishes. Within these groups, geophysical operators need to be particularly cognizant of those species that are rare and endangered or where there are particularly sensitive habitats within their areas of interest. The main groups are briefly described below.

4.1. Marine Mammals

Marine mammals include whales (cetaceans), seals and walrus (pinnipeds), and polar bear.

4.1.1. Cetaceans

Worldwide, there are approximately 78 species of whales, dolphins, and porpoises in the Order Cetacea. Cetaceans are broken into two Suborders: Mysticeti (baleen whales) and Odontoceti (toothed whales). There are 11 species of baleen whales and 67 species of toothed whales. Of these 41 species, subspecies, and subpopulations world-wide are listed in the latest *International Union for Conservation of Nature Red List of Endangered Species* (IUCN 2010) as critically endangered, endangered, vulnerable, or near threatened (Table 4.1).

There are indications based on indirect evidence that some cetaceans may use geomagnetic cues during migrations.

Table 4.1 Conservation designations for cetaceans based upon the latest *International Union for Conservation of Nature Red List of Endangered Species*. Critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT). Species listed as least concern (LC) and data deficient (DD) are not included.

	Family	Common Name	Scientific Name	IUCN
Mysticetae (Baleen Whales)				
	Balaenidae			
		Bowhead Whale	*Balaena mysticetus*	
		Okhotsk Sea subpopulation		EN
		Svaalbard-Barents Sea subpopulation		CR
	Eubalaena			
		Northern Atlantic Right Whale	*Eubalaena glacialis*	EN
		Northern Pacific Right Whale	*Eubalaena japonica*	EN
		Northern Pacific Right Whale	*Eubalaena japonica*	
		Northeast Pacific subpopulation		CR
		Right Whale	*Eubalaena australis*	

	Family	Common Name	Scientific Name	IUCN
		Chile-Peru subpopulation		CR
	Balaenopteridae			
		Blue Whale	*Balaenoptera musculus*	EN
		Antarctic subspecies	*Balaenoptera musculus intermedia*	CR
		North Atlantic subpopulation	*Balaenoptera musculus musculu*	VU
		Fin Whale	*Balaenoptera physalus*	EN
		Sei Whale	*Balaenoptera borealis*	EN
		Humpback Whale	*Megaptera novaeanglia*	
		Arabian Sea subpopulation		EN
		Oceania subpopulation		EN
	Eschrichtiidae			
		Gray Whale	*Eschrichtius robustu*	
		Northwest Pacific subpopulation		CR
Odontoceti (Toothed Whales)				
	Delphinidae			
		Chilean Dolphin	*Cephalorhynchus eutropia*	NT
		Hector's Dolphin	*Cephalorhynchus hectoria*	EN
		Maui's subspecies	*Cephalorhynchus hectoria maui*	CR
		Pacific Humpback Dolphin	*Sousa chinensis*	
		Indo-Pacific species		NT
		Eastern Taiwan Strait subpopulation		CR
		Atlantic Humpback Dolphin	*Sousa teuszii*	VU
		Bottlenose Dolphin		
		Black Sea subspecies	*Tursiops truncatus ponticus*	EN
		Spinner Dolphin		
		Eastern subspecies	*Stenella longirostris orientalis*	VU
		Common Dolphin	*Delphinus delphis*	
		Mediterranean subpopulation		EN
		Black Sea subspecies	*Delphinus delphis ponticu*	VU
		Irrawaddy Dolphin	*Orcaella brevirostri*	VU
		Ayeyarwady River subpopulation		CR
		Mahakam River subpopulation		CR
		Malampaya Sound subpopulation		CR
		Mekong River subpopulation		CR
		Songkhla Lake subpopulation		CR
		Australian snubfin dolphin	*Orcaella heinsohni*	Nt
	Monodontidae			
		Beluga Whale	*Delphinapterus leucas*	NT
		Cook Inlet subpopulation		CR
	Phocoenidae			

	Family	Common Name	Scientific Name	IUCN
		Finless Porpoise	*Neophocaena phocaenoides*	VU
		Yangtze subspecies	*Neophocaena phocaenoides asiaeorientalis*	EN
		Harbor Porpoise	*Phocoena phocoena*	
		Baltic Sea subpopulation		CR
		Black Sea subspecies	*Phocoena phocoena relicta*	EN
		Vaquita	*Phocoena sinus*	CR
	Physeteridae			
		Sperm Whale	*Physeter macrocephalus*	VU
		La Plata Dolphin	*Pontoporia blainvillei*	VU

Source: IUCN (2010).

4.1.2. Pinnipeds

Pinnipeds are a group of semi-aquatic marine mammals comprising the families Odobenidae (walrus, 1 species), Otariidae (eared seals, 17 species), and Phocidae (earless seals, 16 species). Of these 11 species world-wide are listed in the latest *International Union for Conservation of Nature Red List of Endangered Species* (IUCN 2010) as critically endangered, endangered, vulnerable, or near threatened (Table 4.2).

Table 4.2 Conservation designations for pinnepeds based upon the latest *International Union for Conservation of Nature Red List of Endangered Species*. Critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT). Species listed as least concern (LC) and data deficient (DD) are not included.

Family	Common Name	Scientific Name	IUCN
Otariidae	Galápagos Fur Seal	*Arctocephalus galapagoensis*	EN
	Juan Fernández Fur SeaL	*Arctocephalus philippii*	NT
	Guadalupe Fur Seal	*Arctocephalus townsendi*	NT
	Northern Fur Seal	*Callorhinus ursinus*	VU
	Steller Sea Lion	*Eumetopias jubatus*	EN
	Australian Sea Lion	*Neophoca cinerea*	EN
	New Zealand Sea Lion	*Phocarctos hookeri*	VU
	Galápagos Sea Lion	*Zalophus wollebaeki*	EN
Phocidae	Hooded Seal	*Cystophora cristata*	VU
	Mediterranean Monk Seal	*Monachus monachus*	EN
	Hawaiian Monk Seal	*Monachus schauinslandi*	EN

Source: IUCN (2010).

Currently, the authors are aware of no studies dealing with the interaction between pinnipeds and orientation or navigation relative to the Earth's geomagnetic field.

4.1.3. Polar Bear

There is a single species of polar bear (*Ursus maritimus*) and its distribution is limited to the Arctic region. Currently, there are no studies dealing with the interaction between polar bears and the Earth's geomagnetic field and it is also unlikely given their lifestyle that they would be affected by EM survey emissions.

4.1.4. Geomagnetic Navigation in Marine Mammals

Evidence of geomagnetic detection and orientation in cetaceans is limited and mostly theoretical. Unlike sea turtles and some species of fish, the young of which can be studied in sufficient numbers under controlled experimental conditions, whales and dolphins are difficult to study because of their sheer size, scarcity and mobility. The only evidence that cetaceans may be able to detect geomagnetic cues comes from comparing data on mass stranding locations and times to geomagnetic anomalies.

The first major study to suggest the existence of geomagnetic orientation in cetaceans was by Klinowska (1985, 1986). Klinowska (1985) analyzed 3,000 cetacean strandings that occurred over a 70-year period in the United Kingdom (U.K.) and found a pronounced difference between the passive strandings of dead animals and the active strandings of live animals. Whereas stranding sites for dead and decomposed bodies were widely distributed in different coastal regions, live strandings occurred exclusively where geomagnetic contour lines ran perpendicular to, or cut across, the coastline. The author proposed that whales traveling along geomagnetic contours would be diverted onshore in such areas. Active stranding sites were not correlated with tides, currents, common hydrography, or common geography. Most of the dead strandings involved species that live primarily in coastal waters. In contrast, active strandings were largely associated with oceanic species. This led Klinowska (1985) to speculate that these animals may have been outside familiar deep-water areas and hence exposed, perhaps for the first time, to the problems involved in following geomagnetic topography in shallow coastal waters.

Klinowska (1986) also reported that live strandings were correlated with geomagnetic disturbances and that strandings generally occurred 1-2 days after major geomagnetic storms. Animals also appeared to mass strand at places where lines of equal geomagnetic intensity ran parallel to the coastline and then suddenly turned to run perpendicular to the shore. The author postulated that animals make key navigational mistakes at some distance from the shore and that these errors ultimately result in live strandings. These events are associated with geomagnetic disturbances and that the pattern of geomagnetic disturbance, not the absolute level of the disturbance, is the key factor for live strandings. Klinowska (1986) further theorized that cetaceans time their migrations by detecting daily variations in the Earth's magnetic field that they use as a "biological travel clock". Geomagnetic disturbances may disrupt the daily cycle and the "clock" causing navigational errors.

Kirschvink et al. (1986) and Kirschvink (1990) found similar and/or supporting results for some United States (U.S.) strandings data of both odontocetes and mysticetes. Kirschvink et al. (1986) hypothesized that cetaceans possess a highly developed sensitivity to the geomagnetic field which enables them to use local variations for guidance, likely through the presence of specialized receptors capable of transducing weak geomagnetic stimuli to the nervous system. 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).

A live mass stranding of 19 white-sided dolphin in County Mayo, Ireland found results consistent with the previous major U.K. study, but the authors (Rogan et al. 1997) could not rule out other potential factors such as the presence of a sick male animal (the largest animal in the group) and a gradually sloping beach. A study of strandings data (1957-1998) in Hawaii associated mass strandings with fringing reefs, shallow water, sandy bottoms, and gradual sloping beaches with speculation (but no conclusive evidence) on some involvement of geomagnetic factors (Mazzuca et al. 1999).

A study of fin whale sightings during the Cetacean and Turtle Assessment Program (CETAP) aerial surveys over the continental shelf off the northeastern U.S. provided results consistent with the hypothesis that fin whales (and perhaps other baleen whale species) possess a magnetic sense used to travel in areas of low magnetic field gradient and possibly low magnetic intensity during migration (Walker et al. 1992). It remains unclear whether geomagnetic cues could be used in other non-migratory navigational activities. Kirschvink et al. (1986) suggested that geomagnetic cues, such as magnetic “hills” produced by seamounts superimposed on the undulating magnetic topography of the oceans, could be used by cetaceans to find areas, such as seamounts, often associated with higher levels of productivity than the surrounding waters. Therefore, cetaceans might show a seasonal and/or regional shift in magnetic state depending on the behavior being undertaken (use of lows during migration and highs during feeding; Kirschvink et al. 1986).

Vanselow and Ricklefs (2005) analyzed 300 years of North Sea strandings data for the sperm whale and found there to be a correlation with long-term sun spot cycles and stranding activity. The shorter the sun spot cycle, the lower were the number of strandings. They speculated that variations in the Earth’s magnetic field caused by variable energy fluxes from the sun may cause a temporary disorientation of the animals. Data would also be consistent with longer sun spot cycles recorded in the last two decades of the 20th century and a notable increase in sperm whale strandings in the North Sea. In a follow-up study, Vanselow et al. (2009) arrived at the same conclusion.

In contrast to authors who cite evidence for the use of geomagnetic cues in cetaceans, there are others who report no such indications. Hui (1994) found no association between magnetic patterns and the distribution of free-ranging dolphins. Brabyn and Frew (1994) examined whale strandings in New Zealand dating back to 1940 specifically following the analytical methods used by Klinowska (1985) and Kirschvink et al. (1986). The New Zealand cetacean strandings data showed no relationship to regions where geomagnetic contours were perpendicular to the coastline nor to geomagnetic maxima or minima. The authors note that one explanation for the difference in their results and those of

Klinowska (1985) and Kirschvink et al. (1986) is that much of New Zealand is surrounded by a shallow marine platform characterized by no consistent pattern in geomagnetic anomalies. In contrast, the sea floor off the east coast of the U.S. and the U.K. is characterized by strong magnetic lineation. In effect, New Zealand does not have a geomagnetic field of sufficient pattern or intensity to support a cetacean navigation system.

In summary, while there are suggestions that some oceanic cetaceans may somehow use geomagnetic cues for navigation, their use is not consistent across species or regions.

4.1.5. Hearing Abilities of Marine Mammals

While the focus of this EIA is on the effects of electromagnetic emissions, marine mammals are believed to be sensitive to anthropogenic underwater sound (e.g., potentially including that generated by ship propellors and thrusters, including those of EM survey vessels). Some types of EM surveys may require a relatively large amount of maneuvering using the ship's thrusters. Extensive thruster activity has the potential to create more underwater disturbance than steady propulsion noise during towing. Thus, a brief summary of relevant information is included here.

The hearing abilities of marine mammals are reviewed in Richardson et al. (1995) and Au et al. 2000). Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments and monitoring studies also show that they hear and may react to many man-made sounds (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

Mysticetes.—The hearing abilities of baleen whales (mysticetes) have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, with components to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 2000; Parks et al. 2007). Although humpbacks and minke whales may have some auditory sensitivity to frequencies above 22 kHz (Berta et al. 2009), for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear low frequency sounds farther away than can small toothed whales.

Odontocetes.—Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Richardson et al. [1995] and Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009).

Most of the odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

Pinnipeds.—Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for harbour seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbour seal).

***Polar Bear.*—**Data on the specific hearing capabilities of polar bears are limited. A recent study of the in-air hearing of polar bears applied the auditory evoked potential method while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. Although low-frequency hearing was not studied, the data suggested that medium- and some high-frequency sounds may be audible to polar bears. However, polar bears' usual behavior (e.g., remaining on the ice, at the water surface, or on land) reduces or avoids exposure to underwater sounds.

4.2. Sea Turtles

Currently, there are seven recognized species of sea turtles found worldwide. These include green, loggerhead, leatherback, hawksbill, Kemp's ridley, olive ridley, and Australian flatback sea turtles (Table 4.3). According to the latest revision of the *International Union for Conservation of Nature Red List of Endangered Specie*s (IUCN 2010), leatherback, hawksbill and Kemp's ridley sea turtles are classified as critically endangered, green and loggerhead turtles as endangered, and the olive ridley as vulnerable (Table 4.3). There are insufficient data for the Australian flatback sea turtle.

Table 4.3 Conservation designations for sea turtles based upon the latest *International Union for Conservation of Nature Red List of Endangered Species*. Critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), and data deficient (DD).

Common Name	Scientific Name	IUCN
Leatherback	*Dermochelys coriacea*	CR
Hawksbill	*Eretmochelys imbricata*	CR
Green	*Chelonia mydas*	EN
Loggerhead	*Caretta carette*	EN
Olive ridley	*Lepidochelys olivacea*	VU
Kemp's ridley	*Lepidochelys kempii*	CR
Australian flatback	*Natator depressus*	DD

Source: IUCN (2010).

Sea turtles undergo extensive migrations during the course of their lifetime. Newly hatched turtles of most species migrate offshore from their natal beaches into open-ocean convergence zones where they occupy driftline assemblages of seaweed and flotsam (Smith 1968; Fletmeyer 1978; Carr and Meylan 1980; Carr 1987; NRC 1990; Manzella et al. 1991; Witherington 1994; NMFS/USFWS 1996a, b). These convergence zones are areas of high productivity. The notable exception to this offshore movement is the Australian flatback sea turtle (*Natator depressus*), which remains in nearshore waters less than 200 m in depth (Bolton 2003). For the other species, this oceanic period of surface foraging may last from 2-20 years depending upon species and long-term oceanic conditions (Miller 1997; Musick and Limpus 1997). Little is known about this stage of sea turtle life and it is often referred to as "the lost years" (Carr 1982; Musick and Limpus 1997). During this pelagic phase, juvenile turtles can be dispersed for thousands of kilometers by major oceanic gyres and currents (Manzella and Fontaine 1988; Eckert and Martins 1989; Collard and Ogren 1990; Bolton et al. 1990).

When green, loggerhead, Kemp's ridley and hawksbill sea turtles reach subadult size they move to the shallow nearshore benthic feeding grounds that may be hundreds or even thousands of kilometers from their natal beaches (Carr 1987; NCR 1990; Bowen et al. 1995; Sears et al. 1995). Upon reaching sexual maturity, which may take from 15 to 45 years (Musick and Limpus 1997), sea turtles of all species migrate to mating areas. Once mating is completed, the males return to foraging grounds while the females migrate to nesting areas (Miller 1997).

4.2.1. Leatherback

The species has a circumglobal pelagic distribution and has the largest range of any sea turtle (Eckert 1999). There are three major, genetically distinct populations: the Atlantic, the East Pacific and the West Pacific populations. Although nesting is restricted to between 30°N and 30°S latitude, they have been reported from 60° N to 42° S latitude in the Pacific and are considered the most cold tolerant of all the sea turtles (Stinson 1984). Leatherbacks remain pelagic for most of their lives except when adults come onshore to lay eggs (NCR 1990; Musick and Limpus 1997; Bolton 2003). They swim continuously and migrate vast distances across deep oceanic waters and basins (Eckert and Sarti 1997; Eckert 1998). They routinely migrate to tropical waters to nest, then travel to productive, cold-water regions to feed on organisms associated with deep scatter layers (Eckhart et al. 1989). They forage throughout the water column to depths of 1,300 m (Eckert et al. 1986) feeding primarily on jellyfish, salps, and other gelatinous organisms (Bjorndal 1997).

4.2.2. Hawksbill

Hawksbills are found in all tropical seas between about 30°N and 30°S where waters are less than 16 m deep and where reefs, shoals, and estuaries are present (King 1995). Juveniles move onshore into demersal coral reef habitats at 20-25 cm in size and may even recruit as hatchlings (Musick and Limpus 1997). Juveniles and adults exhibit a strong association with hard bottom communities where they forage primarily on sponges, but may also consume bryozoans, coelenterates, and mollusks (Bjorndal 1997).

The hawksbill sea turtle has experienced global population declines of 80 percent or more during the past century and continued declines are projected (USFWS 2011a). Most populations are declining, depleted, or remnants of larger aggregations. Only five regional populations remain with more than 1,000 females nesting annually (Seychelles, Caribbean, Indonesia, and two in Australia). About 15,000 females are estimated to nest each year throughout the world with the Caribbean accounting for 20 to 30 percent of the world’s hawksbill population (USFWS 2011a). Panama, which used to support the single most important nesting population in the Caribbean, has only a remnant population. Mexico is now the most important region for hawksbills in the Caribbean with 3,000 to 4,500 nests/year. Other significant but smaller populations in the Caribbean still occur in Martinique, Jamaica, Guatemala, Nicaragua, Grenada, Dominican Republic, Turks and Caicos, Cuba, Puerto Rico, and U.S. Virgin Islands. In the U.S. Caribbean, about 100 to 350 nests/year are laid on Mona Island, Puerto Rico, and 60 to 120 nests/year on Buck Island Reef National Monument, U.S. Virgin Islands (USFWS 2011a). Pacific, hawksbills nest only on main island beaches in Hawaii, primarily along the east coast of the island of Hawaii. Hawksbill nesting has also been documented in American Samoa and Guam.

4.2.3. Olive Ridley

The olive ridley is distributed circumglobally throughout tropical and warm temperate waters and is widely regarded as the most abundant sea turtle in the world (NMFS/USFWS 1996d). It is the most common sea turtle in the East Pacific (Pitman 1990). The largest East Pacific nesting concentrations occur in southern Mexico and northern Costa Rica (Reviews by Eckert 1993; Cornelius 1995), with occasional nesting reported as far north as Baja California, Mexico (Fritts et al. 1982). In the Indian Ocean, it nests in great abundance in eastern India and Sri Lanka, although minor nesting also occurs at other localities. A small and declining population nests in the West Atlantic, primarily along the coasts of Surinam and French Guiana (USFWS 2011b). There are no known nesting sites of this species anywhere in the U.S. (NMFS/USFWS 1996d). The olive ridley has a tropical distribution and it has been suggested that the limits of its northern range are cold temperate waters (Pitman 1990). Olive ridley sea turtles remain pelagic for most of their lives except when adults come onshore to lay eggs (NRC 1990; Musick and Limpus 1997; Bolton 2003).

The West Atlantic (Suriname, French Guiana, and Guyana) nesting population has declined more than 80% since 1967 (USFWS 2011b). Declines are also documented for Playa Nancite, Costa Rica; however, other nesting populations along the Pacific coast of Mexico and Costa Rica appear stable or increasing. In the Indian Ocean, Gahirmatha located in the Bhitarkanika Wildlife Sanctuary, India supports perhaps one of the largest nesting populations in the world with an average of 398,000 females nesting in a given year (USFWS 2011b).

4.2.4. Green

The green sea turtle is a circumglobal species found in waters at temperatures above 20°C. This limits its range to tropical and subtropical waters along continental coasts and islands between 30°N and 30°S. Nesting occurs in over 80 countries throughout the year and they are thought to inhabit coastal areas of more than 140 countries (NOAA 2011).

It is the only sea turtle that is mostly herbivorous (Mortimer 1995). Throughout most of its range the green turtle forages primarily on sea grasses, but will feed on green, red, or brown algae when seagrasses are absent (Carr 1952; Pritchard 1971; Burke et al. 1992; Wershoven and Wershoven 1991; Mortimer 1995; Balazs et al. 1994; Forbes 1994). This usually limits its adult habitat to shallow coastal waters.

The main nesting sites for the East Pacific green turtle are in the state of Michoacan, southern Mexico and the Galapagos Islands, Ecuador (NMFS/USFWS 1996e). Minor rookeries are found in southern Mexico and along the Central American coast. There are no known nesting sites along the west coast of the U.S. Along the Pacific coast green/black turtles have been reported from Oregon (Forbes and Mckey-Fender 1968), British Columbia (Carl 1955) and in southern Alaskan waters (Hodge 1981). Stinson (1984) reported that the green/black turtle was the most commonly observed "hard-shell" sea turtle on the U.S. West Coast. Nearly 62% of green/black sightings are from Baja California and southern California. The northernmost reported resident population occurs in San Diego Bay where a small group of mature and immature individuals concentrate in the warm water effluent of the San Diego Gas and Electric Power Company power plant (Stinson 1984; Dutton and McDonald 1990a, 1990b, 1992; Dutton et al. 1994).

4.2.5. Loggerhead

Nesting of the loggerhead in the Pacific is restricted to western regions, primarily Japan and Australia, and there are no known nesting sites in the central and eastern Pacific (Dodd 1988; Eckert 1993). Despite the absence of known nesting sites in the central and eastern Pacific basin, juvenile loggerheads are abundant in waters off Baja California, Mexico (Bartlett 1989; Pitman 1990), and occasionally as far south as Chile (Eckert 1993). Both juveniles and adults are rare in waters of the western U.S. Most of these sightings are from southern California (Guess 1981a, 1981b; Stinson 1984) although there have been isolated sightings reported from Washington (Hodge 1982) and Alaska (Bane 1992). The abundance of juvenile loggerheads off Baja California, which is some 10,000-12,000 km from the nearest significant nesting sites, has lead to speculation that West Pacific hatchlings are entrained in the central ocean gyre, and ultimately drift south with the California current to Mexico (NMFS/USFWS 1996b). NMFS/USFWS (1996b) point out that if this dispersal hypothesis is true "it seems remarkable that there are relatively few records of this species in California".

4.2.6. Kemp's Ridley

Kemp's ridley nesting is extremely limited worldwide. They nest primarily along 30 kilometers of Gulf of Mexico (GOM) shoreline near Rancho Nuevo, Tamaulipas, Mexico, with incidental nesting occurring as far north as Padre Island, Texas (NRC 1990; Pritchard 1997). Isolated nests have also been reported on the Atlantic coast of Florida (Fletmeyer 1990, Meylan et al. 1990). Although some young may be carried up the U.S. east coast via the Florida current and the Gulf Stream where they may inhabit coastal areas as far north as Massachusetts (Carr 1980; Collard 1987; Ross et al. 1989), adults are found almost entirely in the GOM (NRC 1990).

In the GOM, the transition from pelagic to demersal neritic habitats takes place at a size of 20 to 25 cm (Musick and Limpus 1997). Turtles move into shallow, warm water areas close to shore (Carr 1980) where they feed primarily on crustaceans such as blue crab as well as molluscs, fish, vegetation, and shrimp (Bjorndal 1997). The Gulf coast from Port Aransas, Texas, through Cedar Keys, Florida, represents the primary habitat for subadult turtles in the northern GOM (Ogren 1988, as cited in GMFMC 2004). Juveniles and adults generally remain in shallow coastal habitats year round (Carr 1980; Musick and Limpus 1997) although there is some evidence of them moving offshore in the winter in response to low water temperatures (Musick and Limpus 1997). Migrations within the GOM, including for breeding adults, are limited to shallow, nearshore areas of the continental shelf (Hildebrand 1995). There is little open-ocean migration.

4.2.7. Flatback

The flatback sea turtle is endemic to the continental shelf of Australia. Nesting occurs across the top half of Australia, from Exmouth in Western Australia to Mon Repos Conservation Park in Queensland. The most significant breeding site is Crab Island in the western Torres Strait. Breeding may also occur on the islands of the southern Great Barrier Reef, and on mainland beaches and offshore islands north of Gladstone. Flatback turtles are usually found in bays, shallow, grassy waters, coral reefs, estuaries and lagoons on the northern coast of Australia and off the coast of Papua New Guinea.

4.2.8. Orientation and Navigation in Sea Turtles

Studies of orientation and navigation in sea turtles have focused primarily on newborn hatchlings. Their small size and seasonal availability makes them easy subjects for study. Evidence indicates that loggerhead hatchlings sequentially use three different sets of cues during their initial migration from their natal beaches out into the open ocean. Newly hatched turtles emerge from their nests and immediately crawl to the water using a combination of visual cues. Hatchlings appear to have a strong tendency to orient toward the brightest direction (Mrosovsky and Shettleworth 1968; Mrosovsky 1972). On undeveloped beaches, water reflects starlight and moonlight better than land and the brighter seaward horizon attracts the hatchlings. Green and loggerhead sea turtles also respond to visual cues that direct them toward open and lower horizons and away from elevated silhouettes (Limpus 1971; van Rhijn and van Gorkom 1983; Salmon et al. 1992). Under natural conditions, the composite visual mechanism causes hatchlings to crawl toward bright, low oceanic horizons and away from elevated silhouettes of vegetation and dunes that typically border the landward edge of the beach (Lohmann et al. 1997).

Once hatchlings reach the water they establish a course toward the open sea (Frick 1976; Salmon and Wyneken 1987). Open-ocean and wave-tank studies of hatchling loggerhead and green sea turtles have shown that when turtles enter the water they orient toward approaching waves and swells (Salmon and Wyneken 1987; Salmon and Lohmann 1989; Lohmann et al. 1990; Wyneken et al. 1990; Lohmann and Lohmann 1992). Because waves and swells in shallow coastal areas typically move toward shore, swimming into them establishes a seaward migration. At this point in turtle development, the wave cue appears to be an autonomous navigation system that does not involve other directional cues. Green sea turtles released in atypical weather conditions consistently swam into waves even when doing so resulted in the turtles heading back toward land (Lohmann and

Lohmann 1992). Visual cues do not appear to play a role in seaward migration as hatchlings orient into waves under a variety of lighting conditions including the absence of visible light (Salmon and Lohmann 1989; Lohmann et al. 1990; Lohmann and Lohmann 1992; Wyneken et al. 1990). Turtles actually orient while underwater by distinguishing the circular and surge patterns of waves (Lohmann et al. 1995a; Manning et al. 1997; Wang et al. 1998). Wave orientation appears to be a short-lived navigational cue that may only operate in extremely shallow waters. Witherington (1995) tracked loggerhead hatchlings and found that once turtles moved seaward of the surf zone, swimming and wave direction rarely coincided.

Once hatchling sea turtles reach the open ocean and for the remainder of their lives, other navigational mechanisms must assuredly come into play. One of the more widely studied theories is that sea turtles navigate by sensing and orienting to the Earth's geomagnetic field.

Lohmann (1991) was one of the first researchers to provide evidence that sea turtles may be capable of detecting the Earth's geomagnetic field. Newly hatched loggerheads were tested under laboratory conditions near Fort Pierce, Florida. When hatchlings were allowed to move freely within a test tank there was a statistically significant tendency for them to swim toward the northeast at a mean direction of 42°. The results were interesting given the life-history pattern of loggerhead turtles that nest on the east coast of Florida. Hatchlings emerging from nests immediately establish offshore headings toward the Gulf Stream Current (Salmon and Wyneken 1987) and the North Atlantic Gyre (Carr 1986, 1987). Turtles entrained into the Gyre are passively transported eastward across the North Atlantic to the East Atlantic, then drift south past the Azores and Canary Islands, eventually returning to the West Atlantic via the North Equatorial Current (Carr 1986). This trans-Atlantic journey has been repeatedly documented (Manzella and Fontaine 1988; Eckert and Martins 1989; Bolton et al. 1990, 1992). Lohmann (1991) reasoned that the results of the laboratory experiment were consistent with this migration pattern. Swimming to the northeast from Fort Pierce would take the turtles directly to the Gulf Stream. A second batch of turtles was tested under identical conditions except that the Earth's geomagnetic field was artificially reversed in polarity by 180°. Turtles from this second group exhibited a statistically significant tendency to swim in a SSW direction at a mean angle of 196°—essentially opposite to that of the group tested under normal geomagnetic conditions. Results suggested that the turtles were orienting in response to the polarity of the Earth's geomagnetic field.

Since then, studies have shown that juvenile loggerheads and leatherbacks can detect changes in their surrounding geomagnetic field (Light et al. 1993; Lohmann and Lohmann 1993, 1994a, 1994b, 1996a; Salmon and Lohmann 1993; Goff et al. 1995; Goff et al. 1998; Irwin and Lohmann 2002; Avins and Lohmann 2003, 2004).

There is little scientific evidence that adult sea turtles use geomagnetics as their primary navigation aid. Papi et al. (2000) attached six powerful static magnets to each of seven adult female green turtles on Ascension Island and then tracked the turtles by satellite during their 5-6 week migration to feeding grounds off the coast of Brazil. Courses were compared to those for eight control turtles without magnets. No differences between magnetically disturbed and undisturbed turtles were observed relative to navigational performance or the straightness of course. In displacement experiments, Luschi et al. (2001) found that displaced green turtles swam indirect, curved routes during their homing migration but usually approached Ascension Island from downwind suggesting that wind was used as a clue at that location. In a later study, Luschi et al. (2007) found that displaced, magnetically disturbed adult green sea turtles, used geomagnetic cues during open sea homing. However, the sample sizes were small and the mechanism remains unknown. Luschi et al (2007) noted that geomagnetic cues were likely not a critical component of green turtle navigation.

4.2.9. Diving Ability

Sea turtles are among the longest and deepest diving of the air-breathing vertebrates and are considered truly sub-aquatic (Lutcavage and Lutz 1997). In some cases, sea turtles may spend as little as 3 to 6% of their time at the surface where energetic and predation costs are high. In other cases, they may spend as much as 19 to 26% of their time at the surface, engaged in surface basking, feeding, orientation, and mating (Standora et al. 1984; Byles 1988; Keinath and MuMusick 1993; Plotkin 1994). The wide variation and surface habits both across and within species reflects size, physiological attributes, ecology, environment, and life history.

The central features of sea turtle diving ability include an efficient oxygen transport system and an extraordinary tolerance to hypoxia, which makes maximum use of limited oxygen stores, intermittent breathing patterns, and adjustable metabolism (Lutcavage and Lutz 1997). The most important respiratory adaptations for breath-hold diving are those that facilitate efficient and rapid gas exchange when the turtles are on the surface, and maximize oxygen storage and tissue oxygen delivery while they are submerged (Lutcavage and Lutz 1997).

The deepest diving of the sea turtles is the pelagic leatherback (Table 4.4). Dives of over 1,000 m have been reported on several occasions although routine diving is generally restricted to the upper 100 m of the water column. Olive ridley sea turtles routinely forage in the top 150 m although dives to nearly 300 m have been recorded. Because hawksbill, Kemp's ridley, and green sea turtles are shallow-water inhabitants (from 20 to 50 m) except during spawning migrations, routine diving depths typically reflect depth-to-bottom where they forage. The longest reported dives were a little over three hours for an olive ridley and five hours for a Kemp's ridley. In most cases, there seems to be no relationship between maximum dive depth and dive duration.

Table 4.4 Reported diving depths and durations for sea turtles.

	Dive Depth (m)		Dive Length (min)		
Species	**Maximum**	**Routine**	**Maximum**	**Routine**	**Source**
Loggerhead					
Post-nesting female	211-233	9-22		17-30	Sakamoto et al. (1990a, b)
Post-nesting female	99	13.5-16.6		14.8-20.5	Sakamoto et al. (1990a)
Subadult		9-22.		19-30	Soma (1985), Byles (1988)
Leatherback					
Post-nesting female	>1,000		37	4-11	Eckert et al. (1989)
Post-nesting female	475	50-80	37.4	10-14.5	Eckert et al. (1986)
Post-nesting female			2-11		Keinath and Musick (1993)
Subadult			7.7		Standora et al. (1984)
Adult females	506-1,186	18-66	72-86	15-23	Lopez-Meddilaharsu et al. (2009)
Olive Ridley					
Adult	254	100-150			Polovina et al. (2002)
Adult	408	<60			Swimmer et al. (2006)
Post-nesting female	290			54.3	Plotkin (1994)
Adult male				28.6	Plotkin (1994)
Adult females	120-140	30-50	135-200	20-45	McMahon et al. (2007)
Green					
Adults					
Daytime		1-4		1-18	Rice and Balazs (2008)
Nighttime		30-35		35-55	Rice and Balazs (2008)
Adult	110				Berkson (1967)
Adult	100	<50			Swimmer et al. (2006)
Subadult		<20	66	9-13	Brill et al. (1995)
Adult female			70	5-50	Hays et al. (1999)
Kemp's Ridely					
Subadult		,50	300	12.7-18.1	Soma (1985), Byles (1988)
Post-nesting female			167	16.7	Mendonca and Pritchard (1986)
Hawksbill					
Adult females		4-20		28-49	Houghton et al. (2008)
Adult females			73.5	56.1	Lutcavage and Lutz (1997)

Source: Bartol and Musick (2003) with additions.

4.2.10. Hearing Abilities of Sea Turtles

Sea turtles do not have an external ear or a tympanic membrane (Ridgway et al. 1969). The region that innervates the inner ear is covered by a thick-skin cutaneous plate, which consists of a ring of scales similar to but smaller than those on the rest of the head. The cutaneous plate serves as a sound receiving surface, and its vibratory movements are communicated inward to the middle and inner ear through fatty material that acts much like a fluid transmitting pressure waves. This system does not provide for good hearing in air but does provide for good hearing underwater (Ridgway et al. 1969).

Most studies of hearing in sea turtles is derived from auditory brainstem responses (ABR). The technique entails presenting an acoustical stimulus to the subject and recording the evoked neural responses from electrodes on the surface of the head (Bartol and Ketten 2006). In general, sea turtles do not respond to sounds above 1,000 Hz (Table 4.5). For green and loggerhead sea turtles, hearing is most sensitive at frequencies ranging from 200 to 600 Hz and auditory thresholds are roughly in the 80 to 100 dB re 1µPa range. Hearing thresholds for Kemp's ridley turtles are a bit higher starting at 103 dB re 1µPa. Age related differences are also apparent. For loggerhead, hearing sensitivity decreases with age with thresholds of 82 dB re 1µPa for 1-year-olds, 85 dB re 1µPa for 2-year-olds, and 94 dB re 1µPa for 3-year-olds.

According to the Office of Naval Research website (www.onr.navy. mil/focus/ocean/life/turtle4.htm), the only behavioral data available on sea turtle hearing capabilities is from a study at the New England Aquarium with one adult green sea turtle. Data indicate that the turtle hears tones ranging from 100 Hz to 500 Hz. Studies indicate that at 200 Hz the threshold is between 107 dB and 119 dB, and at 400 Hz with thresholds between 121 dB and 131 dB. Hearing is also most sensitive at lower frequencies of 100 to 200 Hz. The turtle is at least 70 years old.

Moein et al. (1995; as cited in Bartol and Musick 2003) investigated the use of sound as a sea turtle repellent. Juvenile loggerhead sea turtles were held in a 61 x 18 m enclosure in the York River, VA, and subjected to air gun noise. Sound frequencies of the airguns ranged for 100 to 1,000 Hz. Three decibels levels (175, 177, and 179 dB re 1µPa at 1 m) were used every five seconds for five minutes. Avoidance of the airguns was observed upon first exposure but the animals habituated to the noise. After three separate exposures the turtles no longer avoided the stimuli.

Table 4.5 Hearing thresholds of sea turtles based on auditory brainstem responses (ABR).

Common Name	Stage	Frequency (Hz)	Sound Level Threshold (dB re 1μP)	Most Sensative[1] Frequency (Hz)	Source
Green	Subadult	100-400	86-101	300	Bartol and Ketten (2006)
	Subadult	200-500	83-103	300	Bartol and Ketten (2006)
	Subadult	100-400	98-101	400	Bartol and Ketten (2006)
	Subadult	200-500	88-108	200	Bartol and Ketten (2006)
	Subadult	200-300	87-92	300	Bartol and Ketten (2006)
	Subadult	100-300	92-102	200	Bartol and Ketten (2006)
	Juvenile	100-800	98-117	600	Bartol and Ketten (2006)
	Juvenile	100-800	103-122	600	Bartol and Ketten (2006)
	Juvenile	100-800	94-120	600	Ketten and Bartol (2005)
	Subadult	100-500	96-106	600	Ketten and Bartol (2005)
	Juvenile	200-700			Ridgeway et al. (1969)
Loggerhead	1-year-old	100-900	82-97	500	Ketten and Bartol (2005)
	2-year-old	100-700	86-92	500	Ketten and Bartol (2005)
	3-year-old	100-400	94-102	300	Ketten and Bartol (2005)
	Juvenile	250-1,000			Bartol et al. (1999)
Kemp's ridley	Juvenile	100-500	110-117	100/200	Ketten and Bartol (2005)
	Juvenile	100-500	103-115	100	Bartol and Ketten (2006)
	Juvenile	100-500	111-117	200	Bartol and Ketten (2006)

[1] Frequency at the lowest sound level in range.

4.3. Fishes

There are thousands of species of fish worldwide and it is beyond the scope of this study to provide life history information on them. It is sufficient to state that a diverse assemblage of fishes inhabit all depths of all of the world's oceans and possess a wide variety of life histories. Electro-sensitive fishes (Elasmobranchs) are described in a separate section (Section 5.0); as the group of animals most likely to be affected by EM surveys, they are a primary focus of this EIA.

Research into geomagnetic orientation in fish has focused primarily on two groups that undergo long migrations: (1) salmon, and (2) eels of the genus *Anguilla*. Salmon hatch from freshwater spawning grounds then migrate out to sea where they can undergo extensive oceanic or coastal feeding migrations for hundreds or even thousands of kilometers. After spending their adult lives foraging and growing at sea, salmon migrate back to their natal rivers to spawn. *Anguilla* species have an opposite life cycle. They inhabit coastal rivers throughout the world but migrate back to oceanic breeding grounds to mate and spawn. In the Atlantic, the European eel (*A. anguilla*) migrates to spawning grounds in the Sargasso Sea off the southeastern coast of the U.S. where they spawn and presumably die (Facey and Van Den Avyle 1987). The American eel (*A. rostrata*) migrates from rivers on the U.S. east coast to the same general locale in the Sargasso Sea. Newly spawned eels are carried in the North Atlantic Gyre where they disperse back to rivers in the U.S or Europe. The fact that salmon and eels undergo long ocean migrations makes them likely candidates for a geomagnetic guidance system.

4.3.1. Salmonids and other Finfish

In outdoor tank studies of lake-migrating sockeye salmon fry, a number of studies reported that fish tended to swim in compass directions that would be consistent with their migration route and that they altered their directed movement in response to artificially-induced shifts in the surrounding magnetic field (Quinn 1980; Brannon et al. 1981; Quinn and Brannon 1982). But the ability of the fish to orientate to magnetic cues required exposure to either daytime or nighttime celestial cues. Authors concluded that young sockeye salmon have a magnetic compass but that other cues can over ride or perhaps even calibrate its influence. The migration of sockeye salmon to lake nursery areas is also known to be controlled by rheotaxic (currents) and olfactory (smell) cues (Brannon 1967, 1972; Raleigh 1967, 1971; Bodznick 1978a,b).

Quinn and Groot (1983) conducted outdoor tank studies of hatchery-reared chum salmon (*Oncorhynchus keta*). Fry from the stock being studied first migrate to sea in a southwesterly direction then move rapidly to the northwest up the coast of Vancouver Island, Canada, and north along the coasts of British Columbia and Alaska. Fry moved in the direction appropriate for their southwesterly migration to the sea and a 90° shift in the external magnetic field significantly altered fry orientation. Results were the same in both the presence and the absence of celestial cues.

Taylor (1986, 1987) likewise found that juvenile chinook salmon (*Onchorhyncus tshawytscha*) would orient in to geomagnetic fields and shift their orientation to artificially-induced changes in the field, but that they did so only in the dark. When the fish were exposed to daylight geomagnetic orientation was not evident. Taylor (1987) concluded that that the solar cue was able to override magnetically directed orientation.

Biological magnetite has been extracted from chinook salmon (Kirschvink et al. 1985), sockeye salmon (*Oncorhynchus nerka*) (Walker et al. 1988; Mann et al. 1988; Sakaki et al. 1990 [as cited in Yano et al. 1997]), Atlantic salmon (*Salmo salar)* (Moore et al. 1990) and chum salmon (Ogura et al. 1992). In their studies of sockeye salmon, Walker et al. (1988) further contended that single domain magnetite particles suitable for use in magnetoreception are produced in the skull of the fish throughout its life. By the time sockeye make their run to the sea, the amount of magnetite present is sufficient to provide the fish with a magnetoreceptor capable of detecting small changes in the intensity of the geomagnetic field. In brown trout (*Salmo trutta*), Walker (1997) showed that magnetically sensitive nerves in the ophthalmic branch of the trieminal nerve connect to specialized cells containing magnetite. In a related study, yellowfin tuna (*Thunnus thynnus*) demonstrated an ability to discriminate Earth-strength shifts (i.e., 10,000-50,000 nT) in the ambient magnetic field (Walker 1984).

Excluding the little research cited above, few studies have focused on the role of geomagnetic orientation in fish since the late 1980s and researchers appear to have lost interest in this theory. In their recent review of *The Ocean Life of Atlantic Salmon*, Hansen and Jacobsen (2000) devote only two brief paragraphs to the subject. In their review *Marine Fisheries Ecology*, Jennings et al. (2001) briefly allude to the possibility of a magnetic compass in fishes.

In the review *Sensory Processing in Aquatic Environment* (2003), Doving and Stabell (2003) sound a cautionary note on the idea of a "magnetic map" that could be used for navigation in fish.

> *"Before accepting that salmon make use of an assumed magnetic sense to form a hypothetical magnetic map, one should acknowledge the variations, or noise, in the Earth's magnetic field of several tens of nanoTeslas (nT) at any location, changing with a time scale of hours or days. These variations with time are in the same order of magnitude observed when moving 10 km in a north-south direction, or as the anomalies caused by natural variations of magnetic minerals in the bedrock (Dobrin and Savit 1988). In addition, both temporary variations due to magnetic storms (±200 nT), as well as the fixed magnetic anomalies (±200nT) caused by the magnetic minerals in the oceanic crust, may cast doubt on the prospects of forming an applicable magnetic map. Elaborate corrections using modern computers are always carried out on magnetic survey data before magnetic maps can be produced. It is not likely that a fish has this capacity. It should be noted also, that such a map should not only be formed, but also memorized by the migrating animal. Capabilities of this kind have yet to be demonstrated in fishes..."*

The authors concluded that

> *"...magnetic detection may at best be a remote tool in orientation ability of migrating fish."*

4.3.2. Eels

In general, studies of magnetic compass orientation in eels have had mixed results. Branover et al. (1970) and Ovchinnikov et al. (1973) reported that European eel elvers (larvae) allowed to freely move through a labyrinth showed marked preferences to certain geographical directions. When the surrounding magnetic field was neutralized, the preferences disappeared. Unfortunately, neither study adequately explained experimental and statistical procedures nor would these early papers stand up to current scientific scrutiny.

Rommel and McCleave (1973) used electrocardiograms to detect changes in the heart rates of American eels subjected to Earth-strength shifts in surrounding magnetic fields. Of 22 eels tested, only one exhibited a significant response to any of the magnetic conditions.

Zimmerman and McCleave (1975) tested the orientation and turning behavior of elvers of American eels in weak magnetic fields in both arena and maze tests. Some eels were tested under the Earth's normal magnetic field while others tests were conducted with the horizontal component of the Earth's magnetic field (normally 16,000 nT) lowered to 1,000 nT. Over the course of two months 57,633 experiments were conducted. No preference for any particular geographic direction was exhibited in either the normal or modified magnetic fields.

McCleave and Power (1978) studied the turning behavior of eels in a semi-circular test arena in which magnetic fields could be manipulated. Magnetic experiments examined turning angles in seawater only. They were also conducted under four field conditions: (1) in the Earth's normal field (54,000 nT), (2) in a null field (2,000 nT), (3) in a reversed field (54,000 nT), and (4) in an augmented field of 200,000 nT. Eels did not respond to any of the tests.

The only instance of magnetite deposition in eels was by Hanson et al. (1984a) who found magnetic material in the skull, vertebral column and pelvic girdle of the European eel. Hanson et al. (1984b) subsequently identified the particles as magnetite and hemotite (a-Fe_2O_3).

4.4. Invertebrates

The western Atlantic spiny lobster (*Panulirus argus*) has been the subject of several magnetic orientation studies. The spiny lobster 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

(Lohmann 1985; Lohmann et al. 1995b) They have also shown that they can orient in the field along specific geomagnetic compass bearings (Boyles and Lohmann 2003). Based upon the testing criteria of the studies, the authors concluded that lobsters orient to the polarity of the Earth's field (polarity compass) and not its inclination (inclination compass).

Lohmann and Willows (1987) observed the body angle alignment of the marine mollusc *Tritonia diomedea* (nudibranch) under two geomagnetic fields: the Earth's normal field, and a field in which the horizontal component of the Earth's field was neutralized. In the Earth's field, the orientation of the animals was significant along a mean angle of 87.6° (approximately east). Animals tested in the canceled field oriented randomly. Results suggested that eastward orientation was mediated by magnetic field detection. Preferred magnetic direction also shifted with the day of the lunar month. Lohmann et al. (1991) later found that there was altered electrical activity in the brain neurons of *Tritonia* in response to changes in ambient Earth-strength magnetic fields.

4.5. Sea Birds

According to the International Ornithological Congress (IOC), there are 233 families of birds worldwide (IOC 2010). Of these, 14 are considered families of pelagic or oceanic seabirds that live part of their lives ranging far out to sea. Conservation status is shown in Table 4.6.

Table 4.6 Conservation designations for seabirds based upon the latest *International Union for Conservation of Nature Red List of Endangered Species*. Critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT). Species listed as least concern (LC) and data deficient (DD) are not included.

		Common Name	**Scientific Name**	**IUCN**	**Habitat**
Procellariiformes					
	Diomedeidae				
		Amsterdam Albatross	*Diomedea amsterdamensis*	CR	Pelagic, S. Indian Ocean
		Antipodean Albatross	*Diomedea antipodensis*	VU	Pelagic, S. Pacific
		Tristan Albatross	*Diomedea dabbenena*	CR	Pelagic, S. Atlantic
		Southern Royal Albatross	*Diomedea epomophora*	VU	Pelagic, S. Oceans
		Wandering Albatross	*Diomedea exulans*	VU	Pelagic, S. Oceans
		Northern Royal Albatross	*Diomedea sanfordi*	EN	Pelagic, S. Oceans
		Short-tailed Albatross	*Phoebastria albatrus*	VU	Pelagic, N. Pacific
		Laysan Albatross	*Phoebastria immutabilis*	NT	Pelagic, N. Pacific
		Waved Albatross	*Phoebastria irrorata*	CR	Pelagic, Coastal, Peru
		Black-footed Albatross	*Phoebastria nigripes*	EN	Pelagic, N. Pacific
		Sooty Albatross	*Phoebetria fusca*	EN	Pelagic, S. Oceans
		Buller's Albatross	*Thalassarche bulleri*	NT	Pelagic, S. Pacific
		Indian Yellow-nosed Albatross	*Thalassarche carteri*	EN	Pelagic, S. Oceans
		Shy Albatross	*Thalassarche cauta*	NT	Pelagic, S. Oceans
		Atlantic Yellow-nosed Albatross	*Thalassarche chlororhynchos*	EN	Pelagic, S. Atlantic
		Grey-headed Albatross	*Thalassarche chrysostoma*	VU	Pelagic, S. Oceans

		Common Name	Scientific Name	IUCN	Habitat
		Chatham Albatross	*Thalassarche eremita*	VU	Pelagic, S. Pacific
		Campbell Albatross	*Thalassarche impavida*	VU	Pelagic, S. Oceans
		Black-browed Albatross	*Thalassarche melanophrys*	EN	Pelagic, S. Pacific
		Salvin's Albatross	*Thalassarche salvini*	VU	Pelagic, S. Oceans
		White-capped Albatross	*Thalassarche steadi*	NT	Pelagic, S. Oceans
		Great-winged Petrel	*Pterodroma macroptera*	LC	Pelagic, S. Oceans
	Procellariidae				
		Jouanin's Petrel	*Bulweria fallax*	NT	Pelagic, Indian Ocean
		Cape Verde Shearwater	*Calonectris edwardsii*	NT	Pelagic[1]
		White-chinned Petrel	*Procellaria aequinoctialis*	VU	Pelagic, S. Oceans
		Grey Petrel	*Procellaria cinerea*	NT	Pelagic, S. Oceans
		Spectacled Petrel	*Procellaria conspicillata*	VU	Pelagic, S. Oceans
		Parkinson's Petrel	*Procellaria parkinsoni*	VU	Pelagic, S. Oceans
		Westland Petrel	*Procellaria westlandica*	VU	Pelagic, S. Oceans
		Mascarene Petrel	*Pseudobulweria aterrima*	CR	Pelagic Madagasgar
		Beck's Petrel	*Pseudobulweria becki*	CR	Pelagic, SW Pacific
		Fiji Petrel	*Pseudobulweria macgillivrayi*	CR	Pelagic, Fiji
		Tahiti Petrel	*Pseudobulweria rostrata*	NT	S. Pacific
		Phoenix Petrel	*Pterodroma alba*	EN	S.Central Pacific
		Trindade Petrel	*Pterodroma arminjoniana*	VU	Pelagic, S. Atlantic
		Henderson Petrel	*Pterodroma atrata*	EN	Pelagic, Central Pacific
		Barau's Petrel	*Pterodroma baraui*	EN	Pelagic, S. Oceans
		Collared Petrel	*Pterodroma brevipes*	NT	Pelagic, Indian Ocean
		Bermuda Petre	*Pterodroma cahow*	EN	Pelagic, Bermuda
		Jamaica Petrel	*Pterodroma caribbaea*	CR	Pelagic, Jamaica
		White-necked Petrel	*Pterodroma cervicalis*	VU	Pelagic, Pacific
		Cook's Petrel	*Pterodroma cookii*	VU	Pelagic, Pacific
		De Filippi's Petrel	*Pterodroma defilippiana*	VU	Pelagic, Chile
		Juan Fernandez Petrel	*Pterodroma externa*	VU	Pelagic, E. Pacific
		Fea's Petrel	*Pterodroma feae*	NT	Pelagic, Central Atlantic
		Black-capped Petrel	*Pterodroma hasitata*	EN	Pelagic, Caribbean
		Atlantic Petrel	*Pterodroma incerta*	EN	Pelagic, S. Oceans
		Mottled Petrel	*Pterodroma inexpectata*	NT	Pelagic, Pacific
		Gould's Petrel	*Pterodroma leucoptera*	VU	Pelagic, S. Pacific
		Zino's Petrel	*Pterodroma madeira*	EN	Pelagic, N. Africa
		Magenta Petrel	*Pterodroma magentae*	CR	Pelagic, S. Pacific
		Galapagos Petrel	*Pterodroma phaeopygia*	CR	Pelagic, E. Central Pacific
		Pycroft's Petrel	*Pterodroma pycrofti*	VU	Pelagic, Atlantic
		Hawaiian Petrel	*Pterodroma sandwichensis*	VU	Pelagic, Hawaii
		Providence Petrel	*Pterodroma solandri*	VU	Pelagic, Pacific
		Murphy's Petrel	*Pterodroma ultima*	NT	Pelagic, E. Pacific
		Townsend's Shearwater	*Puffinus auricularis*	CR	Pelagic, Pacific, C.A.
		Buller's Shearwater	*Puffinus bulleri*	VU	Pelagic, Pacific
		Pink-footed Shearwater	*Puffinus creatopus*	VU	Coastal
		Sooty Shearwater	*Puffinus griseus*	NT	Pelagic, Circumglobal
		Heinroth's Shearwater	*Puffinus heinrothi*	VU	Pelagic, New Guinea
		Hutton's Shearwater	*Puffinus huttoni*	EN	Pelagic, Australia/N.Z.

		Common Name	Scientific Name	IUCN	Habitat
		Balearic Shearwater	*Puffinus mauretanicus*	CR	Pelagic, Europe
		Newell's Shearwater	*Puffinus newelli*	EN	Pelagic, Central Pacific
		Black-vented Shearwater	*Puffinus opisthomelas*	NT	Pelagic, Eastern U.S.
		Yelkouan Shearwater	*Puffinus yelkouan*	NT	Pelagic, Mediterranean
Pelicaniformes					
	Pelecanidae				
		Dalmatian Pelican	*Pelecanus crispus*	VU	Coastal, Inland
		Spot-billed Pelican	*Pelecanus philippensis*	NT	Coastal, Inland
		Peruvian Pelican	*Pelecanus thagus*	NT	Coastal, Inland
	Sulidae				
		Cape Gannet	*Morus capensis*	VU	Coastal
		Abbott's Booby	*Papasula abbotti*	EN	Coastal
	Phalacrocoraeidae				
		Guanay Cormorant	*Phalacrocorax bougainvillii*	NT	Coastal, Inland
		Campbell Island Shag	*Phalacrocorax campbelli*	VU	Coastal, Inland
		Cape Cormorant	*Phalacrocorax capensis*	NT	Coastal, Inland
		New Zealand King Shag	*Phalacrocorax carunculatus*	VU	Coastal, Inland
		Stewart Island Shag	*Phalacrocorax chalconotus*	VU	Coastal, Inland
		Auckland Islands Shag	*Phalacrocorax colensoi*	VU	Coastal, Inland
		Crowned Cormorant	*Phalacrocorax coronatus*	NT	Coastal, Inland
		Pitt Island Shag	*Phalacrocorax featherstoni*	EN	Coastal, Inland
		Red-legged Cormorant	*Phalacrocorax gaimardi*	NT	Coastal, Inland
		Flightless Cormorant	*Phalacrocorax harrisi*	EN	Coastal, Inland
		Bank Cormorant	*Phalacrocorax neglectus*	EN	Coastal, Inland
		Socotra Cormorant	*Phalacrocorax nigrogularis*	VU	Coastal, Inland
		Chatham Islands Shag	*Phalacrocorax onslowi*	CR	Coastal, Inland
		Bounty Islands Shag	*Phalacrocorax ranfurlyi*	VU	Coastal, Inland
	Fregatidae				
		Christmas Frigatebird	*Fregata andrewsi*	CR	Pelagic, Malasia
		Ascension Frigatebird	*Fregata aquila*	VU	Pelagic, S. Atlantic
Charadriiformes					
	Laridae				
		Inca Tern	*Larosterna inca*	NT	Coastal
		Olrog's Gull	*Larus atlanticus*	VU	Coastal
		Audouin's Gull	*Larus audouinii*	NT	Mediterranean
		Black-billed Gull	*Larus bulleri*	EN	Coastal
		Lava Gull	*Larus fuliginosus*	VU	Coastal
		Heermann's Gull	*Larus heermanni*	NT	Coastal
		White-eyed Gull	*Larus leucophthalmus*	NT	Coastal
		Relict Gull	*Larus relictus*	VU	Inland
		Saunders's Gull	*Larus saundersi*	VU	Coastal
		Ivory Gull	*Pagophila eburnea*	NT	Arctic
		Red-legged Kittiwake	*Rissa brevirostris*	VU	Pelagic, N. Pacific
		Indian Skimmer	*Rynchops albicollis*	VU	Coastal
		African Skimmer	*Rynchops flavirostris*	NT	Coastal
		Black-bellied Tern	*Sterna acuticauda*	NT	Coastal
		Black-fronted Tern	*Sterna albostriata*	EN	Coastal

		Common Name	**Scientific Name**	**IUCN**	**Habitat**
		Damara Tern	*Sterna balaenarum*	NT	Coastal
		Chinese Crested Tern	*Sterna bernsteini*	CR	Coastal
		Elegant Tern	*Sterna elegans*	NT	Coastal
		Peruvian Tern	*Sterna lorata*	EN	Coastal
		Fairy Tern	*Sterna nereis*	VU	Coastal
		Kerguelen Tern	*Sterna virgata*	NT	Pelagic S. Oceans
	Alcidae				
		Kittlitz's Murrelet	*Brachyramphus brevirostris*	CR	Coastal
		Marbled Murrelet	*Brachyramphus marmoratus*	EN	Coastal
		Long-billed Murrelet	*Brachyramphus perdix*	NT	Coastal
		Craveri's Murrelet	*Synthliboramphus craveri*	VU	Coastal
		Xantus's Murrelet	*Synthliboramphus hypoleucus*	VU	Coastal
		Japanese Murrelet	*Synthliboramphus wumizusume*	VU	Coastal
[1] Small area off Africa					

Source: IUCN (2010).

Although geomagnetic navigation has been demonstrated in several species of terrestrial birds, few seabirds have been studied (Thorup and Holland 2009; Wiltschko and Wiltschko 2009). In experiments with juvenile herring gull and ring-billed gull, orientation to a migratory heading toward the species' usual wintering grounds is disrupted in experiments in which the earth's magnetic field is disturbed by magnetic storms or by the placement of magnets on the birds or in their cages (Southern 1972, 1974; Moore 1975). In contrast, placing magnets on the heads of procellariiforme seabirds (black-browed albatross *Thalassarche melanophris*, wandering albatross *Diomedea exulans*, and white-chinned petrel *Procellaria aequinoctialis*) did not prevent them from homing to nesting colonies when returning from their typically long foraging trips (Benhamou et al. 2003; Bonadonna et al. 2003; Bonadonna et al. 2005).

One of the more notable examples of multiple navigation systems at play comes from studies of homing pigeons as reviewed by Wiltschko and Wiltschko (1996). In pigeons, the magnetic compass is involved in the learning processes that lead to the establishment of the sun compass. Young, inexperienced pigeons use the magnetic compass before they can use the sun compass (Wiltschko and Wiltschko 1981), and there are indications that the magnetic compass serves as a directional reference system to establish the sun compass (Wiltschko et al. 1983). Later, however, the sun compass becomes the preferred system. This development is demonstrated by the effects of manipulating the birds' internal clock, which alters the readings of the sun compass without affecting the magnetic compass: these birds show characteristic deflections from the mean headings of untreated controls (e.g., Schmidt-Koenig 1961). However, a recent analysis of clock-shift experiments suggests that the magnetic compass is possibly still involved to some extent (Wiltschko et al. 1994). Also, the magnetic compass may play an important role when clock-shifted pigeons return home. Despite their deflected departure directions, the majority of these birds return on the day of release, i.e. before the sun compass is readjusted. It seems most likely that in these cases the sun compass is abandoned in favor of the magnetic compass.

The interaction of the magnetic compass and the star compass in the orientation of nocturnal migrants is more complex. The star compass develops with celestial rotation as a directional reference, independently from the magnetic field (Emlen 1970; Wiltschko et al. 1987). During the pre-migratory phase, celestial rotation proved dominant over magnetic information in cases of conflict; it altered the migratory course with respect to the magnetic field (e.g., Bingman 1983; Able and Able 1990, 1993, 1995; Prinz and Wiltschko 1992). However, when celestial cues and the magnetic field gave conflicting information during migration, the magnetic compass turned out to be the dominant system that changed the directional significance of the stars (e.g., Wiltschko and Wiltschko 1975a,b; Bingman 1987; Beason 1989) and of the pattern of the polarized light at sunset (Bingman and Wiltschko 1988).

A review of recent literature revealed that seabirds have not been studied at the frequencies, electric field strengths and magnetic field strengths at levels of those produced by EM surveys. However, reported effects at levels produced near high-voltage electrical transmission lines (Fernie and Reynolds 2005; Dell'Omo et al. 2009) are unlikely to occur during EM surveys because of attenuation and short exposure times.

4.6. Sensitive Habitats

Sensitive habitats may include critical habitat for migration, feeding or reproduction for any of the groups discussed in the previous sections. In addition, sensitive benthic habitats may include chemosynthetic communities and coral reefs. These habitat types should be identified during the site-specific EIA process. Special mitigations may be required in these areas. For example, more precise positioning and handling of receiver anchors may be required in areas containing sensitive benthic habitat.

5.0 ELECTRORECEPTIVE FISHES (ELASMOBRANCHS)

Organisms generate electric fields associated with virtually every type of biological activity. The entire nervous system operates under a regime of fluctuating voltage potentials across cell membranes that are propagated along neural pathways throughout the body (Stryer 1988). Electrical synapses in the central nervous systems of vertebrates synchronize the activity of neurons that control rapid movements such as the tail-flapping reflex in fish (Campbell 1990). The flexing of muscle requires stimulation for electrically excited motor neurons. Epithelia (membranes) such as those found in gills have electric potential across them and are electric current sources. In fishes, the rhythmic opening and closing of the mouth and gill operculi (flaps) while ventilating produces an electric signal that exceeds the detection threshold for many electroreceptive fish (von der Emde 1998). 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. Particularly strong fields emanate from wounded crustaceans (Kalmijn 1971).

Within the animal kingdom there are groups of fishes that are classified as electroreceptive because they can sense weak electric currents. The principal group of electroreceptive fishes in the marine environment are the elasmobranchs (sharks, skates, and rays), and chimeras or deep sea ratfish (von der Emde 1998). Very little research has been conducted on chimerids.

According to the *IUCN Species Survival Commission Shark Specialists Group* (Camhi et al. 2009), there are 64 species of pelagic sharks and rays worldwide (skates are shallow-water species). Of these, none are considered critically endangered, whereas four are endangered, 16 vulnerable, and 15 near threatened (Table 5.1).

5.1. Commercial Fisheries

Pelagic sharks and rays are taken in fisheries in all the world's oceans (Camhi et al. 2009). In most regions their catch in longline, purse-seine, and gillnet fisheries is well known but poorly understood. Management of these pelagic fisheries is poor and although there are national and international requirements for reporting catches, landings and discards, compliance is poor. The U.N. Food and Agriculture Organization (FAO) is the primary collector of global fishery data.

Table 5.1 Conservation designations for elasmobranchs based upon the latest *IUCN Species Survival Commission Shark Specialists Group*. Critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT). Species listed as least concern (LC) and data deficient (DD) are not included.

Species Endangered	**Common Name**	**Red List Category**	**Classification**	**Depth Range (m)**
Aetomykaeys vesoertukui	Ornate eagle ray	EN	Semipelagic	110
Mobula mobula	Giant devilray	EN	Oceanic	surface->200?
Sphyrna lewini	Scalloped hammerhead	EN	Semipelagic	surface->275?
Sphyrna mokarran	Great hammerhead	EN	Semipelagic	surface->80
Vulnerable				
Rhincodon typus	Whale shark	VU	Oceanic	surface->1,000
Odontaspis ferox	Smalltooth sand tiger	VU	Semipelagic	20-850
Alopias pelagicus	Pelagic thresher	VU	Oceanic	surface->152
Alopias superciliosus	Bigeye thresher	VU	Oceanic	surface-723
Alopias vulpinus	Thresher shark	VU	Oceanic	surface-366
Cetorhinus maximus	Basking shark	VU	Semipelagic	surface->1,250?
Carcharodon carcharias	Great white	VU	Oceanic	surface->1,000
Isurus oxyrinchus	Shortfin mako	VU	Oceanic	surface->500
Isurus paucus	Longfin mako	VU	Oceanic	?
Lamna nasus	Porbeagle shark	VU	Oceanic	surface->700
Galeorhinus galeus	Tope shark	VU	Semipelagic	1-800
Carcharhinus longimanus	Oceanic whitetip shark	VU	Oceanic	surface->200
Carcharhinus obscurus	Dusky shark	VU	Semipelagic	surface-400
Carcharhinus plumbeus	Sandbar shark	VU	Semipelagic	surface-280
Carcharhinus signatus	Night shark	VU	Semipelagic	surface-600
Sphyrna zygaena	Smooth hammerhead	VU	Semipelagic	surface->200?
Near-Threatened				
Chlamydoselachus anguineus	Frilled shark	NT	Semipelagic	51-1,440
Hexanchus griseus	Bluntnose sixgill shark	NT	Semipelagic	surface-2,000
Aetobatus narinari	Spotted eagle ray	NT	Semipelagic	surface-60
Manta birostris	Manta	NT	Oceanic	surface->200?
Mobula japanica	Spinetail devilray	NT	Oceanic	?
Pseudocarcharias kamoharai	Crocodile shark	NT	Oceanic	surface->590
Carcharhinus albimarginatus	Silvertip shark	NT	Semipelagic	surface->800
Carcharhinus brachyurus	Bronze whaler	NT	Semipelagic	surface-100
Carcharhinus brevipinna	Spinner shark	NT	Semipelagic	<5->75
Carcharhinus falciformis	Sikly shark	NT	Oceanic	surface->500
Carcharhinus galapagensis	Galapagos shark	NT	Semipelagic	2->180
Carcharhinus leucas	Bull shark	NT	Semipelagic	surface->152
Carcharhinus limbatus	Blacktip shark	NT	Semipelagic	surface-30
Galeocerdo	Tiger shark	NT	Semipelagic	surface-140
Prionace glauca	Blue shark	NT	Oceanic	surface-350

Source: Camhi et al. (2009).

In 2007, 134 fishing countries voluntarily submitted shark landings data to the FAO (Table 5.2). Blue sharks (*Prionace glauca*) and thresher sharks (*Alopias* spp.) dominated global catch, the former being taken primarily in the Atlantic and the latter almost exclusively in the Pacific. Although FAO offers the most comprehensive fisheries database available, its quality suffers from poor research and management priorities in most nations (Camhi et al. 2009). In addition to widespread under-reporting, intentional under-representation of elasmobranch catches is prevalent. FAO data are further limited to landings data only and do not account for discards. Longline fishing for highly migratory species has an average discard rate of 28%, and the blue shark is the most commonly discarded species from longlines (Maguire et al. 2006). Overall, experts believe that FAO data greatly underestimate the level of fishing mortality and even landings for all species (Camhi et al. 2009).

Table 5.2 Globally-reported landings (tonnes) of pelagic elasmobranch species and species groups in 2007.

Species or Species Group	Common Name	Atlantic	Indian	Pacific	Total
Alopias pelagicus	Pelagic thresher	*	*	2,556	2,556
Alopias spp.	Thresher sharks	4	830	15,049	15,833
Alopias superciliosus	Bigeye thresher	210	*	100	310
Alopias vulpinus	Thresher sharks nei	210	2	236	448
Carcharhinus falciformis	Sikly shark	69	983	1,433	2,485
Carcharhinus longimanus	Oceanic whitetip shark	14	*	*	14
Carcharodon carcharias	Great whiteshark	*	*	<0.5	<0.5
Cetorhinus maximus	Basking shark	82	*	7	89
Isurus oxyrinchus	Shortfin mako	4,496	407	866	5,769
Isurus paucus	Longfin mako	2	*	*	2
Isurus spp.	Mako sharks	33	*	120	153
Lamna nasus	Porbeagle shark	808	9	70	887
Manta spp., *Mobula* spp.	Mantas, devilrays nei	*	*	3,310	3,310
Prionace glauca	Blue shark	35,706	3,843	5,538	45,087
Pseudocarcharias kamoharai	Crocodile shark	7	*	*	7
Sphyrna lewini	Scalloped hammerhead	150	*	52	202
Sphyrna spp.	Smooth hammerhead	3,389	119	137	3,645
Sphyrna zygaena	Smooth hammerhead	181	*	138	319
Subtotal pelagic species		45,361	6,193	29,612	81,116
[a]* = no FAO landings reported from this ocean in 2007.					
[b] Total includes 4,037t from the Southern Ocean.					

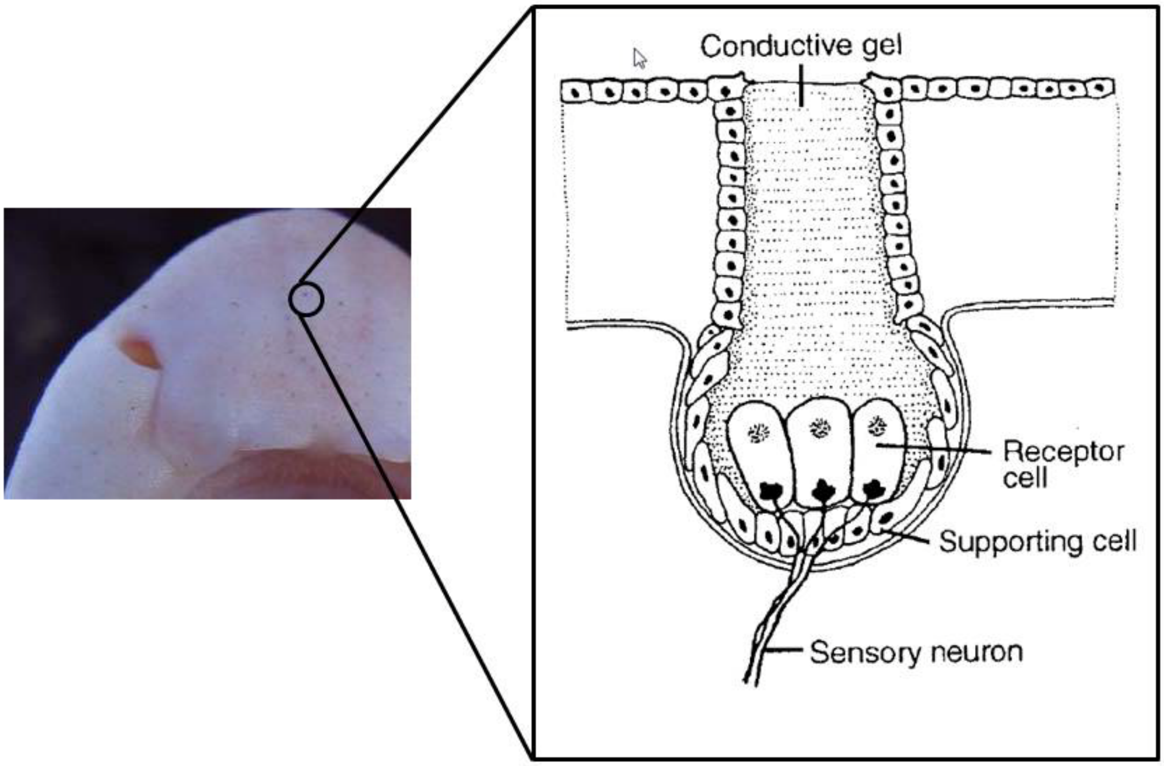
Source: FAO (2009) as cited in Camhi et al. (2009).

5.2. Electroreception in Elasmobranchs

There are two types of electroreceptor organs: ampullary receptors, which are termed the ampullae of Lorenzini in elasmobranchs (sharks, skates, and rays), and tuberous electroreceptors. Tuberous electroreceptor organs are found exclusively in the freshwater South American Gymnotids and African Mormyrids (von der Emde 1998) and, therefore, are not relevant to this report.

Ampullae of Lorenzini appear to be present in all elasmobranch species. Ampullae are found scattered over the head in sharks, and the head and pectoral fins in skates and rays. In marine species, ampullae consist of clusters of up to 400 tube-like canals each about 1 mm in diameter and up to 20 mm in length (Figure 5.1). Each canal runs from an opening in the skin down to basal swellings called ampullae. Electroreceptor cells line the walls of the ampullae, and each has a synaptic contact with an electrosensory nerve fiber. The canals are filled with transparent, jelly-like mucopolysaccharides that have an electric resistance similar to surrounding seawater. In contrast, the walls of the canals, the intervening connecting tissue, and the skin of the fish have much higher electrical resistances. The canals act as electrical cables connecting receptor nerve cells deep within the fish with the outside medium. There are also inherent structural components of the ampullae that shunt high frequency fields away from basal receptor cells making them low frequency electroreceptive organs that are most sensitive to frequencies between 1 to 8 Hz (von der Emde 1998; Bleckman and Hofmann 1999; Bodznick et al. 2003).

Internal-external voltage gradients drive the electroreceptor system. When the outside medium becomes electrically negative relative to the inside, the potential is conducted through the canal to the receptor cell where it depolarizes the cell membrane. This depolarization leads to an increase in the electrical impulse frequency within the connecting nerve fiber. Conversely, when the external medium becomes electrically positive relative to the inside, the potential is conducted down the canals to the receptor cell where it hyperpolarizes the cell membrane. This causes a decrease in nerve impulse activity. The sensitivity of the ampullary receptor cells results from the constant interplay between negative and positive electrical potentials that are continually transmitted along the canals. The amplitude and frequency of the encoded stimuli are transmitted to the brain via nerve connections to the receptor cell. The clustering of ampullae and canals within the ampullae over the surface of the body result in unequal stimulation relative to weak electric fields proximal to the fish. This unequal stimulation enables elasmobranchs to determine the intensity, spatial configuration and direction of the low-frequency electrical source (von der Emde 1998; Tricus 2001).



Source: Modified from Helfman et al. 2002.

Figure 5.1 Ampullae of Lorenzini.

It is well documented that ampullae of Lorenzini in marine species are capable of detecting weak electric currents in seawater (Murray 1960, 1962; Kalmijn 1966, 1971). Kalmijn (1966) showed that swimming sharks and rays exhibited avoidance responses when subjected to voltage gradients of 1-10 µV cm^{-1} (1,000-10,000 nV cm^{-1}). Sedate sharks and rays visibly responded to a square wave field of 5 Hz with a voltage gradient of 0.1 µV cm^{-1}(100 nV cm^{-1}). Changes in the heart rate of a ray were detected down to a voltage gradient of 0.01 µV cm^{-1} (10 $nVcm^{-1}$). The dogfish (*Mustelus canis*) showed behavioral responses to gradients as low as 5 nV/ cm^{-1} (Kalmijn 1982). The blacktip reef shark (*Carcharhinus melanopterus*) and whitetail stingray (*Himantura granulata*) both showed threshold responses at about 4 nV cm^{-1} (Haine et al. 2001). Results from additional studies are listed in Table 5.3.

Table 5.3 Electroreceptive thresholds: b is from behavioral studies; e is from electrophysiological recordings of afferent nerves or fibers. 2AFC = two-alternative forced-choice experiment; JND = just notable difference defined according to different criteria.

Common Name	Scientific Name	b (Vcm^{-1})	e (Vcm^{-1})	Criterion	References
Skate	*Raja* sp.		1.0×10^{-6}	JND spike rate	Murray (1960)
Skate	*Raja* sp.		1.0×10^{-6}	JND spike rate	Murray (1962)
Small-Spotted Catshark	*Scyliorhinus canicula*		1.0×10^{-6}	JND spike rate	Murray (1962)
Small-Spotted Catshark	*Scyliorhinus canicula*	1.0×10^{-7}		Eyeblink reflex	Dijkgraaf and Kalmijy (1962)
Thornback Ray	*Raja clavata*	1.0×10^{-7}		Respiratory reflex	Dijkgraaf and Kalmijy (1962)
Small-Spotted Catshark	*Scyliorhinus canicula*	1.5×10^{-6}		Eyeblink reflex	Dijkgraaf and Kalmijy (1963)
Thornback Ray	*Raja clavata*	1.0×10^{-8}		Bradycardia	Dijkgraaf and Kalmijy (1966); Kalmijn (1966)
Common Stingray	*Raja* sp., *Trigon pastinaca*		2.0×10^{-7}	JND spike rate	Akoev and Ilyinskii (1972)
Common Stingray	*Trigon pastinaca*		2.0×10^{-7}	JND spike rate	Andrianov et al. (1974)
Common Stingray	*Trigon pastinaca*		2.0×10^{-8}	JND spike rate	Akoev et al. (1974)
Eyed Electric Ray	*Raja torpedo*		2.0×10^{-8}	JND spike rate	Akoev et al. (1975)
Smooth Dogfish	*Mustelus canis*	1.9×10^{-8}		Head turning, dipole	Kalmijn (1982)
Nurse Shark	*Ginglymostoma cirratum*	5.0×10^{-9}		2AFC, a.c., uniform[4]	Johnson et al. (1984)
Nurse Shark	*Ginglymostoma cirratum*	1.0×10^{-8}		2AFC, a.c., uniform[4]	Johnson et al. (1984)
Nurse Shark	*Ginglymostoma cirratum*	2.5×10^{-8}		2AFC, d.c., dipole	Johnson et al. (1984)
Small-Spotted Catshark	*Scyliorhinus canicula*	2.0×10^{-8}		Respiratory reflex	Peters and Evers (1985)
Spotted Ratfish	*Hydrolagus colliei*	2.0×10^{-7}	2.0×10^{-7}	Avoidance, JND	Fields et al. (1993)
Skate	*Raja* sp.		$<3.0 \times 10^{-6}$	JND spike rate	Lu and Fishman (1994)
Round Stingray	*Urobatis halleri*		2.0×10^{-8}	JND spike rate	Tricas and New (1998)
Sandbar Shark	*Carcharhinus plumbeus*	1.0×10^{-9}		Head turning	Kajiura and Holland (2002)
Scalloped Hammerhead	*Sphyrna lewini*	1.0×10^{-9}		Head turning	Kajiura and Holland (2002)
Bonnethead	*Sphyrna tiburo*	1.0×10^{-9}		Head turning	Kajiura (2003)
Bonnethead	*Sphyrna tiburo*	2.0×10^{-8}		Head turning	Kajiura (2003)
Bonnethead	*Sphyrna tiburo*	4.7×10^{-8}		Head turning	Kajiura (2003)
Sea Lamprey	*Petromyzon marinus*	1.0×10^{-7}		Orientation	Chung-Davidson et al. (2004)

Source: Peters et al. (2007).

Despite evidence that elasmobranchs can detect DC electric fields, ampullae of Lorenzini are not DC receptors. Rather, they detect changes in the surrounding electric field, making them AC receptors with an adaptation time constant of about 3-5 seconds (Kalmijn 2003). When a shark, skate, or ray moves in a straight line for more than 3-5 seconds at a constant velocity in a uniform DC field, its sense organs do not register the field. Ampullae can only detect AC changes in the field. The fish must actually explore and probe its surroundings by purposely varying its direction of travel (Kalmijn 2003).

It is the unequal clustering of ampullae over the surface of the body that enables elasmobranchs to determine, by constant intra-ampullae comparison of microchanges in the surrounding field, the intensity, spatial configuration and direction of the electrical source.

There is preliminary evidence that electric organs are used for communication in several species of skates (Bratton and Ayers 1987) and electric organs appear to be universal within all 234 species of skates (Rajidae) (Jacob et al. 1994). Also, electrocyte morphology and size of electric organ varies among genera of skates and both may be species specific (Jacob et al. 1994). Discharge also varies among different species and probably among different genera (Brock et al. 1953; Bratton and Ayers 1987).

Electrosensitivity may also be a function of the depth at which the animals live. In a study of skate species that live at depths ranging from 63 to 2,058 m, Raschi (1986; cited in Collin and Whitehead 2004) found that the number and size of ampullae increased significantly with depth. Results suggest that species inhabiting deeper regions of the ocean, where sunlight does not penetrate, possess higher numbers of receptor cells and may rely more heavily on electroreception (Raschi and Adams (1988; cited in Collin and Whitehead 2004).

5.2.1. Range of Sensitivity

Despite the extraordinary electrosensory capabilities of elasmobranchs, the effective range for detection of prey in nature is rather short. This is not because ampullae are short-range sensors. But the electric fields produced by aquatic organisms are very weak and the elasmobranch must pass close to the source to detect them. Haine et al. (2001) conducted electrosensory studies on the blacktip reef shark (*Carcharhinus melanopterus*) and whitetail stingray (*Himantura granulata*) and found that both exhibited threshold responses at about 0.004 $\mu V\ cm^{-1}$ (4 $nV\ cm^{-1}$). Kajura and Holland (2002) obtained similar results for scalloped hammerhead shark (*Sphyrna lewini*) and sandbar sharks (*Carcharhinus plumbeus*) with median behavioral responses of 0.025 to 0.030 μVcm^{-1}(25-30 $nV\ cm^{-1}$). Haine et al. (2001) also measured the electrical field strengths emitted by five invertebrate and three fish taxa (Table 5.4).

The electric fields generated by invertebrates were size dependant with large specimens giving off stronger fields. For both invertebrates and fish, fields were strongest at their anterior ends presumably because of the closer proximity to physical and neural activity associated with feeding and respiratory processes. Peak fields were about 100 µV cm^{-1} (100,000 nV cm^{-1}), many times higher than the threshold level of the shark and skate. But electric potentials decreased significantly with distance. For the bivalve *Mactra* sp., electric field intensity dropped 10 fold at a distance of 9 cm from the siphon. For the fish, decrease in potentials with distance from the mouth decayed with a relationship of $V \alpha 1/r^4$, where r is the radial distance in cm. 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.

Table 5.4 Electric field strengths at 1 mm from source for various marine taxa.

Common Name	Scientific name	Carapace Width (cm)	Voltage (nV cm^{-1})		
			Anteriorly	Laterally	Posteriorly
Invertebrates					
Bivalve	*Mactra* sp.	-	20,000-100,000		1,000-2,000
Brachyuran Crab	*Thalamita crenata*	10	20,000-100,000	50,000-100,000[1]	1,000-2,000
Hermit Crab	*Pagurus* spp.	1	2,000		
Brachyuran Crab	*Matuta* spp.	-	10,000		10,000
Shore Crab	*Sesarma* spp.	2	2,000		1,000
Fish					
Damselfish	*Pomocentrus amboinensis*	-	40,000-100,000	3,000	1,000-2,000
Sand Smelt	*Sillago sihama*	-	40,000-100,000	3,000	1,000-2,000
Whipfin Silverbiddy	*Gerres filamentosus*	-	40,000-100,000	3,000	1,000-2,000

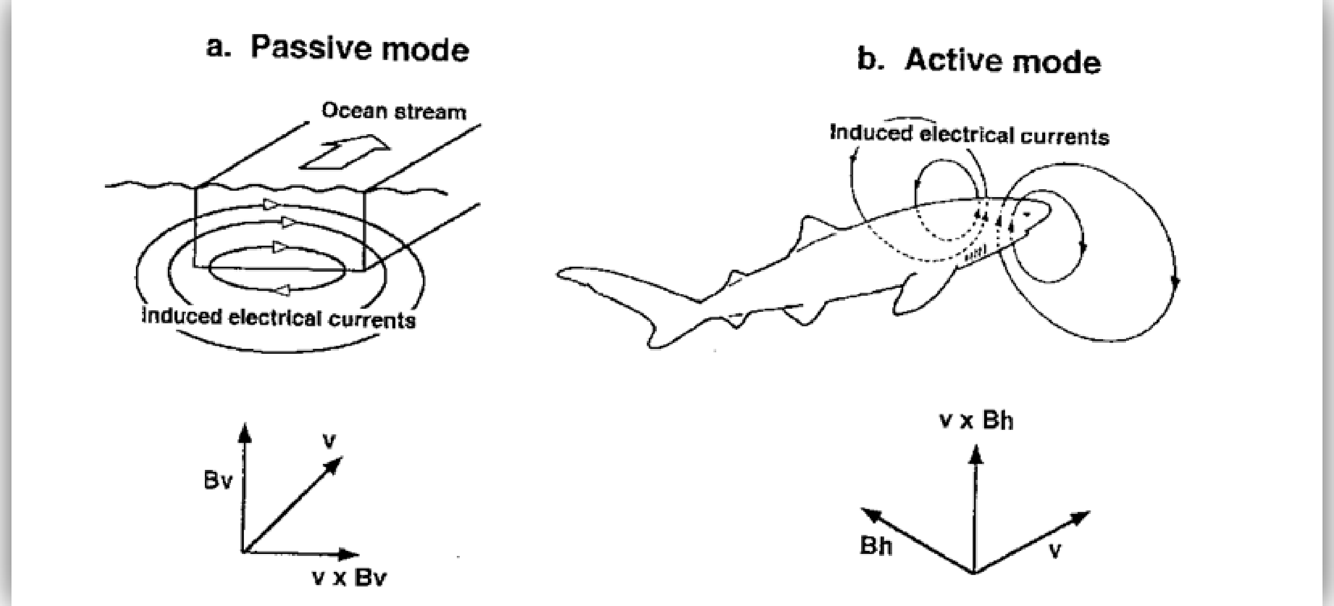
[1] Just below the chelipeds

Source: Haine et al. (2001).

5.2.2. Electroreception and Navigation

Kalmijn (1982, 1984, 2000, 2003) proposed that the electroreceptive system in elasmobranchs could allow them to orient and navigate using the Earth's geomagnetic field (see Figure 5.2). As described in Section 3.0, Faraday's Law states that an electromotive force is induced in a conductor moving in a magnetic field. In the ocean, the movement of water within the Earth's magnetic field gives rise to electric currents via the same principal of induction. DC voltage gradients resulting from currents in the Atlantic typically range from 0.05 to 0.5 µV cm^{-1} (50-500 nV cm^{-1}) (von Arx 1962 as cited in Kalmijn [1971]). The voltage gradient associated with the strong tidal currents in the English Channel reach 0.25 µV cm^{-1} (250 nV cm^{-1}) (Barber and Longuet-Higgins 1948 as cited in Kalmijn [1971]). These current-generated voltage gradients are well within the sensitivity threshold of some elasmobranchs and their detection could also give elasmobranchs a mechanism for detecting geomagnetic fields. In this "passive mode" model, the horizontal movement of ocean water, which generates a DC field, interacting with the vertical component of the Earth's geomagnetic field produces a horizontal electromotive field that the fish can detect. A major problem with the passive mode model of navigation is that it is intuitively unreliable. Electric fields generated by ocean water flow are too variable with regard to speed and direction to provide a reliable measure of location and direction. Fish swimming in coastal areas and among depth strata could encounter all sorts of perturbations in current flow and speed that would disrupt navigational continuity.

In the "active mode" model of navigation, the fish senses voltage gradients in its own body that it inductively generates as it swims through the Earth's geomagnetic field (Figure 5.2). The horizontal velocity of the animal interacts with the horizontal component of the geomagnetic field producing a vertical electromotive field. The theoretical advantage of the "active" model is that the movement of the fish itself gives it the capacity for directional navigation. 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. The Earth's geomagnetic field lines generally run in a north-south direction. A shark swimming in an easterly or westerly direction would move perpendicular to the Earth's field lines thereby generating the maximum voltage potential. Because the Earth's geomagnetic field lines are unidirectional (south to north poles), the induced voltage within the shark moving east would have a polarity the reverse of that in a shark swimming to the west. Swimming in a northerly or southerly direction, the fish would be moving parallel to the field lines and would not cross them which results in no voltage being generated. In this "active" navigation model, northeast cannot be distinguished from southeast and northwest cannot be distinguished from southwest. The shark can determine which of the two possibilities is correct by sensing what happens when it turns. If the fish is swimming northeast and turns to the right, thereby increasing its angle of attack on the north-south geomagnetic field lines, induced voltage will increase. If it turns left, bringing its course more parallel to field lines, induced voltage will decrease. Theoretically, the elasmobranch electrosensory system could provide it with 360° navigational ability (see Paulin 1995; Kalmijn 2000, 2003; Montgomery and Walker 2001).



Source: Kalmijn (1987).

Figure 5.2 Sources of electrosensory navigation in elasmobranchs. In the passive mode (a), horizontal electric fields generated by movement of ocean streams within the Earth's magnetic field are used in orientation. In the active mode (b), the horizontal velocity of the animal interacting with the horizontal component of the magnetic field produces a vertical electromotive field.

5.3. Geomagnetic Navigation in Elasmobranchs

Empirical evidence that elasmobranchs can detect magnetic fields is limited to laboratory behavioral studies. Behavioral responses to shifts in geomagnetic fields have been documented for leopard sharks (*Triakis semifasciata*), round stingrays (*Urolophus halleri*), sandbar sharks (*Carcharhinus plumbeus*), and scalloped hammerhead sharks (*Sphyrna lewini*) (Kalmijn 1978; Meyer et al. 2004).

In field studies, Carey and Scharold (1990) and Klimley (1993) found evidence that hammerhead sharks in the Gulf of California did exhibit movement patterns consistent with tropotaxis. Telemetry studies indicated that some individuals followed consistent foraging routes from their daytime resting area in the vicinity of a seamount to their nocturnal feeding grounds. While the pattern was unrelated to current patterns or bottom topography, more than a random number of routes were associated with sharp gradients in the local geomagnetic landscape. Klimley (1993) hypothesized that hammerheads could find seamounts using geomagnetic tropotaxis. The shark could be attracted to and move back and forth along ridges and valleys in the magnetic relief. If true, sharks were detecting and navigating along geomagnetic gradients that ranged from 0.0138 to 0.0374 nT m^{-1}.

6.0 EFFECTS ASSESSMENT

This section provides a generic assessment of the potential effects of EM technologies on marine fauna. Many of the predictions here are based upon information previously described in the preceding background sections.

6.1. EIA Methodology

As previously discussed, this EIA is generic in order to make it generally applicable to the numerous jurisdictions around the world where IAGC members may operate. The focus here is on assessing the effects that are either unique to offshore EM surveys or may be key issues in some regions.

EM emissions from a towed source represent a unique potential source of environmental effects from EM surveys and thus provide the primary focus for this EIA. In order to provide a basis for the assessment, members of the EM survey industry provided attenuation data calculated on standard parameters and the specific characteristics of their EM sources. These data provided electric and magnetic field strengths at increasing distances from the source. These data tables coupled with sensitivity thresholds derived from the published literature facilitated predictions of potential effects on the marine animals of interest. Additional refinements concerning specific species in different parts of the world are possible using data provided in this report on the depths that these animals are typically found (see Appendix A).

6.1.1. Scope of the Assessment

This EIA has been scoped by the IAGC and the authors to include the following:

- Projects that employ EM technologies for petroleum exploration in the marine environment, specifically CSEM and MTEM (collectively termed EM surveys).
- Geographic boundaries are marine environments worldwide. As such, the EIA is generic and generally applicable to a wide variety of species and jurisdictions.
- Temporal boundaries will be determined by the lifespan of the technologies, probably on the order of 10 years and/or scientific advances in effects analyses (believed to be 5-10 years).

6.1.2. Valued Ecosystem Components (VEC)

Every EIA practitioner must select those key components of the ecosystem upon which to assess effects because it is impractical (and unnecessary) to assess everything. In the present case, the VEC approach of Beanlands and Duinker (1984a,b) was chosen. Normally, VECs (usually species, groups, or habitats) are identified through professional judgement and expertise, information reviews, and consultations with regulators and stakeholders. Criteria for VEC selection include importance for ecological, social or cultural, scientific, or economic reasons. A species or group may also qualify on the basis of its conservation status (e.g., endangered species). In addition, there should be enough available information to allow some level of effects prediction as well as some evidence that the VEC has potential to be affected by a project.

The VECs selected for this EIA include:

- Marine fish and fisheries
- Seabirds
- Marine mammals and sea turtles
- Sensitive habitats

These VECs are typical ones for marine EIAs and meet all of the criteria listed above to varying degrees.

6.1.3. Activities to Assess

This EIA because of its generic nature focuses on those materials, activities and infrastructure of an EM survey that have potential to create what can be perceived as significant effects or effects that might not be encountered with most other types of marine projects (i.e., effects unique to marine EM surveys). Activities and emissions that would normally be assessed for any offshore project in most jurisdictions have intentionally been excluded. Such activities (e.g., waste handling, air emissions, etc.) are routine for many types of marine projects that employ vessels although different jurisdictions may handle them differently in their regulatory processes.

Activities assessed here include:

- Vessel operations
    - Underwater noise
    - Light emissions
- EM source emissions (electromagnetic and chemical)
- EM receivers deployment and retrieval
- Accidental events
    - Vessel/towed gear strikes
    - Spills

6.1.4. Mitigations

In many cases, EM survey companies will have mitigations built into their normal operating procedures and hence the effects predictions can be considered “residual effects”. That is, the predictions contained in this EIA include what can be considered “standard” mitigations for offshore projects. In addition, supplemental mitigations are listed where relevant.

6.1.5. Significance of Effects

The term "significant effect" is a specific term used in EIA to denote an important effect that may have implications at the population level. As such, the term should only be used in a formal EIA prediction.

Definitions of the significance of environmental effects vary considerably by jurisdiction and by EIA practitioner. The best definitions are those that incorporate some combination of direction (i.e., positive or negative), magnitude, geographic extent, duration, and perhaps frequency. Important modifiers may include present conditions (e.g., level of "pristineness"), reversibility, certainty of predictions, and likelihood of occurrence.

Specific predictions on significance are avoided in this EIA because they are usually quite site specific. Nonetheless, some generic predictions are provided for certain situations which likely would be considered "significant" in many areas.

6.2. Vessel Operations

Vessel operations associated with marine EM surveys that may produce some effects include the physical presence of the vessel and underwater sounds produced by propellers and thrusters. With the exception of some potential short term behavioral changes for some animals such as seabirds, there are few concerns associated with the physical presence of the vessel. Most survey vessels tow at such low speeds, collisions with large marine animals are very unlikely. On the other hand, vessels deploying and retrieving large numbers of bottom-mounted receivers will likely use their thrusters more often than most other types of vessels.

6.2.1. Ship Noise

Fish, seabirds, and marine mammals are all capable of hearing ship noise and may respond to it. Fish and fisheries and seabirds are not believed to be particularly sensitive to ship noise generated by survey vessels and are not considered further. A review of the voluminous literature on underwater noise and its potential effects is beyond the scope of the present EIA. The noise generated by an EM survey vessel is likely no more, and probably less due to low survey speeds, than that generated by other similar-sized vessels. Of these groups, marine mammals, and possibly sea turtles, are believed to be sensitive to noise and effects on these groups are briefly discussed here.

Marine mammal responses to ships are presumably responses to noise, but visual or other cues are also likely involved. Marine mammal response (or lack thereof) to ships and boats (pre-1995 studies) are summarized in Richardson et al. (1995), p. 252-274. Some recent studies are briefly summarized below.

Mysticetes.—Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). Recent studies of humpback whale responses to approaching vessels have been carried out on breeding grounds. Off the coast of mainland Ecuador, humpback whales were found to react to the approach of whale-watching boats by increasing swim speeds significantly (Scheidat et al. 2004). Behavioral responses including abrupt course changes and long dive times have also been reported for humpback whales in Hawaiian waters (Green 1998 *in* Nowacek et al. 2007). The response of humpback whales to whale-watching vessels in Hervey Bay, Australia was monitored in 1994 in an attempt to develop design criteria for vessels to minimize disturbance to whales (McCauley and Cato 2001). It was found that rapid increases in vessel noise produced more responses by humpbacks.

Marine mammal monitoring was undertaken from a high-speed, catamaran car ferry transiting the Bay of Fundy during the summers of 1998-2002 (Dufault and Davis 2003). The ferry had no propellers but used four water jets for power and sailed at speeds of 40 knots. The majority of baleen whales (including fin, humpback and minke whales) sighted from the ferry appeared to exhibit avoidance behavior including heading away, changing heading, or diving (Dufault and Davis 2003). Avoidance responses were greater for humpback whales than for the other species of baleen whales that were seen.

The influence of whale-watching vessels on the behavior of migrating (southbound and northbound) gray whales in Baja California, Mexico during the winters of 1998 and 1999 was examined by Heckel et al. (2001). The presence of vessels appeared to affect whale swim direction (whale headings were more variable) and velocity (became more variable), but results were inconsistent for whales migrating north vs. south. Also, a head-on approach by whale-watching boats significantly affected whale swimming direction and velocity vs. approaches towards the rear or flanks of the whale. This study provides no information on the types of whale-watching vessels and their sound levels. Increased vessel traffic (primarily fishing vessels) at two known calving sites for gray whales in the Gulf of California, Mexico has been attributed to the absence of whales in recent years (Findley and Vidal 2002). Semi-continuous dredging to clear and deepen the channel leading into the bays also likely contributed to the abandonment of the area.

Odontocetes.—Sperm whales often can be approached with small motorized or sailing vessels (Papastavrou et al. 1989), but have been reported to avoid outboard-powered whale watching vessels up to 2 km away (J. McGibbon *in* Cawthorn 1992). André et al. (1997) were unable to elicit any reaction from sperm whales off the Canary Islands in response to playbacks of engine noise (source level of 180 dB re 1 µPa/Hz, generated from the engine of a 15 m, 19-gross-ton ship traveling at 25 knots) at a distance of 100 m from the animals during their investigations to discover a noise that could potentially deter sperm whales from ferry routes. Those investigators speculated that the sperm whales they were investigating in the Canary Islands may have lost hearing sensitivity to the low frequencies generated by ships' engines and propellers because of the heavy marine traffic in the area.

As mentioned above, those investigators were successful at eliciting reactions in response to a higher frequency 10-kHz pulse.

There were 87 sightings of sperm whales during the 1992–1994 GulfCet shipboard surveys in the north central and western Gulf of Mexico (Würsig et al. 1998). However, sperm whale reactions were only recorded for 15 of those sightings, as the researchers reported that reactions tended to be "non-existent" unless the vessel approached the animals within several hundred meters. Of the 15 sightings of sperm whales during which responses were recorded, on 11 occasions the sperm whales were reported to have exhibited no reaction. During the other four encounters, the sperm whales dove abruptly. All four of those occurred within 200 m of the ship. Sperm whales were never reported to approach the survey vessel. The authors of that report estimated the sound levels of their survey vessels in the 20–1,000 Hz frequency range to be on the order of 120–150 dB re 1 µPa at 200 m and 105-125 dB re 1 µPa at 9-10 km. These estimates were based not on direct measurements, but on comparisons with supply vessels of similar sizes.

Several different groups have examined the effects of whale watching boats on sperm whales. Richter et al. (2003) reported that male sperm whales off Kaikoura, New Zealand, had shorter mean and median blow intervals in the presence of their research vessel and/or whale watching boats and that the sperm whales in that study spent more time at the surface and changed heading more frequently in the presence of whale watching boats. Resident sperm whales, in general, appeared to show fewer reactions and less-pronounced reactions to whale watching vessels than did transient animals, suggesting habituation to the disturbance. Sperm whales off the Azores were studied using both land- and boat-based observations to assess the effects of whale watching boats on those animals, without any clear evidence of disturbance (Magalhães et al. 2002). Gordon et al. (1998) reported that sperm whale calves often approached whale watching boats off Dominica.

There are little systematic data on the behavioral reactions of beaked whales to vessel noise. Most beaked whales tend to avoid approaching vessels (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Aguilar-Soto et al. (2006) suggest that foraging efficiency of Cuvier’s beaked whales may be reduced by close approach of a vessel based on dive and acoustic data received from one whale; the authors caution that no conclusions can be drawn based on their single observation.

Vessel traffic has been shown to affect the behavior of southern resident killer whales from shore-based observations during periods of vessel presence and vessel absence along San Juan Island, Washington, U.S. (Lusseau et al. 2009; Williams et al. 2009). Lusseau et al. (2009) noted that vessel traffic significantly affected the transition probabilities between activity states and resulted in a reduction in time spent foraging. Whales were significantly less likely to be foraging and more likely to be traveling when vessels were in the area (Lusseau et al. 2009). The authors however warned that it was unclear whether this reduction in foraging effort would result in a reduced prey capture, and hence, a decreased energy acquisition. Williams et al. (2009) observed that the distances travelled by killer whales increased in the presence of vessels.

Short-term effects of boats on coastal bottlenose dolphins have been documented in several studies, but long-term effects are as yet speculative. Janik and Thompson (1996) assessed the surfacing patterns of bottlenose dolphins in response to passing boats in the Moray Firth, Scotland, a heavily trafficked area connecting the Caledonian Canal with the North Sea. Janik and Thompson (1996) found a statistically significant effect of the dolphin-watching boat on bottlenose dolphin surfacing rate, but no significant effect of other boat traffic.

There were 110 sightings of bottlenose dolphins during the shipboard portion of the 1992–1994 GulfCet program (Würsig et al. 1998). Reactions to the survey ship were reported for 88 of those encounters. Most of the reported reactions were positive, with the dolphins' bowriding the vessel during 68 of the sightings and merely approaching the vessel on an additional six occasions. For the remaining 14 sightings, the bottlenose dolphins were reported to have displayed no reaction. No avoidance reactions were observed. In a study involving bottlenose dolphins off Port Phillip Bay, Australia, Scarpaci et al. (2001) used focal group observations from land to assess the dolphins' responses to boats. They found the dolphins to feed less when vessels were present (9.5% of observations) than absent (19.7%). In the Bay of Islands, New Zealand, Constantine et al. (2004) evaluated the effects of dolphin-watching boats on bottlenose dolphins. In that study, the dolphins' behaviors were found to vary significantly ($p < 0.0001$) with the number of boats present. Resting behavior seemed to be most affected, decreasing with increasing numbers of boats. Resting behavior was only observed 0.5% of the time when three or more boats were present. In Western Australia, bottlenose dolphin behavior became more erratic and dolphin schools tightened in response to controlled boat interactions (Bejder et al. 2006). During vessel interactions with bottlenose dolphins in New Zealand, travelling behavior increased and resting behavior decreased (Lusseau 2003, 2004). Also, dolphins apparently avoided areas and times characterized by high vessel traffic (Lusseau 2005). Common dolphins in New Zealand have also reacted to boats with changes in their overall behavior, including decreases in foraging and resting times and increases in socializing and milling behavior (Stockin et al. 2008).

There were 14 sightings of spinner dolphins during the shipboard portion of the 1992–1994 GulfCet program (Würsig et al. 1998). For all 14 of those sightings, the spinner dolphins were reported to have been bow riding the survey vessel. No avoidance reactions were observed. There were 177 sightings of pantropical spotted dolphins during those shipboard surveys. Response to the survey vessel was reported for 165 of those sightings. In general, the responses of spotted dolphins to the survey vessel were positive. During 137 (83%) of those encounters, the dolphins were observed bow riding with the vessel and for an additional 18 sightings, they were observed approaching the ship. On nine occasions, the spotted dolphins did not appear to react to the survey vessel, while there was a single sighting during which they exhibited avoidance behavior.

Reactions of beluga whales to ships and boats are highly variable depending on the circumstances, ranging from very tolerant to highly responsive (Richardson et al. 1995). The effect of vessel noise on beluga whales in the St. Lawrence River estuary, Québec, Canada, was assessed by Lesage et al. (1999). They used controlled experiments to record the surface behavior and vocalizations of beluga whales before, during, and after the passing of two different types of boats—an outboard motorboat moving rapidly and erratically on an unpredictable course, and a ferry moving regularly and slowly through the study area on a predictable route. Noise from the motorboat peaked at a frequency of 6 kHz, but was strong up to 16 kHz, with a second peak at 11.5 kHz. The noise from the ferry, on the other hand, had its greatest sound levels below 6 kHz and its engines generated a tone at around 175 Hz. Beluga whales changed their vocalizations in response to both these vessels. Changes included the use of higher-frequency vocalizations, a greater redundancy in vocalizations (more calls emitted in a series), and a lower calling rate. The lower calling rate persisted for longer during exposure to the ferry than to the motorboat. Investigators attempting to record beluga whale vocalizations off Norway found those whales to be surprisingly silent most of the time. The whales were silent during 72% of the recordings when the whales were known to be in the vicinity. Those researchers suggested that the relative silence of this usually vocal species could be attributed to the presence of the research vessel in an area where whales are not accustomed to boat traffic (Karlsen et al. 2002).

Harbour porpoises, in general, tend to show avoidance behavior toward boats (see Richardson et al. 1995). Palka (1996) reported that some harbour porpoises showed avoidance reactions at greater than 700 m from a survey vessel in the Gulf of Maine.

Pinnipeds.—When in the water (vs. hauled out), seals appear less responsive to approaching vessels. Some seals will approach a vessel out of apparent curiosity, including noisy vessels such as those operating airgun arrays (Moulton and Lawson 2002). Suryan and Harvey (1999) reported that Pacific harbour seals (*Phoca vitulina richardsi*), commonly left the shore when powerboat operators approached to observe them. These seals apparently detected a powerboat at a mean distance of 264 m, and seals left their haul-out sites when boats approached to within 144 m.

Polar Bears.—Like seals, polar bears exhibit variable responses to boats. Some seem to approach vessels while others exhibit avoidance (e.g., Harwood et al. 2005).

Sea Turtles.— Noise-induced stress has not been studied in sea turtles. Captive loggerhead and Kemp's ridley turtles exposed to brief audio-frequency vibrations initially showed startle responses of slight head retraction and limb extension (Lenhardt et al. 1983). Sound-induced swimming has been observed for captive loggerheads and greens (O'Hara and Wilcox 1990; Moein et al. 1995; Lenhardt 1994). Some loggerheads exposed to low-frequency sound responded by swimming towards the surface at the onset of the sound, presumably to lessen the effects of the transmissions (Lenhardt, 1994). Sea turtles have been observed noticeably increasing their swimming in response to an operating seismic source at 166 dB re- 1µPa-m (McCauley et al. 2000). If vessel noise does bother sea turtles they would likely respond by avoiding the seismic ship.

6.2.2. Thruster Noise

The brief review in the previous section demonstrates that marine mammals and sea turtles detect underwater noise and often react to it. Thruster noise may be a source of potential effects on marine mammals during CSEM surveys that deploy and retrieve numerous receivers. During this process, the thrusters may be particularly active while the ship is maneuvering. Broadband source levels (at 1 m) for most small ships where marine mammal reactions have been measured are in the 170-180 dB re 1 µPa range, excluding infrasonic components (Richardson et al. 1995). Broadband underwater sounds from the offshore supply ship *Robert Lemeur* in the Beaufort Sea were 130 dB at a distance of 0.56 km (0.3 nautical miles) (Greene 1987), and were 11 dB higher when bow thrusters were operating than when they were not (Greene 1985, 1987). The *Robert Lemeur* had nozzles around the thruster propellers. Broadband noise levels from ships lacking nozzles or cowlings around the propellers can be about 10 dB higher than those from ships with the nozzles (Greene 1987).

Observations by LGL biologists (Abgrall et al. 2008a), off northeast Newfoundland indicated that marine mammal sighting rates during periods when dynamic positioning (DP) thrusters were active on a deep water survey site were approximately half of those during periods when DP thrusters were not active. The largest decrease in sighting rates when the DP thrusters were active was observed for baleen whales, followed by dolphins. The sighting rate of large odontocetes (sperm whales and northern bottlenose whales) did not differ during periods when the DP thrusters were active vs. inactive. However, these results should be interpreted with caution since the data recording protocols were not designed to isolate the effect of DP thrusters. Other variables, such as source activity, speed of vessel and sighting conditions (although the data used for the comparison of sighting rates with DP thruster activity only considered sighting conditions when the sea state was Beaufort 5 or less and visibility was of at least 1 km) were likely not constant. In addition, the data recording protocol only considered whether the DP thrusters were active or inactive. The protocol did not consider the number or type of thrusters being used or a level of activity. More detailed analyses could also consider whether sighting rates varied with increasing distance from the vessel when the DP thrusters were active vs. inactive.

If the noise levels produced by the DP thrusters planned for a specific program are of possible concern for marine mammals according to regional noise exposure threshold regulations, the noise levels of the DP thrusters should be measured and a sound propagation modeling of the survey area should be performed in order to identify if any DP thruster shutdown criteria should be considered. Similar sound propagation modeling has previously been done when assessing the noise levels of thrusters from liquid natural gas (LNG) carriers associated with the Neptune LNG project in the area of Massachusetts Bay (LGL and JASCO Research 2005; Davis 2006, 2009).

6.2.3. Light Emissions

Light emissions from platforms or vessels at sea may affect the local distribution of fish, sea turtles, seabirds and marine mammals by attracting their prey. The attraction of seabirds is an issue because some species may become disoriented and collide with or strand on the platform. This latter effect is discussed below.

Artificial lighting on ships at sea, offshore oil/gas drilling or production structures, coastal communities, and oceanic island communities regularly attracts nocturnally-active seabirds and nocturnally-migrating land- and water-birds, sometimes in large numbers (Montevecchi et al. 1999; Gauthreaux and Belser 2006; Montevecchi 2006). This may result in bird mortality, occasionally due to collisions with non-illuminated structures near the lights that the birds cannot see, or more rarely, with the lights themselves. However, most mortality occurs because these birds mill about near the lights and eventually land on the deck or ground, after which seabirds in this situation typically are unable to take off and eventually succumb to dehydration, starvation, exhaustion, or hypothermia or drowning in water-filled cavities on deck. Birds may be attracted to artificial lighting from a distance of up to 5 km in the case of offshore oil/gas installations with 30 kW of lighting (Poot et al. 2008).

Attraction to artificial lighting and attendant grounding appears to be widespread among procellariiform seabird species, i.e., petrels, shearwaters, and prions (Procellariidae), storm-petrels (Hydrobatidae), and diving-petrels (Pelecanoididae) (but not albatrosses Diomedeidae), and has been observed in more than 20 species (Imber 1975; Reed et al. 1985; Telfer et al. 1987; Le Corre et al. 2002; Black 2005; Montevecchi 2006; Abgrall et al. 2008b; Rodríguez and Rodríguez 2009; Miles et al. 2010). Several species of procellariiforms are endemic to certain archipelagos or individual islands and are threatened or critically endangered (Reed et al. 1985; Le Corre et al. 2002; Rodríguez and Rodríguez 2009). Light attraction has also been noted in Atlantic puffin (Miles et al. 2010), crested auklet (Dick and Donaldson 1978), Xantu's murrelet (Carter et al. 2000 and Pacific Seabird Group 2002 cited in (Montevecchi 2006), and common eider (Merkel 2010). Attraction of migrating land-birds to artificial lighting at sea is found in a large diversity of orders and families, although the majority of species landing on deck are readily able to take off again if uninjured (Russell 2005; Gauthreaux and Belser 2006).

The attraction of seabirds to artificial lighting occurs at all times of the year, but tends to be more common at the end of the nesting season (Telfer et al. 1987; Le Corre et al. 2002; Miles et al. 2010). In studies in which the age of the grounded seabirds has been determined, the majority of individuals have been newly fledged young, particularly near seabird nesting colonies (Imber 1975; Telfer et al. 1987; Rodríguez and Rodríguez 2009; Miles et al. 2010).

Greater numbers of individual birds are attracted to artificial lighting when there is a low cloud cover, particularly when accompanied by fog or rain (Hope-Jones 1980 and Wallis 1981 cited in Montevecchi 2006; Telfer et al. 1987; Black 2005; Russell 2005; Abgrall et al. 2008a,b; Poot et al. 2008). Light attraction among seabirds also seems to peak when moonlight levels are lowest, i.e., around the time of the new moon (Telfer et al. 1987; Rodríguez and Rodríguez 2009; Miles et al. 2010). The reason for peaks in activity during overcast or new moon lighting conditions may be a lack of ambient light for navigation (Reed et al. 1985). Alternatively, because aerial activity at seabird nesting colonies is lowest around the time of the full moon (Imber 1975; Bretagnolle 1990), a preference among seabirds for dark nights may be a mechanism for avoiding predators (Watanuki 1986; Mougeot and Bretagnolle 2000; Oro et al. 2005).

The reason for the attraction of birds to artificial lighting is not clear. One hypothesis is that because of the low level of ambient light under overcast or new moon lighting conditions, artificial lighting becomes a strong visual orientation cue (Reed et al. 1985). Once attracted to artificial lighting, birds may be reluctant to leave because they have lost their visual orientation to the horizon (Russell 2005). Alternatively, nocturnally-active seabirds and migrating birds may be disorientated by the effect of artificial lighting on their ability to navigate via cues from the Earth's magnetic field (Poot et al. 2008). In the laboratory, long-wavelength visible light, i.e., red light or the red component of white light, disrupts magnetic orientation in birds (Wiltschko et al. 1993). Seabirds may instead be attracted to artificial lighting because of a preference for bioluminescent prey (Imber 1975).

Bird attraction to artificial lighting at sea may be mitigated in a variety of ways. Recovering grounded seabirds and returning them to sea when their plumage has dried greatly reduces mortality (Telfer et al. 1987; Le Corre et al. 2002; Abgrall et al. 2008b; Rodríguez and Rodríguez 2009; Williams and Chardine n.d.). Reducing, shielding or eliminating skyward radiation from artificial lighting also achieves great reductions in the numbers of birds grounded (Reed et al. 1985; Rodríguez and Rodríguez 2009; Miles et al. 2010). A preliminary study of the effect of replacing white and red lights on an offshore natural gas production platform with green lights showed large reductions in the number of birds attracted to artificial lighting (Poot et al. 2008).

6.3. EM Source Emissions

The potential effects of EM emissions on marine animals are a function of magnitude and duration of exposure and degree of sensitivity or threshold of effect. The geographic extent, magnitude and duration are dependent upon source strength and attenuation with distance (as illustrated in animal dive depth tables in Appendix A) and EM emissions attenuation data provided by the EM industry. Electromagnetic energy obeys the diffusion equation and thus the signal strength dissipates relatively rapidly and proportionally to r^2 (where r is the distance from the source). The following sections address these elements of the assessment.

6.3.1. Generic Effects of Electromagnetic Radiation

Most studies dealing with the effects of electromagnetic fields on biological organisms have centered on human health issues. High-frequency electromagnetic fields contain enough energy to break down molecular bonds and are classified as ionizing radiation. Brief exposure can lead to sterilization, cancer, and even death by molecular disintegration. The effects of ionizing radiation are not, however, relevant to EM surveys because of the ultra low frequency (e.g. 0.25-10 Hz), low electric field strengths (<30 mV m^{-1}) (<30,000,000 nV cm^{-1}), and low magnetic field strengths (<7,400 nT) that are involved in the technologies. Generic effects of electromagnetic radiation are therefore limited to ELF (extremely low frequency) magnetic fields that fall below 300 Hz (World Health Organization 2005).

Studies into the biological effects of non-ionizing radiation have generated thousands of published articles over the past 30 years (World Health Organization 2005). At least 27 countries currently support research into the effects of electromagnetic fields on human health (Barr 1997). Studies have focused on health issues associated with normal exposure sources of ELF magnetic fields such as transmission lines, electric utility exposure in the home or workplace, television and radio, mobile telephones, radar, and security systems. Health concerns have focused on pregnancy and fetal development, cataracts, cancer, epidemiology, epilepsy, headaches, behavior, physiological responses and more.

Based upon continually updated review of global scientific research into the effects of ELF magnetic fields on both humans and animals, the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP 2009, 2010) has issued guidelines for human exposure to both static and time-varying ELF magnetic fields (Table 6.1). For time-varying fields, the exposure limit for humans at 1 Hz is approximately 80,000 times higher than typical CSEM and MTEM transmission field strengths (e.g., 2,500 nT).

Table 6.1 ICNIRP 2009 reference levels for human exposure to static and time-varying ELF magnetic fields.

Magnetic Field	Exposure Characteristics	Magnetic Flux Density
Static	Occupational	
	Exposure of head and trunk	2,000,000,000 nT
	Exposure of limbs	8,000,000,000 nT
	General Public	
	Exposure to any part of body	400,000,000 nT
Time Varying	1 Hz-8 Hz	200,000,000 nT-3,125,000 nT
	8 Hz-25 Hz	3,125,000 nT-1,000,000 nT
	25 Hz-300 Hz	1,000,000 nT

ICNIRP (2010) also provides guidelines for time-varying electric fields (Table 6.2). The sole criterion for the electrical field limits are avoidance of retinal phosphenes (perception of flashes of light when no light is entering the eye). It is purely a sensory phenomenon and at threshold levels carries no long-term ill effects. Phosphene thresholds are minimal at 20 Hz and rise rapidly at higher and lower frequencies. For electric fields, the exposure limit for humans at 1 Hz is approximately 16 times higher than typical EM survey transmission field strengths (<30 mV m-^{1}) (30,000,000 nV cm^{-1}). By comparison, other electrical thresholds reported by ICNIRP (2010) are 4,000-6,000 mV m^{-1} for peripheral nerve stimulation (So et al. 2004), 10,000 mV m^{-1} for stimulation of myelinated nerve fibers (Reilly 1998, 2002), and 10,000,000 mV m^{-1} to elicit behavioral responses in volunteers.

Although there is much less information on the effects of static electric fields, the European Union stated in 1999 that there should be no human discomfort within an exposure limit of 25 kV m^{-1} (25x10^{8} mV m^{-1}) (http://www.emfs.info/Related+Issues/limits/static/). The 1999 EU Recommendations do not contain any limits for static electric fields. Instead, there is a statement: "For most people, the annoying perception of surface electric charge will not occur at field strengths less than 25 kV/m. Spark discharges causing stress or annoyance should be avoided."

It is reasonable to extrapolate these exposure levels to marine organisms. Given the extremely low-intensity electromagnetic fields propagated by CSEM and MTEM technologies, neither poses a generic threat to marine organisms at the cellular or physiological level.

Table 6.2 ICNIRP 2010 reference levels for human exposure to time-varying ELF electric fields.

Exposure Characteristics	Frequency Range	Electric Field (m^{-1})
Occupational		
CNS tissue of the head	1 Hz-10 Hz	500-50 mV
	10 Hz-25 Hz	50 mV
	25 Hz-400 Hz	800 mV
All tissues of head and body	1 Hz-3 kHz	800 mV
General Public		
CNS tissue of the head	1 Hz-10 Hz	100-10 mV
	10 Hz-25 Hz	10 mV
	25 Hz-1000 Hz	400 mV
All tissues of head and body	1 Hz-3 kHz	400 mV

6.3.2. Effects on Geomagnetic Orientation and Navigation

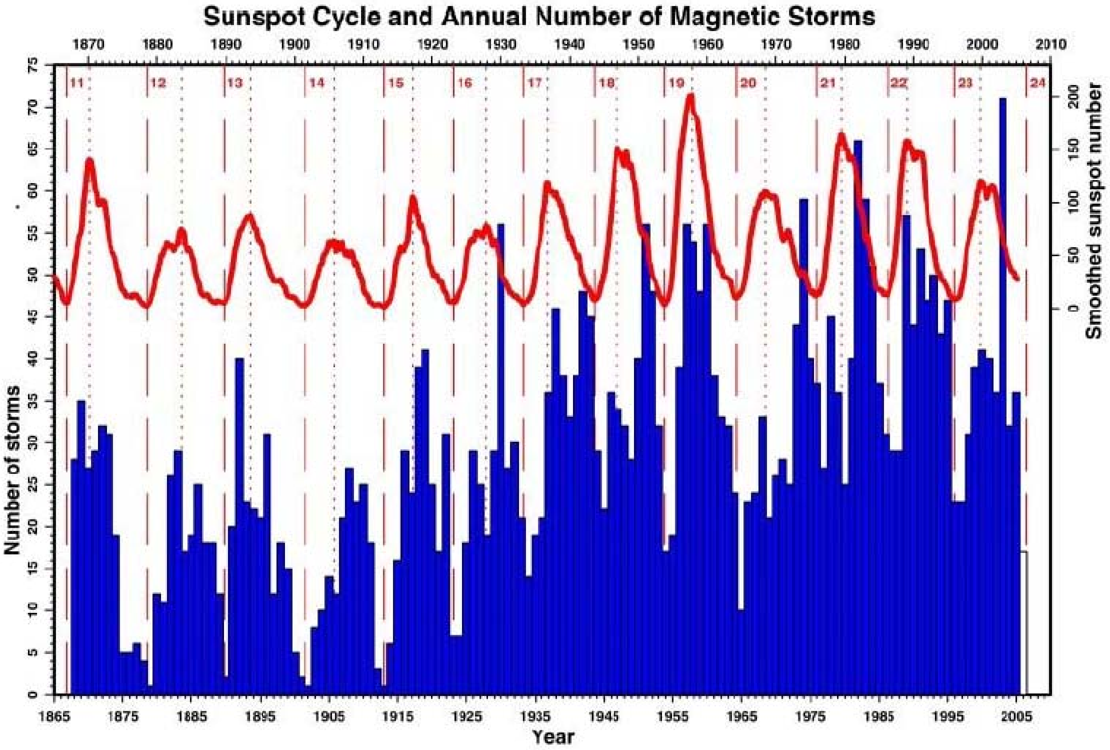
While animals can detect and orient to geomagnetic fields (see Section 3.4), it is still uncertain how that capability integrates into a bi-coordinate mapping system that is necessary for navigation. For such a system to be functional the animal would need some mechanism for filtering out anomalous natural geomagnetic noise.

Natural Magnetic Perturbations

A geomagnetic storm is a disturbance in the Earth's magnetic field caused by coronal mass ejections (CMEs) or solar flares from the Sun (CENTRA Technology, Inc. 2011). A magnetic storm usually begins between 24 and 36 hours after the solar event, when a shock wave of solar wind reaches the Earth's ionosphere. When the storm reaches the Earth‘s magnetic field, it progresses through three phases, the initial phase, the main phase and the recovery phase. The initial phase takes minutes to hours to complete and can emit a maximum of tens of nTs. The main phase can take between 30 minutes and several hours and produces negative hundreds of nTs. The duration of the recovery phase, which is the longest of the three, ranges from tens of hours up to a week and is the phase in which nT levels return back to normal (Tsurutani and Gonzalez 1993). In general, magnetic storms of recorded magnitude typically last 24 to 48 hours.

Typical daily variations of geomagnetic field strength are measured by one of two indices. The K-index, which is recorded over a three-hour interval round the clock, quantifies disturbances in the horizontal component of Earth's magnetic field with an integer in the range 0-9 with 1 (0-5 nT) being calm and 5 (70-120 nT) or more indicating a geomagnetic storm (NOAA 2011). It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during the three-hour interval. Another index of geomagnetic variability is the Dst (Disturbance storm time) index (Rao et al. 2010). The Dst index is expressed in nT and is based on the average value of the horizontal component of the Earth’s magnetic field measured hourly at four near equatorial geomagnetic observatories. Use of the Dst as an index of storm strength is possible because the strength of the surface magnetic field at low latitudes is inversely proportional to the energy content of the ring current, which increases during geomagnetic storms.

The connection between magnetic storms and sunspots was well established around the turn of the century (British Geological Survey 2010). When large active sunspots were visible, big magnetic storms were much more likely. The solar cycle, which is a periodic change in the amount of irradiation from the sun that is experienced on Earth, has a period of about 11 years. There are also aperiodic fluctuations. Figure 6.1 shows the sunspot cycle and annual number of magnetic storms from 1867 to 2006 (British Geological Survey 2010). Since 1935, the number of geomagnetic storms in excess of 70 nT has ranged from approximately 20 to 70 per year.



Source: British Geological Survey (2010).

Figure 6.1 Sunspot cycle and annual number of magnetic storms.

NOAA's (2011) Space Weather Scale for Geomagnetic Storms relies on the Kp Index (Table 6.3). The official planetary Kp index is derived by calculating a weighted average of K-indices from a network of geomagnetic observatories.

The data in Table 6.3 are from the Boulder Colorado NOAA Magnetometer and represent an average over the historical record. An event spans a three-hour observation period. A 24-hr solar storm thus represents eight events; a 48-hr storm 16 events. As an estimate of annual frequency, we calculated the number of 24- and 48-hr geomagnetic storms based upon the total number of annual events. 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.

Table 6.3 NOAA Space Weather Scale for Geomagnetic Storms. Number of events based upon standard solar storm 11-year cycle. An event represents a three-hour observation period.

Kp Index[1]	NOAA Classification	nT	Events per 11-yr Cycle[2]	Events per Year	Number of Equivalent 24-hr Storm[3]	Number of Equivalent 48-hr Storm[3]
5	Minor	70-120	1,700	154.5	19.3	9.7
6	Moderate	120-200	600	54.5	6.8	3.4
7	Strong	200-330	200	18.2	2.3	1.1
8	Severe	330-500	100	9.1	1.1	0.6

Notes:

[1] NOAA 2011

[2] NOAA Boulder Magnetometer data

[3] LGL Limited calculation

The Earth's geomagnetic field also undergoes regular, small variations every 24 hours (British Geological Survey 2011). This regular fluctuation is caused by electrical currents high in the ionosphere that begins at an altitude of about 100 km. In the ionosphere, high energy ultra-violet rays and X-rays from the Sun displace electrons from the neutral (uncharged) molecules in the air to produce positive and negatively charged particles. These charges allow the air to conduct. At any point on Earth, the Sun is at its most intense around midday and is therefore generating the most charges in the ionosphere overhead, which allows the air to conduct better. After dusk, in the absence of ionizing radiation, the charges begin to recombine into neutral molecules again and so the ability for the air to conduct is reduced. This cycle is repeated each day. The process causes small shifts in the geomagnetic field. Inclination varies by less than a tenth of a degree and the total intensity of the magnetic field is perturbed by only a few tens of nT (British Geological Survey 2011).

Determining Thresholds of Effects

Although there are numerous studies showing that many different varieties of animal can detect and orient to magnetic fields (see Sections 3.0 to 5.0), the vast majority of research has involved behavioral or physiological responses to Earth-strength shifts in ambient fields (i.e., tens of thousands of nT). Very little work has been done on threshold sensitivity to small shifts in magnetic field strength. This would be a critical component for navigating the Earth's geomagnetic landscape. Estimates are summarized below.

- In a study of honey bee (*Apis mellifera*) behavior, Lindauer and Martin (1972, as cited in Keeton et al. 1974) found that fluctuations in magnetic field strength of less than 100 nT had a detectable affect on the bees' waggle dance.
- In release studies of homing pigeons (*Columba livia domestica*), Keeton et al. (1974) reported that the mean initial bearing upon release back to the home loft showed a significant inverse relationship with the K-index of magnetic activity. Since daily magnetic

activity seldom exceeded 70 nT and were commonly less than 40 nT, Keeton et al. (1974) concluded that pigeons must have been responding to magnetic fluctuations of less than 70 nT and probably less than 40 nT.

- Walker and Bitterman (1989) trained honeybees (*Apis mellifera*) to respond to modified magnetic fields with food rewards. One honeybee was able to discriminate a threshold of 26 nT above ambient, a figure that is cited often in the literature. Of interest is that of nine bees tested, two could not discriminate below 2,600 nT. The median sensitivity for all of the bees was 260 nT.
- Semm and Beason (1990) found that spontaneous firings of the ophthalmic nerve and the trigeminal ganglion of the bobolink (*Dolichonyx oryzivorus*) increased noticeably when the bird was subjected to changes in the geomagnetic field down to 200 nT. This was the lowest level they tried and the authors speculated that one might expect even greater sensitivity based on behavioral responses.
- Based upon 70 years of data, Klinowska (1986) reported that live whale strandings in the U.K. were associated with geomagnetic disturbances and that strandings generally occurred 1-2 days after major geomagnetic storms (Section 4.1). Klinowska (1986) further found that a correlation between live strandings and higher geomagnetic disturbances appeared in the most northerly U.K. region. This was also the only group to incur geomagnetic disturbances that exceeded 3.0 on the K-index, which corresponds to a disturbance of 40-70 nT.
- Kirschvink et al. (1986) and Kirschvink (1990) found similar and/or supporting results for some U.S. strandings data of both odontocetes and mysticetes (Section 4.1). Total intensity variations of as little as 50 nT (0.1% of the total field) were sufficient to influence stranding location in the data analyses (Kirschvink et al. 1986).
- Wiltschko and Wiltschko (1996), two of the noted researchers in the study of bird geonavigation, theorized that geomagnetic orientation in birds would require an ability to detect differences of about of 10 nT against a background of 30,000-50,000 nT, but this theory has never been proved.

One problem in assessing the potential effects of EM surveys is that while there is considerable evidence that geomagnetic orientation exists within the animal kingdom, the actual operating mechanisms by which species acquire, process, and exploit magnetic data is unknown. Without understanding how animals magnetically orient, it is difficult to predict how and to what extent they may respond to disruptions in their magnetic environment. Further, the mere presence of a geomagnetic navigation system within the animal kingdom does not guarantee its ecological significance in all environments, for all species, or even within species. Tropotaxis may be an important navigational tool for cetaceans inhabiting the North Atlantic where the ocean floor is characterized by strong magnetic lineation, yet may be relatively useless in the geomagnetically featureless areas around Australia, New Zealand, and the Indian Ocean. Sea turtles may rely on compass orientation during early stages of their life but may have little need for it as adults.

In Klinowsksa's (1985, 1986) landmark study of cetacean strandings in the U.K., the author found all 137 live strandings (as opposed to passive strandings when dead animals wash up on shore) involving pelagic cetaceans occurred *exclusively* at local geomagnetic anomalies where field lines ran perpendicular to the coast and within one to two days after geomagnetic storms. The pattern was not evident for nearshore coastal species. Klinowska (1985, 1986) reasoned that geomagnetic storms temporarily disrupted the geonavigational capabilities of the cetaceans but that coastal animals were familiar with navigating in shallow, nearshore waters and likely relied on other navigational cues (e.g., olfaction, echolocation, bottom features, coastal topography). If pelagic cetaceans were temporarily disoriented and, by chance, happened to head shoreward they would enter unfamiliar settings and hence be exposed, perhaps for the first time, to the problems involved in following geomagnetic and other topography in coastal waters.

As a general observation, Klinowska (1985) noted:

> *In most cases, even animals unfamiliar with the area are obviously able to deal with the problems: live strandings are very rare events. In 70 years, only 137 incidents have been recorded for 14,100 km of coastline. In comparison with almost 3,000 strandings of all types so far recorded, and with the hundreds of thousands of animals alive at sea, live strandings or major orientation mistakes, are rare indeed. It is remarkable that when mistakes are made, they are all related to the geomagnetic topography. This must either imply that the animals are unable to use any other orientation information at that time—perhaps because of illness—or that they have not paid sufficient attention to other available information. In the latter context, the mass near strandings may well represent last-moment error corrections. The geomagnetic topography thus appears to be dangerous to inexperienced animals in coastal waters, but not overwhelmingly so—otherwise there would be more live strandings.*

Klinowska's (1985) observation is a critical element in the idea of geomagnetic navigation in cetaceans, sea turtles, and others. For the mechanism to be functional, animals must, for the most part, be able to withstand or compensate for the constant bombardment of geomagnetic noise that characterizes their world. Based upon NOAA's (2011) Space Weather Scale for Geomagnetic Storms and assuming storm duration of from 24 to 48 hr, there are approximately 9.7 to 19.3 disturbances of 70-120 nT annually (see Table 6.3). Moderate K=6 disturbances of 120 to 200 nT occur from 3.4 to 6.8 times per year. Even strong K=7 disturbances of 200-330 nT occur every one to two years. These levels match or exceed the few threshold levels that have been reported or estimated in the literature.

For animals to be able to function under these conditions they would either have to have (1) threshold levels above background geomagnetic noise, (2) some mechanism for filtering out the erratic magnetic noise, or (3) they would have to shut down the geomagnetic component of their navigation system and rely on some other cueing mechanism. This has certainly been shown to be the case with passerine birds that rely on redundant cues and at times switch back and forth between cueing systems. When

Brabyn and Frew (1994) found no relationship with whale strandings and geomagnetic topography around New Zealand, the authors noted that much of New Zealand is surrounded by a shallow marine platform characterized by no consistent pattern in geomagnetic anomalies. In effect, New Zealand does not have a geomagnetic field of sufficient pattern or intensity to support a cetacean navigation system. If this is the case, cetaceans around New Zealand must being relying on some other type of navigation system during their migrations.

Thresholds of Effects

In an EIA it is useful to define thresholds of effects in order to be able to describe potential zones of influence and to subsequently predict effects. Based on presently available information, the review and discussion contained in the preceding sections and the professional judgement of the authors it is reasonable to select 200 nT and 386 nV cm^{-1} as generic thresholds of effects for magnetic and electric fields generated by EM surveys. Effects in this case simply mean an elicited response of some kind with no negative or positive connotations. It is recognized that many animals will have no reactions to these levels while others may be able to detect fields below these values. These values are used in the following sections.

Effects of Deep EM Surveys on Orientation/Navigation

As described earlier, EM sources may be towed near surface or near bottom. The following describes potential effects of deep tows based upon data generated by the EM industry using standard parameters.

An attribute of EM technology is that EM fields attenuate rapidly with distance from source. Electromagnetic energy obeys the diffusion equation which means that the signal strength falls off proportionally to r^2 (where r is the distance from the source) unlike seismic energy which obeys the wave equation where the signal strength falls off proportionally to r. Therefore, EM energy attenuates far more rapidly than seismic energy and thus its effect is much more localised. This is beneficial in that the EM source zone of influence is relatively localised and for a given transit speed the duration of any effects will be shorter.

Magnetic field strength estimates were provided by the IAGC based on actual data provided by the EM survey industry. A summary of deep tow data is provided in Table 6.4. Field strengths were calculated based upon the different company's specific survey protocols. Fields were calculated for variable source frequencies ranging for 0.25 to 10 Hz. Using standard parameters for water depths and conductivity, three companies provided their EM data by assuming a towed source antenna 30-50 m above the seafloor (total water depth 4,000 m). For one data set, field strengths were maximal at a water depth of 3,900 m (i.e., 50 m above the source), ranging from 3,956 to 3,991 nT depending upon source frequency. In all cases, field strengths attenuated to less than 200 nT within 400 vertical meters above the source (Table 6.4). For another set of estimates, field strength was greatest at 4,000 m water

Table 6.4 Distribution of magnetic fields exceeding 200 nT for deep towed EM source.

Source	Current	Frequency	Radial			Intensity (nT)			
Depth (m)	(A)	(Hz)	Distance (m)	*3500 m*	*3600 m*	*3700 m*	*3800 m*	*3900 m*	*4000 m*
3950	1000	0.25	0	145	241	450	1028	3991	3319
			100	136	220	394	851	3524	2902
			200	112	169	265	433	598	735
			300	84	114	148	163	66	218
			400	59	71	76	60	3	106
		0.5	0	126	221	429	1009	3981	3311
			100	118	200	374	833	3514	2894
			200	96	152	248	419	592	728
			300	70	99	134	153	63	212
			400	47	59	66	53	5	101
		1	0	98	187	390	969	3956	3292
			100	91	168	337	796	3492	2875
			200	73	124	218	391	578	715
			300	51	78	113	135	57	200
			400	33	44	52	43	6	91
3970	1250	0.25	0	154	254	466	1031	3456	7383
			100	144	232	406	833	2709	6413
			200	120	178	274	427	545	761
			300	90	121	155	169	73	235
			400	63	75	81	64	5	117
		0.5	0	133	231	442	1009	3443	7375
			100	124	210	383	813	2697	6406
			200	102	159	255	411	537	754
			300	75	105	140	157	69	229
			400	50	63	70	56	7	112
		1	0	103	193	398	964	3411	7358
			100	95	174	342	771	2669	6389
			200	76	129	221	379	520	740
			300	54	81	116	137	61	217
			400	34	46	54	45	10	102
		10	0	7	26	104	469	2770	6971
			100	6	21	83	352	2153	6033
			200	4	13	42	134	320	539
			300	2	6	15	30	17	104
			400	1	2	4	4	5	31
Notes: numbers in italics are water depths									
Shaded areas are those depths >200 nT									

depth with intensities ranging from 6,971 to 7,383 nT. Again, field strengths attenuated to less than 200 nT within 400 vertical meters above the source (Table 6.4). For the third set of estimates, field strength was greatest at 100 m above the seafloor with intensities ranging from 11,504 to 12,336 nT. And again, field strengths attenuated to less than 200 nT within 400 vertical meters above the source.

For deep-tow EM surveys at depths of 1,000 m or greater, surface waters would be effectively buffered from the EM transmission. Most cetaceans, sea turtles, pinnipeds, and seabirds spend a good deal of their time in the upper 200 m of the water column (Lutcavage and Lutz 1997; Schreer and Kovaks 1997). Notable exceptions in temperate and tropical waters are the deep diving sperm whale which may regularly dive to depths of 3,000 m. Maximum diving depths of 1,500 m have been reported for other species of cetacean (Appendix A) but this diving activity does not represent the norm. Except for some Arctic species, pinnipeds are largely confined to the upper 200 m of the water column with maximum diving depths typically limited to the top 500 m (see Appendix A). Most seabirds are shallow divers, being limited to top 100 m of the water column (see Appendix A).

For deep-tow EM surveys, most cetaceans, turtles, pinnipeds, and sea birds would be effectively insulated from EM transmissions. For surveys in waters shallower than 700 to 800 m, field strengths in excess of 200 nT might start to penetrate the upper part of the water column—the shallower the water the higher the field strength. In terms of radial distance from source, EM strength usually drops to below 200 nT within 400 m (Table 6.4).

There is no information on the effects of magnetic fields on deep-water fish and invertebrates. In the Bathypelagic Zone (>1,000 m), deep-sea anglerfishes (Ceratioidae) dominate in most seas (McEachran and Fechhelm 1998). Some species of bristlemouths (*Cyclothone* spp.) are found at depths below 1,000 m and do not undergo vertical migrations at night. Several species of scaleless dragonfish (Melanostomiidae) have been taken at depths down to 3,000 m. Other bathypelagic species include smoothheads (Alepocephalidae), black dragonfishes (Idiacanthidae), loosejaws (Malacosteidae), scaly dragonfishes (Stomiidae), Ipnopids, and deep-sea smelts (Bathylagidae). Most fishes of the bathypelagic zone appear to have overlapping mesopelagic/bathypelagic distributions (McEachran and Fechhelm 1998). How these fauna might react to magnetic fields is unknown but any exposure to EM survey emissions would be of short duration.

Little is known about deep sea invertebrates. Two of the most comprehensive deep-sea benthic studies were conducted in the northern Gulf of Mexico: the Northern Gulf of Mexico Continental Slope (NGMCS) Study conducted from 1983 to 1987 (Gallaway 1988a,b,c) and the Northern Gulf of Mexico Continental Slope Habitats and Benthic Ecology Study from 2000 to 2002 (Rowe and Kennicutt 2001, 2002, 2006). The studies showed a sharp decline in invertebrate abundance and diversity with depth. In the Upper Abyssal Zone (1,000-2,275 m), the number of fish species declined substantially from that observed in shallower waters. Dominant invertebrates included sea cucumbers, galatheid crabs, deep-water carideans, gastropods, and sponges. In the Mesoabyssal Zone (2,300-3,225 m), true deep-sea faunas prevailed characterized by low abundance and a predominance of invertebrates (sea cucumbers, galatheid crabs, deep-water carideans). In the Lower Abyssal Zone (3,250-3,850), deep-sea fish and invertebrate densities were universally low with asteroids and sea cucumbers dominating. Overall, the deeper the depth the lower is the abundance and diversity of deep sea fishes and invertebrates. This would tend to minimize effects on the ecosystem if in fact there would be any. Fauna abundance is low and the distribution of the few species there are would be dispersed across a wide abyssal realm. Any effect of EM if it did occur would be limited to an infinitesimal proportion of the population over a very short duration.

Although elasmobranchs are renowned for their electroreceptive capabilities, little is known about their sensitivity to changes in magnetic fields. Empirical evidence that elasmobranchs can detect magnetic fields is limited to a few laboratory behavioral studies (Section 5.0) and in all cases responses required changes to the surrounding magnetic field of Earth strength magnitudes. But whereas detection of geomagnetic topography by birds, cetaceans, sea turtles, and others is believed to function through some combination of magnetite and radical pair mechanisms, Kalmijn (1978) theorized that the ability of elasmobranchs to detect magnetic fields was a function of their acute electrosensory capabilities and the simple principal of induction. When a conductor (shark) moves through a magnetic field (Earth's) electric currents are induced in the conductor. The shark's electrosensory ability could potentially allow it to interpret the electric currents generated by the magnetic field. Induction is the transducer that coverts magnetic data into electrical data.

Given their acute sensitivity to electric fields, it is possible that elasmobranchs also will be sensitive to the magnetic component of the EM transmissions. The depth distribution of sharks skates and rays varies greatly among genera, family, and order. Reports can be deceiving because the deep limit of depth ranges often represents a single take and is more of an outlier than the norm. In the review of *Fishes of the Gulf of Mexico*, McEachran and Fechhelm (1998) state that skates and rays occur from the shoreline to 2,000 m. Depth range data were provided for 24 species of skate (Rajidae). Of these, only two species were found in waters deeper than 1,110 m and only a single species, *Rajella fuligina*, was taken at 2,280 m.

For other species depth ranges vary. Mackerel sharks (Lamnidae), requiem sharks (Carcharhinidae), and hammerhead sharks (Sphyrnidae) typically occupy water between 20 and 500 m in depth McEachran and Fechhelm (1998). Conversely, sixgill and sevengill sharks (Hexanchidae) range throughout the water column from the surface to 1,875 m. Dogfish (Squalinidae) have been taken to 1,500 m, while sand tiger sharks have been reported to 1,600 m. Diversity does decrease with depth but select species are likely outside the 2,000-m isobath with some species ranging throughout the water column. How these species would respond to EM waves is unknown but any exposure would be brief.

A major ameliorating factor is that EM surveys are transitory as are most of the mobile fauna discussed above. The exception would be skates and rays, which are largely sedentary, but they are typically rare deeper than 1,000 m. Marine fauna spend a good deal of their time on the move. Groups may linger in areas of high productivity but continue on once food sources are depleted. Even in areas of high productivity, animals likely range within an area of dozens of square kilometers. With a ship survey speed of about 2 knots it is unlikely that fauna and the research vessel will spend any significant time in close proximity to each other. Given the likely very brief exposure times, coupled with the attenuation rate of the magnetic field, it can be predicted that the magnetic component of EM bottom surveys will have a negligible effect on marine animals.

In summary and in general, any potential effects of deep-tow EM surveys on marine biota orientation or navigation and will likely be confined to a zone of influence on the order of 400 m.

Effects of Near-Surface EM Surveys on Orientation/Navigation

Magnetic field strength intensities were provided by IAGC for near-surface EM tows (Table 6.5). In this scenario, the transmission source was towed 50 m below the sea surface. Examples are for source frequencies of 0.25, 0.5, 1.0 and 10.0 HZ. Peak intensities were at 100 m and ranged from 3,553 to 4,190 nT. Surface magnetic field intensities attenuated to less the 200 nT within 400 radial m from source depending upon frequency (Table 6.5). The higher the frequency, the smaller is the area affected.

Surface waters are the primary oceanic habitat from cetaceans, sea turtles, pinnipeds, sea birds, and pelagic sharks. These field intensities are within the general threshold levels reported in the literature for different animal phyla (see previous sections). The question becomes how animals will react. Given that animals are subjected to 3-6 moderate (120-200 nT) geomagnetic storms per year some of which may last 24- to 48- hr, animals seem perfectly capable of dealing with intensities approaching 200 nT for brief periods of time. Field strength intensities attenuate to <200 nT within 300 to 400 radial m from source.

Another issue is time of exposure. Using the data from a randomly chosen 0.5 Hz scenario and a threshold reference of 200 nT, the surface field strength attenuates to <200 nT between 300 to 400 m. If one assumes a mean radial distance of 350 m, or a diameter of 700 m, and a survey vessel towing speed of 2 knots, any fixed point in the ocean would be subject to field intensities of >200 nT for only about 14 minutes. This is the worst case scenario in which the fixed points lie directly along the axis of the tow. With attenuation, field intensities decreases laterally or perpendicular to the axis of the tow and exposure time will drop rapidly. For example, at a distance of 100 m abeam of the axis of tow exposure time would drop to about 8 minutes[1]. However, surface fauna are not fixed points, they are constantly moving. The odds that a faunal group would encounter and be exposed to intensities of >200 nT for anything more than a few minutes is intuitively quite low.

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[1] Calculated using the Pythagorean theorem

Table 6.5 Distribution of magnetic fields exceeding 200 nT for shallow towed EM source.

Source	Current	Frequency	Radial		Intensity (nT)				
Depth (m)	(A)	(Hz)	Distance (m)	*0 m*	*100 m*	*200 m*	*300 m*	*400 m*	*500 m*
50	1000	0.25	0	2864	4190	1127	507	277	169
			100	2450	3677	933	444	253	158
			200	888	642	478	300	195	131
			300	333	53	178	167	131	98
			400	172	23	60	85	81	68
50	1000	0.5	0	2846	4185	1110	485	254	148
			100	2432	3673	917	423	231	138
			200	872	641	466	282	176	113
			300	319	54	169	154	116	83
			400	161	21	55	75	69	56
50	1000	1	0	2810	4166	1068	441	215	115
			100	2397	3656	879	382	194	107
			200	844	632	437	249	144	86
			300	297	52	152	130	91	60
			400	144	20	46	59	51	39
50	1000	10	0	2334	3553	543	120	29	8
.			100	1971	3150	426	97	25	7
			200	573	434	168	50	15	4
			300	143	17	36	18	7	2
			400	50	12	5	5	2	1
Notes: numbers in italics are water depths									
Shaded areas are those depths >200 nT									

In addition, fauna have other mechanisms for dealing with high magnetic field disruptions. If field strengths are enough to disrupt geomagnetic navigation, animals may merely shut that system down and rely on an alternate navigation system. The use of multiple navigation systems has been clearly demonstrated for passerine birds[2]. Experiments have shown that experienced pigeons use the sun as a preferred compass and when it is not available they rely on magnetic cues (Walcott 2005). Evidence suggests that cetaceans inhabiting the geomagnetically featureless waters around New Zealand do not rely on geonavigation (Brabyn and Frew 1994). There is simply no geomagnetic landscape on which to cue. Yet these animals survive quite well obviously relying on some other navigation system.

Another coping mechanism is avoidance. Cetaceans and pinnipeds are powerful swimmers. Sea birds have the ability to fly. Requiem and hammerhead sharks are among the most powerful swimmers in the class Chondrichthyes (shark, skates, rays, chimeras). The slowest swimming is the sea turtle. Sea turtles are among the slowest swimmers averaging cruising speed of 1.5 to 2.5 km $h^{-1.}$ (0.8-1.3 knots). Yet, given the slow tow speed of the ship and the rapid attenuation of field intensity as one moves

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[2] Passerine birds are historically the most intensely studied group with regard to navigation systems and most breakthroughs in the field have come from research on this group.

laterally away from the axis of the tow, it is likely that turtles would be able to avoid areas of high intensity if they chose to do so.

Overall, given the rapid attenuation of magnetic field strength, the relatively small area affected, the brief period of exposure, the likelihood that animals rely on more than one navigation system, and their capacity for avoidance, it can be predicted that surface EM surveys pose little threat to marine fauna. Any effects will likely be contained with a 400 m zone of influence (Table 6.5) for a short duration.

6.3.3. Effects on Electroreception

As discussed previously, elasmobranchs have highly acute electrosensory capabilities and are likely capable of detecting EM emissions from some relatively great distance. For such a system to be functional the animal would need some mechanism for dealing with anomalous natural electrical noise.

Natural Electrical Perturbations

Behavioral and electrophysiological studies have documented elasmobranch threshold sensitivity to electric fields ranging from 1 μVcm^{-1} (1,000 $nV\ cm^{-1}$) down to 0.001 μVcm^{-1} (1 $nV\ cm^{-1}$) (Section 5.0). Yet these animals live in an environment that is filled with variable and erratic electric fields. Motional induction, seawater flowing through the Earth's geomagnetic field, creates electric fields in seawater. Voltage gradients resulting from currents in the Atlantic typically range from 0.05 to 0.5 $\mu V\ cm^{-1}$ (50-500 $nV\ cm^{-1}$) (von Arx 1962 as cited in Kalmijn [1971]). The voltage gradient associated with the strong tidal currents in the English Channel reach 0.25 μVcm^{-1} (250 $nV\ cm^{-1}$) twice a day (Barber and Longuet-Higgins 1948 as cited in Kalmijn [1971]). In six cross sections of the Gulf Stream, total electric field intensities ranged as high as 0.46 $\mu V\ cm^{-1}$ (450 $nV\ cm^{-1}$) (Rommel and Mccleave 1973). Electric fields in the ocean tend to be greatest in areas of large volume transport or strong flow in shallow water and can reach magnitudes of about 0.10 $\mu V\ cm^{-1}$ (100 $nV\ cm^{-1}$) (Tyler and Mysak 1997). Whitehead (2002) reported DC electric field strengths in Bass Strait, Australia, that ranged between 0.0285 and 0.2540 μVcm^{-1} (29-254 $nV\ cm^{-1}$), and in Cook Strait, New Zealand, that ranged between 0.179 and 0.370 μVcm^{-1} (179-370 $nV\ cm^{-1}$). Electric field strengths measured in the North Sea reached up to 0.35 $\mu V\ cm^{-1}$ (350 $nV\ cm^{-1}$) (Pals et al. 1982).

These motional induced fields are from 20 to 500 times stronger than the 0.001 $\mu V\ cm^{-1}$ (1 $nV\ cm^{-1}$) threshold observed for sandbar sharks, bonnetheads and scalloped hammerhead sharks (Kajiura and Holland 2002; Kajiura 2003). This electric noise is a constant characteristic of the elasmobranch environment yet sharks, skates, and rays successfully function in it. In the previous section on geomagnetic navigation it was noted that cetaceans, sea turtles and others had three alternatives in dealing with magnetic noise in the sea. They would either have to have (1) threshold levels above background geomagnetic noise, (2) some mechanism for filtering out the erratic magnetic noise, or

(3) they would have to shut down the geomagnetic component of their navigation system and rely on some other cueing mechanism. The first alternative does not hold for electric noise since background electric fields are well within elasmobranch threshold levels. Nor is the third alternative possible. Because electroreception is a primary component in elasmobranch sensory system in a noise filled environment, animals must have the capacity to filter electric information or adjust their actions to counteract the noise.

It is likely that prey detection would be minimally affected. With prey bioelectric fields ranging from 2,000 to 100,000 times the electroreceptive threshold of elasmobranchs, skates, rays and benthic sharks would just have to pass a little closer to their target. In the "passive mode" electronavigation model, motional induced electric fields caused by a shark swimming through the Earth’s geomagnetic field are actually part of the theorized mechanism by which sharks navigate (Section 5.0.). The intensity of the induced electro-magnetic fields will be a function of the fish’s swimming speed, the geomagnetic intensity of the local landscape, and even the direction in which the shark is swimming. Swimming across magnetic field flux lines induces stronger fields than swimming parallel to them.

Elasmobranches also successfully deal with large scale perturbations in the Earth’s magnetic field. Solar storms can induce electric fields of between 0.60 and 1.25 µV cm^{-1} (600-1,250 nV cm^{-1}) in the sea (Brown et al. 1979 as cited in David Balloch and Associates 2003). That is 600 to 1,250 times stronger than the 1 nV cm^{-1} threshold observed for sandbar sharks, bonnetheads and scalloped hammerhead sharks (Kajiura and Holland 2002; Kajiura 2003).

Effects of Bottom EM Surveys on Electroreception

Given the acute sensitivity of electroreceptive fish to electric fields, the fields associated with EM technologies are at intensities well in excess of the often cited sensitivity threshold of 1 nV cm^{-1}. But to use this value as a benchmark for an environmental assessment is intuitively unrealistic. As discussed above, elasmobranches are constantly subjected to natural electric noise caused by the movement of seawater through the planet’s geomagnetic field. The swifter the ocean or tidal current the stronger is the field. Yet elasmobranches have obviously evolved mechanisms for dealing with this background interference.

Table 6.6 lists motionally induced electric fields found in the natural environment listed in the literature. Values are expressed in units of nV cm^{-1}. Numbers represent upper values in a reported range. Even some of these values are not constant. Electric fields recorded in the English Channel are based upon tidal currents and only reach maximum intensity twice a day at peak tidal flow. Nevertheless, they are representative of fields that elasmobranchs encounter on a regular basis. Using the values in Table 6.6, a mean value of 386 nV cm^{-1} was defined as a threshold reference. [Note that the outlier value of 750 nV cm^{-1} was excluded from the calculation.] Members of the suborder Elasmobrachii regularly and successfully deal with electric noise in this realm. For purposes of assessment, field strengths less than 386 nV cm^{-1} are considered manageable levels of electric noise.

Table 6.6 Motionally induced electric field strengths reported in the literature. These are naturally occurring electric fields caused by seawater flowing through the Earth's geomagnetic field. Values are highest of the reported range.

Motional Induced Electric Field Strengths	Location	Reference
500 nV cm^{-1}	Atlantic Ocean	von Arx 1962 (as cited in Kalmijn 1971)
250 nV cm^{-1}	English Channel	Barber and Longuet-Higgins 1948 (as cited in Kalmijn 1971)
460 nV cm^{-1}	Gulf Stream	Rommel and Mccleave (1973)
370 nV cm^{-1}	Cook Straight, New Zealand	Whitehead (2002)
350 nV cm^{-1}	North Sea	Pals et al. (1982)
750 nV cm-1	Schelde Estuary, Netherlands	Pals et al. (1982)

As noted previously, electric field strength estimates were provided by IAGC (Table 6.7). Field strengths were calculated based upon each company's specific survey protocols. Fields were calculated for variable source frequencies ranging for 0.25 to 10 Hz. The EM data are based on towing the source antenna 30-50 m above the seafloor. For one set, field strengths were maximal at 50 m below the source at a water depth of 4,000 m, ranging from 63,272 to 66,609 nV cm^{-1} depending upon source frequency (Table 6.7). In all cases, field strengths attenuated to less than 386 nV cm^{-1} within 800 vertical meters from source (Table 6.7). For the other estimates, field strengths were greatest 30 m below the source at 4,000 m water depth with intensities ranging from 187,373 to 271,103 nV cm^{-1}. For all estimates, field strengths attenuated to less than 386 nV cm^{-1} within 500 to 800 vertical and radial meters from source depending upon frequency (Table 6.7).

The critical issue again becomes exposure time. Using the mean case attenuation radial radius of 650 m, and assuming a towing speed of 2 knots, a fixed location on the seafloor would be exposed to field intensities greater than 386 nV cm^{-1} for about 21 minutes. A point 250 m abeam of the axis of tow would be exposed for about 8 minutes. With animals constantly on the move and avoidance possible, the likelihood of prolonged exposure is very small. Given the attenuation rates of the electric fields and the minimal times of exposure, it can be predicted that bottom EM surveys pose no serious threat to elasmobranches.

Table 6.7 Distribution of electric fields exceeding 386 nV/cm for deep towed source.

Source	Current	Frequency	Radial			Intensity (nV/cm)						
Depth (m)	**(A)**	**(Hz)**	**Distance (m)**	*3200 m*	*3300 m*	*3400 m*	*3500 m*	*3600 m*	*3700 m*	*3800 m*	*3900 m*	*4000 m*
3950	1000	0.25	0	304	445	682	1115	2004	4132	10043	24197	29990
			100	297	435	665	1089	1974	4212	11902	58623	63272
			200	279	405	615	999	1797	3793	10590	53033	54014
			300	252	360	537	847	1444	2713	5589	10831	12572
			400	219	306	443	667	1050	1712	2763	3948	4341
			500	183	250	349	499	725	1054	1468	1842	1963
			600	150	199	267	362	493	658	840	985	1033
			700	120	154	200	260	335	423	510	575	598
			800	94	118	149	186	231	279	324	357	369
3950	1000	0.5	0	298	458	728	1219	2209	4503	10695	25640	31364
			100	290	443	701	1171	2127	4462	12273	59342	64189
			200	267	402	628	1031	1845	3829	10526	52639	53548
			300	233	344	523	830	1408	2620	5380	10481	12216
			400	194	279	409	619	972	1582	2561	3690	4086
			500	155	216	305	438	637	928	1304	1654	1779
			600	120	162	220	300	410	552	712	847	898
			700	90	118	155	203	264	336	412	472	498
			800	67	85	109	137	172	211	249	280	295
3950	1000	1	0	245	409	704	1264	2412	5055	12006	29481	35118
			100	236	392	670	1192	2264	4820	13025	61244	66609
			200	212	346	578	1002	1846	3837	10378	51745	52534
			300	178	282	456	755	1305	2430	4977	9787	11522
			400	141	216	333	521	830	1356	2211	3238	3645
			500	106	156	230	339	499	734	1046	1357	1493
			600	76	108	152	213	294	402	530	649	708
			700	53	73	98	131	173	225	285	340	371
			800	36	48	63	81	103	131	161	190	209
3970	1250	0.25	0	330	483	739	1204	2158	4457	11206	31830	50143
			100	322	472	720	1174	2114	4463	12367	62252	187373
			200	304	440	666	1075	1911	3932	10198	38937	81588
			300	274	392	581	911	1537	2831	5652	10908	14038
			400	238	333	481	720	1126	1820	2923	4232	4802
			500	200	273	380	541	785	1138	1589	2014	2178
			600	164	217	292	396	537	719	920	1087	1149
			700	131	169	220	285	368	465	562	638	666
			800	104	130	164	205	255	308	359	397	412
			900	81	99	122	148	178	209	238	259	268
3970	1250	0.5	0	322	493	783	1308	2364	4833	11855	33037	52133
			100	312	477	754	1255	2267	4710	12711	62759	188394
			200	288	434	675	1103	1955	3960	10122	38559	81008
			300	251	371	563	889	1493	2728	5431	10536	13634
			400	210	301	442	666	1040	1678	2705	3950	4516
			500	168	234	330	473	688	1001	1409	1806	1971
			600	130	176	239	327	446	601	779	933	998
			700	98	129	170	222	289	369	454	523	554
			800	73	93	119	151	189	232	276	312	329
			900	54	67	83	103	125	150	175	194	205
3970	1250	1	0	261	435	748	1339	2552	5364	13110	36133	57987
			100	252	417	711	1263	2386	5040	13368	64045	191193
			200	226	368	614	1060	1937	3941	9937	37713	79715
			300	190	301	485	800	1373	2516	5005	9804	12845
			400	150	230	355	555	881	1432	2327	3456	4020
			500	113	167	246	363	535	787	1127	1478	1650
			600	82	116	164	229	318	436	578	715	786
			700	57	78	106	142	189	247	314	376	413
			800	39	52	68	88	113	144	179	212	234
			900	26	34	43	55	70	87	107	126	141
3970	1250	10	0	6	20	72	264	996	3962	16938	81139	193006
			100	5	19	65	230	845	3253	13923	85630	271103
			200	4	14	46	155	519	1759	6193	26152	61349
			300	3	9	27	82	239	658	1637	3683	6264
			400	2	5	13	36	89	195	376	740	1321
			500	1	2	6	13	28	52	95	209	409
			600	0	1	2	4	8	14	32	75	154
			700	0	0	1	1	2	5	13	30	63
			800	0	0	0	0	1	2	6	12	27
			900	0	0	0	0	0	1	2	5	12
Notes: numbers in italics are water depths												
Shaded areas >386 nV/cm												

In summary, elasmobranchs are known to be among the most sensitive marine animals to electric fields (there may be others, unknown at present) and they are likely able to detect emissions at some distance. If received emissions are "too strong" elasmobranchs may be repelled but if they are within the range emitted by prey, they may be attracted. In any event, any effects will be of very short duration and likely of little consequence.

Effects of Surface EM Surveys on Electroreception

Electric field strength estimates were provided by IAGC for near-surface EM surveys during which the source is towed 50 m below the sea surface (Table 6.8). Field strengths were calculated based upon an EM contractor's specific survey protocols. Fields were calculated for variable source frequencies ranging from 0.25 to 10 Hz. Field strengths were maximal at 100 m radial distance, ranging from 107,758 to 165,677 nV cm^{-1} depending upon source frequency. In all cases, field strengths attenuated to less than 386 $nVcm^{-1}$ within 400 to 800 m vertical and 1,000 to 1,900 m radial from the EM source (Table 6.8). Interestingly, based on the data provided by IAGC, the shallow-towed source in contrast to the deep-towed source, radiates electrical energy over a wider area and the radial area increases with frequency while the vertical area decreases with frequency. This may be due to the characteristics of the wave form. Again, given the existing information on the effects of electric fields on elasmobranchs, the substantial rates of attenuation coupled with brief exposure periods (see above), we believe that surface EM surveys pose no serious threat to elasmobranchs. They may detect the fields and may have some reaction to them but should not be harmed at the expected levels of emissions.

Lastly, in behavioral studies designed to develop electric shark deterrents, Marcotte and Lowe (2008) observed that sharks would exhibit head twitches and retreat responses at 185,000 ± 133,700 µV cm^{-1} (185,000,000 +/- 133,700,000 nV cm^{-1}) for hammerheads and 96,400 ± 102,800 µV cm^{-1} (96,400,000 +/- 102,800,000 nV cm^{-1}) for leopard sharks. Smith (1974, 1991 as cited in Marcotte and Lowe 2008) reported that sharks would not approach a voltage gradient greater than 55,000 µV cm^{-1}(55,000,000 nV cm^{-1}). The maximum surface intensities (0 to 100 m water depths) predicted by IAGC range from 39,415 nV cm^{-1} to 165,677 nV cm^{-1} (Table 6.8). Thus, electric field strengths that elicit avoidance or deterrent response in sharks in the upper water column are from 332 to 1,395 times higher than the highest EM transmission intensities in the data sets used. It appears that the EM technologies have little or no deterrent effect on elasmobranchs, at least on the ones that have been studied.

Table 6.8 Distribution of electric fields exceeding 386 nV/cm for shallow towed source.

Source	**Current**	**Frequency**	**Radial**			**Intensity (nV/cm)**						
Depth (m)	**(A)**	**(Hz)**	**Distance (m)**	*0 m*	*100 m*	*200 m*	*300 m*	*400 m*	*500 m*	*600 m*	*700 m*	*800 m*
50	1000	0.25	0	39415	28123	11593	4851	2391	1346	831	546	375
			100	106883	63406	13516	4930	2356	1316	812	534	368
			200	98443	56871	12047	4461	2156	1215	755	500	347
			300	17718	12907	6623	3257	1756	1040	664	448	314
			400	6005	4977	3414	2112	1300	830	554	384	275
			500	2767	2385	1869	1332	916	631	442	318	233
			600	1523	1294	1091	850	634	466	343	255	192
			700	949	762	671	554	439	340	261	201	155
			800	650	476	431	370	306	247	197	156	124
			900	479	309	286	253	216	180	148	120	98
			1000	373	208	195	176	154	132	111	92	77
			1100	302	143	136	125	111	97	84	71	60
50	1000	0.5	0	40908	29635	12320	5273	2625	1466	883	560	367
			100	107758	64197	13940	5218	2533	1411	853	543	357
			200	98234	56462	11996	4511	2215	1252	768	495	330
			300	17495	12528	6403	3160	1718	1021	646	427	290
			400	5914	4684	3192	1968	1213	774	513	350	243
			500	2786	2161	1680	1189	814	558	389	275	197
			600	1617	1122	938	725	536	391	285	209	154
			700	1082	629	550	450	353	271	206	156	118
			800	795	372	335	286	234	186	147	114	89
			900	620	229	211	185	156	128	104	83	66
			1000	502	146	136	122	106	89	74	60	49
			1100	415	96	90	82	72	62	53	44	36
			1200	350	66	61	56	50	44	38	32	27
50	1000	1	0	45050	33614	13758	5884	2848	1509	849	497	299
			100	110135	66254	14775	5616	2680	1428	809	477	289
			200	97907	55520	11852	4521	2209	1210	703	423	260
			300	17230	11768	5965	2945	1593	925	560	348	220
			400	5996	4158	2795	1707	1042	652	416	269	176
			500	3071	1794	1374	958	647	435	293	198	134
			600	1963	864	713	541	393	281	199	140	98
			700	1410	448	387	311	239	179	132	96	70
			800	1075	246	218	182	146	113	87	65	48
			900	848	143	127	109	90	72	57	44	33
			1000	684	90	78	67	57	46	37	29	23
			1100	562	63	51	43	36	30	25	20	16
			1200	468	47	36	29	24	20	17	14	11
			1300	395	38	27	21	17	14	12	9	7
			1400	338	31	22	16	12	10	8	7	5
50	1000	10	0	124728	93570	18886	4486	1135	302	83	23	7
			100	165677	104122	16452	3760	971	264	74	21	6
			200	100910	41297	7826	2099	606	179	53	16	5
			300	21911	4964	2105	803	284	96	32	10	3
			400	10572	1017	528	249	107	42	16	6	2
			500	6289	294	149	75	36	16	7	3	1
			600	4170	147	57	26	12	6	3	1	0
			700	2984	94	32	12	5	2	1	0	0
			800	2251	62	21	7	3	1	0	0	0
			900	1762	43	14	5	2	1	0	0	0
			1000	1417	31	10	3	1	0	0	0	0
			1100	1165	23	8	2	1	0	0	0	0
			1200	975	17	6	2	1	0	0	0	0
			1300	829	14	5	2	1	0	0	0	0
			1400	713	11	4	1	0	0	0	0	0
			1500	620	9	3	1	0	0	0	0	0
			1600	544	7	2	1	0	0	0	0	0
			1700	481	6	2	1	0	0	0	0	0
			1800	429	5	2	0	0	0	0	0	0
			1900	385	4	1	0	0	0	0	0	0
Notes: numbers in italics are water depths.												
Shaded areas >386 nV/cm												

Effects of Electrodes

The EM source electrodes may be manufactured from copper, stainless steel or titanium which will corrode at varying rates depending upon composition and environmental conditions such as temperature and salinity. Electrolysis at the electrodes will produce chlorine gas, while toxic to marine life will react very quickly in seawater to form a variety of inorganic and organic compounds. Some of the halogenated organic compounds may be carcinogens.

When chlorine dissolves in sea water in hydrolyzes rapidly according to the following equations:

Cl_2+H_2O------HOCl+H^++Cl_-
HOCl+Br------HOBr+Cl_-

Bromide (Br) occurs in seawater at about 60 mg/L and very rapidly hydrolyzes to bromine. Chlorine demand in seawater is about 3.0 mg/L per hour (Macdonald 1978).

Chlorine is widely used in various forms to purify water for swimming pools and for consumption as well as for antifouling purposes. Thus, relatively large amounts in various forms enter the marine environment. Total residual chlorine (TRC) as expressed in the Red Book of the United States of Environmental Protection Agency (EPA) specifies 0.2 mg/L TRC. It should not exceed 160 minutes for 24 hours (www.iecfabchem.in). The Canadian Council of Ministers of the Environment (CCME) guideline for Cl in water is 0.5 µg/L (0.0005 mg/L). Toxicity to marine organisms starts at about 0.02 mg/L (Macdonald 1978).

The maximum amount of chlorine that can be produced by the electrodes is defined by:

$M_{Cl}=3.7x10^{-4}[g/A/s]$

g = grams
A=amperes
S=seconds

However, this is the maximum instantaneous amount because less than 50% (probably much less) will actually be available in the form of fast-acting hypochlorous acid (www.iecfabchem.in).

In summary, while the chemistry involved will be site specific and complex, chlorine gas will be produced by the source electrodes but will be very quickly hydrolyzed into other forms. In addition, the source’s position underwater, natural water currents, plus the towing at 2-4 knots will rapidly disperse any residual chlorine or harmful compounds. In addition, at depths below 50 m, any residual chlorine or chorine compounds will be heavier than water and tend to sink under most conditions (Macdonald 1978).

6.4. Effects of EM Receivers

The deployment and retrieval of CSEM bottom receivers is relatively straightforward and environmentally benign unless located in a particularly sensitive area (e.g., important coral). Receivers are typically anchored to the bottom at regularly spaced intervals using blocks (can be made of compacted sand material that breaks down in 6-9 months) and retrieved using acoustic releases. Underwater noise (discussed above) levels may be greater than during the actual survey if vessel maneuvering is conducted using thrusters.

In some jurisdictions (e.g., Canada), some concern has been raised about the habitat changes induced by large number of anchors left on the sea bed, especially in pristine deepwater environments. This concern can be mitigated by using a compacted sand mixture that slowly breaks down in seawater.

6.5. Accidental Events

There are two accidental events that could affect the marine environment during EM activities: (1) vessel strikes, and (2) small petroleum hydrocarbon spills (e.g., flotation fluids, fuels and lubricants, etc.).

6.5.1. Vessel Strikes

In addition to the potential effect of vessel noise on marine mammal behavior, the presence of vessels can increase the risk of direct mortality via vessel or towed gear collisions. Evidence suggests that a greater rate of mortality and serious injury to large whales is correlated with a greater vessel speed at the time of a ship strike (Laist et al. 2001; Vanderlaan and Taggart 2007). Most lethal and severe injuries to large whales resulting from documented ship strikes have occurred when vessels were travelling at 14 knots or greater (Laist et al. 2001). Vanderlaan and Taggart (2007), using a logistic regression modelling approach based upon vessel strike records, found that for vessel speeds greater than 15 knots, the probability of a lethal injury (mortality or severely injured) approaches 1.0. The probability of lethal injury declined to approximately 0.2 at speeds of 8.6 knots (Vanderlaan and Taggart 2007).

In a review of 58 large whale ship strikes in which the vessel speed was known, the average speed of vessels involved in ship strikes that resulted in mortality or serious injuries to the whale was found to be 18.6 knots (Jensen and Silber 2003). The frequency of incidents of ship strikes more than doubled when vessel speeds were 13-15 knots as opposed to 10 knots or less (Jensen and Silber 2003). Most lethal or severe injuries are caused by vessels >80 m in length (Laist et al. 2001).

Given the mobility of cetaceans, ship strikes during electromagnetic surveys are unlikely given the slow speed (about 1.5-2 knots) of the vessel while towing the source.

All sea turtles, with the exception of the leatherback turtle, have hard carapaces that offer some protection from vessel collision. But even these shells are unable to withstand the strike of a large boat or the cut of a powerful propeller. Sea turtles are vulnerable to vessel collision or being struck by propellers when they stay close to the surface. Time of exposure can vary greatly. In some cases, sea turtles may spend as little as 3 to 6% of their time at the surface breathing and at other times they may spend as much as 19 to 26% of their time there, engaged in surface basking, feeding, orientation, and mating (Standora et al. 1984; Byles 1988; Keinath and MuMusick 1993; Plotkin 1994).

Stranding data indicate that vessel traffic is an important cause of sea turtle mortality. Stranding data for the U.S. Gulf and Atlantic Coasts, Puerto Rico, and the U.S. Virgin Islands show that between 1986 and 1993 about 9% of living and dead stranded sea turtles had boat strike injuries (n=16,102) (Lutcavage et al. 1997). It is unknown how many of the dead turtles were struck post-mortem. Surveyed strandings of Kemp's ridley turtles along the U.S. Texas coast indicated that from 4.5% (Shaver 1998) to 12.3% (Cannon 1998) exhibited obvious propeller cuts. Vessel-related injuries were noted in 13 percent of stranded turtles examined from the Gulf of Mexico and the Atlantic during 1993 (Teas 1994). In Florida, where coastal boating is popular, 18% of strandings documented between 1991 and 1993 were attributed to vessel collisions (Lutcavage et al. 1997). Large numbers of loggerheads and 5-50 Kemp's ridley turtles are estimated to be killed by vessel traffic per year in the U.S. (Lutcavage et al. 1997).

Greater vessel speed increases the probability that turtles would fail to flee from the approaching vessel and collisions are likely highest for recreational vessels. Witzell and Schmid (2004) contend that young turtles are very alert and are less likely to be hit by the slower moving commercial fishing, oil platform supply, or seismic vessels. Their small size, reduced mass, and pliable carapace likely prevents them from being cracked by anything but fast vessels, and are more likely to simply be brushed aside by large slow moving vessels. The trauma of a vessel impact must be extensive in order to kill these small turtles because they have a remarkable ability to survive severe damage from fast boats (Witzell and Schmid 2004).

During EM surveys, the likelihood of a collision with sea turtles would be lowest during the actual transmission period itself. This would be when vessels travel their slowest (2-3 knots). While cruising speeds for sea turtles are typically slower, they are still powerful swimmers. Average swimming speeds for hatchlings have reported as leatherback, 0.91 kmh^{-1} (0.49 knots), loggerhead, 1.26 kmh^{-1} (1.80 knots) and green, 1.57 kmh^{-1} (0.85 knots) (Wyneken 1997). Prange (1976) measured swimming speeds averaging 1.4 to 3.6 kmh^{-1} (0.8-1.9 knots) for adult green sea turtles. Slightly lower cruising speeds of 1.4 to 2.2 kmh^{-1} (0.8-1.2 knots) were reported by Oliver (1955) for adult greens. In all cases, burst swimming speeds could be substantially faster. On their website, NOAA Fisheries Service (2011) claims that green sea turtles have been known to reach 20 mph (17 knots) in bursts when fleeing predators, but no citation is given and the number seems extraordinarily high. Eckert (2002) recorded swimming speed, dive behavior and movements for seven female leatherback sea turtles during a single internesting interval near St Croix in the U.S. Virgin Islands. Modal speeds ranged from 2.0 to 3.0 kmh^{-1}

(1.1-1.6 knots) whereas maximum burst speed ranged from 6.8 to 10.0 kmh^{-1} (3.7-5.4 knots). This suggests bursts speeds in excess of 300% above cruise speeds. It is plausible that turtles would be able to actively avoid collisions during the EM source-on phase of the survey.

6.5.2. Others

Sargassum is a mixture of three species of brown algae that form floating rafts covering hundreds to thousands of square meters (Dooley 1972; Benfield and Shaw 2005). These mats provide habitat for a diverse community of biota including algae, fungi, at least 100 species of attached, sessile, or motile invertebrates, over 100 species of fish, and four species of sea turtles (Dooley 1972; Coston-Clements et al. 1991; Atlantic States Marine Fisheries Commission 1999). Fishes regularly associated with driftline mats are the sargassum fish, sargassum pipefish, and dwarf seahorse. Sargassum mats also provide nursery habitat and shelter for the postlarvae and juveniles of numerous other finfish species and young sea turtles. These concentrated assemblages attract larger open-water predators such as mackerels, tuna, dolphinfish, and jacks. Sargassum mats are also found in oceanic convergence zones but fish assemblages may differ in species makeup depending on location and proximity to source stocks.

The probability of encountering a sargassum raft is small, but if encountered they should be avoided.

6.5.3. Oil Spills

Oil spills, depending upon the amount and type of oil and environmental conditions can potentially affect all of the VECs of interest. There are no characteristics of EM survey vessels that make them more susceptible than other vessels to accidental spills with the possible exception of the loss of winch lubricants or floatation fluids. Most modern survey vessels use marine diesel for propulsion and power generation. Isopar™ is a common flotation fluid used in marine geophysical surveys.

Marine Invertebrates and Fish

Assessment of the effect of oil on marine invertebrate and fish species is complicated by the fact that refined petroleum products are complex mixtures of organic compounds. Hydrocarbons typically comprise about 75% of oil, the remainder consisting of various sulphur, oxygen and nitrogen-containing organic compounds (Kallio 1976 *in* Neff and Anderson 1981). Based on chemical structure, there are essentially three different types of hydrocarbons: (1) paraffins; (2) naphthenes; and (3) aromatics. Of these, the aromatic hydrocarbons, particularly monoaromatics, are usually most toxic to biota (Neff and Anderson 1981). The types of oils that could potentially be released to the marine environment during a CSEM survey include Isopar^{TM} fluids, diesel fuel oil, lubricants and hydraulic fluid, all of which are categorized as light oils/middle distillates.

Isopar$^{\text{T™}}$ fluids (synthetic isoparaffins) have extremely low levels of aromatics, and typically <1ppm of both benzene and sulphur. These isoparaffins are characterized by low reactivity and little biological activity (ExxonMobil 2011). Diesel fuel oil, likely No. 6 in this case, consists of paraffins, naphthenes and aromatics. Typically, aromatics constitute about 25% of diesel fuel oil hydrocarbon content. Both lubricants and hydraulic fluids consist primarily of mineral oils. Of the four types of oil that have the most potential of accidental release to the marine environment during EM surveys, diesel fuel oil is most toxic due to its higher aromatics content.

When discussing the potential effects of an oil spill on marine invertebrates and fishes, the primary concern pertains to those hydrocarbons below the water surface. Despite being lighter than water, some of the oil will enter the water column below the slick by dispersion through wave action (oil-in-water dispersion [OWD], and by vertical mixing and chemical dissolution (water soluble fraction [WSF]) (Schneider 1976 *in* Neff and Anderson 1981). Dissolution is a less important pathway since the most soluble substances are light aromatics (e.g., benzene, toluene) and they are the first to be lost through evaporation. It is generally accepted that most cases of acute toxicity of a petroleum product is directly correlated to its content of soluble aromatic derivatives including benzene, naphthalene, phenanthrene and their alkyl homologs (Moore and Dwyer 1974 *in* Neff and Anderson 1981).

The perseverance and toxicity of oil are affected by several other factors including weathering and emulsification. While the toxicity of fresh oil is correlated to its polyaromatic hydrocarbon (PAH) content, weathered oil does not exhibit the same association (Barron et al. 1999 *in* Hjermann et al. 2007). Barron et al. (2003 *in* Hjermann et al. 2007) found that toxicity of weathered oil and PAH increases significantly in the presence of sunlight (UV light effects). Generally, the use of chemical dispersants will temporarily increase the toxic effects of oil on fish larvae (Couillard et al. 2005 *in* Hjermann et al. 2007). Lastly, oil toxicity appears to vary between warm water and cold water species. Most toxicity test procedures typically use 25°C water and warm-water organisms, which may be more robust than cold-water organisms (Perkins et al. *in* Hjermann et al. 2007). Booman et al. (1995 *in* Hjermann et al. 2007) tested the susceptibility of NE Atlantic cod larvae to highly volatile BTEX (benzene, toluene, ethylbenzene, xylene which make up 80-90% of water-soluble fraction of oil) and found them to be relatively susceptible compared to laboratory animals commonly used.

Marine invertebrate and fish egg, larval and juvenile stages are typically more sensitive to the WSF of oil than to OWD, with lethal concentrations often within the 0.1-1 ppm range (Schneider 1976 *in* Neff and Anderson 1981). The lethal concentrations of the WSF of oil for adult stages are typically within the 1-100 ppm range. The other aspect of impact of exposure to oil on marine invertebrates and fishes relates to the potential chronic effects on such life history aspects as reproductive success, fecundity, embryonic and larval development rate, larval and juvenile growth rate, and occurrence of developmental abnormalities (Neff and Anderson 1981). Since juvenile and adult stages are capable of avoiding contaminated areas, the potential for acute and/or chronic impact on these stages is minimal. Even if individuals were adversely affected, no measurable population effect would be evident. Being passive drifters, eggs and larvae are more susceptible to prolonged exposure to oil fractions. However, it is unlikely that any lethal effects of exposure to oil on eggs and larvae could be distinguished from natural mortality (e.g., predation). In summary, exposure of marine invertebrates and fishes to oil accidentally introduced to the marine environment during EM surveys is not likely to cause any measurable impact on the respective invertebrate and fish populations.

Fish eggs and larvae are the most sensitive life stages of fish partly because of their delicate nature and because of their lack of mobility. For the most part adult fish will detect and avoid an oil spill if they are able to do so.

Marine Mammals and Sea Turtles

Most marine mammals, with the exception of fur seals, polar bears, and sea otters, are considered to be not directly susceptible to deleterious effects of oil. There is not clear evidence implicating oil spills with the mortality of cetaceans (Geraci 1990), although there was a significant decrease and lack of recovery in the population size of a killer whale pod that uses the area of the *Exxon Valdez* oil spill (Dahlheim and Matkin 1994). Several species of cetaceans and seals have been documented behaving normally in the presence of oil (St. Aubin 1990; Harvey and Dahlheim 1994; Matkin et al. 1994). There may have been a long-term decline by 36% in the number of moulting harbour seals at oiled haul-out sites in Prince William Sound following the *Exxon Valdez* oil spill (Frost et al. 1994). Pup mortality at these beaches was 23-26%, which may have been higher than natural mortality. Further analyses do not support high mortality, but indicated that seals moved away from some oiled haul-out sites (Hoover-Miller et al. 2001).

There are several physical and internal functions that may be affected by oil fouling of marine mammals. Whales and seals rely on a layer of blubber for insulation, and so oil has little effect on thermoregulation. It can be assumed that if oil contacted the eyes, effects would be similar to that observed in ringed seals (conjunctivitis, corneal abrasion, and swollen nictitating membranes), and that continued exposure to eyes could cause permanent damage (St. Aubin 1990). Damage to the visual system would likely limit foraging abilities, as vision is an important sensory modality used to locate and capture prey, particularly for marine mammals. Animals could ingest oil with water, contaminated food, or oil could be absorbed through the respiratory tract; absorbed oil could cause toxic effects (Geraci 1990). Inhalation of vapours from volatile fractions of oil from a spill could potentially irritate respiratory membranes and hydrocarbons could be absorbed into the bloodstream. Absorbed oil can cause toxic effects such as minor kidney, liver, and brain lesions (Geraci and Smith 1976; Spraker et al. 1994), but contaminated animals could depurate this oil when returned to clean water (Engelhardt 1982).

In baleen whales, crude oil could coat the baleen and reduce filtration efficiency, but these effects are considered to be reversible (Geraci 1990). Seals fouled externally with heavy oil may also encounter problems with locomotion, with flippers becoming stuck to their sides (Sergeant 1991). Stressed individuals or those that could not escape a contaminated area would be most at risk to potentially deleterious effects. Animals exposed to heavy doses of oil for prolonged periods could experience mortality.

Sea turtles can probably avoid oil spills to some extent. Similar to marine mammals, if lightly oiled they could incur some respiratory damage but if very heavily oiled they could suffer some mortality.

Seabirds

The most vulnerable group to oil spills is seabirds. Seabirds may encounter oil spills on the surface of the water or on a ship's deck. Even a small amount of oil can be fatal if a seabird loses its feathers' insulation value due to oiling.

Mitigations for small surface oils spills include a spill response plan, utilization of onboard containment equipment and dispersal of small surface spills using workboat or ship's propellers.

6.6. Cumulative Effects

Depending upon location, the marine environment can be a "noisy" place in terms of electromagnetic emissions. In addition to natural background signals from the Earth's core, earthquakes, sunspots, lightning, radiation, and water currents there are a number of anthropogenic sources. These include a variety of ELF sources, AC and DC and covering a range of amperages. Some primary examples include:

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

These are all subject to Faraday's Law (see Section 3.0) and may produce both direct and induced electromagnetic fields. Of these, and 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 in the case of DC lines may be operated in mono- or dipole mode with in-water electrodes. The lines have potential to affect fish migration and prey detection, especially for elasmobranchs. The electrodes (in water or along shore) may be operated on the order of 1,500 A and produce chorine gas.

Wind farms and associated power lines have undergone many assessments and some monitoring studies. Some sources of information include Andrulewicz et al. (2003), Gill et al. (2005), and OSPAR (2008). Thus far, predicted effects and measured effects have been generally acceptable to society.

Effects from EM surveys will certainly be significantly less (by orders of magnitude) in geographic extent, magnitiude, frequency and duration than those produced by an underwater transmission line, especially a DC line operated with in-water electrodes. As such, EM surveys are not predicted to produce significant cumulative effects in combination with other anthropogenic electromagnetic emissions in the marine environment.

7.0 SUMMARY OF EFFECTS AND POTENTIAL MITIGATIONS

As discussed in previous sections, emissions associated with EM surveys (CSEM or MTEM) that have at least some potential to affect the key animal groups of fish, sea turtles, seabirds, and marine mammals include light, underwater noise, accidental spills, and electromagnetic and chemical emissions.

7.1. Potential Effects

Light emissions from any work platform at sea have the potential to attract prey that in turn may attract predators such as fish, sea turtles, seabirds, and marine mammals. In the case of an EM survey vessel with work lights illuminated the decks, such attractions can be considered localized and transitory, and any effects are probably negligible. However, it is well documented that light emissions can attract birds at night and in some cases (e.g., on nights with poor visibility) birds may collide with the superstructure and become stranded and/or suffer mortality. In the NW Atlantic, this is a relatively common occurrence with Leaches Storm-Petrels. Mitigations can greatly reduce mortalities and these include bird handling and release protocols, lighting modifications, and placing of mesh over dangerous areas where birds may become trapped or oiled.

Fish, seabirds, and sea turtles are all capable of detecting underwater sound and may react to those sounds. In general, these groups are considered to be not nearly as sensitive as marine mammals, especially cetaceans. Some EM survey vessels may use thrusters extensively and intermittently when retrieving bottom-mounted receivers, which could number as many as 200 or so. The underwater noise generated by thrusters may be a source of disturbance to marine mammals, perhaps more so than the steady noise of ship propulsion noise when moving at a constant slow speed. There is no mitigation for this type of disturbance except to select quieter models of thruster if available and to minimize the use of thrusters where feasible.

Accidents such as ship strikes of sea turtles and marine mammals are unlikely given the slow speeds used during EM surveys. Accidental petroleum hydrocarbon spills (e.g., fuels, lubricants, hydraulic fluids, and flotation fluids) have the potential to affect all of the animal groups of interest. None of these types of fluids are unique to an EM survey with the possible exception of Isopar™, a floatation fluid used in geophysical cables. For seismic contractors, Isopar™ appears to be in the process of being phased out in favor of solid floatation. Small spills on the order of a few liters to a few hundred are possible when it is used. Such spills are of little concern for most marine animals with the exception of seabirds where even a small amount of oil can cause a loss of insulation and subsequent mortality. Mitigations for this situation include use of solid flotation where feasible, rapid spill clean-up with appropriate materials and training, dispersal of any spilled oil with ship's props, and minimizing bird attractions.

The unique aspects of EM surveys are the electromagnetic emissions from a towed electrical source. The source may be towed near surface or near bottom in shallow or deep water. There is little or no potential for the extremely low frequency EM emissions to cause health effects on marine animals. However, a wide variety of marine animals are known to be able to detect electric and/or magnetic fields, some use these fields for orientation, and some may use them for navigation. Elasmobranchs may be the most sensitive group to EM emissions since they have been shown to use them to detect prey at close range particularly in areas of low visibility. Based upon attenuation data provided by the EM industry, studies of the reactions of various animal groups to electric and magnetic fields, and some simple calculations by the authors, it can be concluded that the "zone of influence" of a typical source would be less than a 400 m radius in most cases. In addition, the time of exposure would be on the order of minutes between a moving source and a mobile animal.

As noted above, some animals may use electric or magnetic fields for navigational purposes. However, it is highly likely that these fields would represent only one cue among a suite of navigational cues such as sun angle, olfactory, current strength, and possibly others. A total dependence upon geomagnetic cues likely would render the system useless during times (e.g., solar storms) or locations of anomalies.

At the time of this writing, there were no prescribed mitigations specific to EM surveys. On the east coast of Canada, onboard environmental observers (to collect observations and handle stranded seabirds), source ramp-ups, and turning the source off when over the shelf were used by one operator at a location where biological data were very scarce. Other available mitigations could include fine tuning source equipment to produce emissions no stronger than necessary to accomplish the mission, minimizing bottom disturbance by minimizing or eliminating the use of anchors (especially in areas of known sensitivity such as chemosynthetic or coral communities), and by careful selection of vessels, material and equipment (e.g., electrode type) to minimize environmental footprints. For programs using bottom-mounted receivers, anchors that break down quickly into natural substances can be used. If helicopter logistics are used, route selection away from sensitive areas such as bird colonies is an important mitigation. Site-specific EIAs should be conducted to assess any potential local issues and special mitigations and environmental protection plans may need to be developed to alleviate concerns.

Aside from potential effects caused by accidental spills and light attraction/collision, any effects from EM surveys can be considered relatively minor. Based upon existing knowledge it is reasonable to conclude that EM survey emissions are detectable by marine animals and may affect their behavior somewhat but that any effects will be localized and of relatively short duration. The geographic extent (i.e., on the order of hundreds of meters) and magnitude (i.e., use of ELFs and a very small percentage of any population affected in minor ways, mostly behavioral) are both small. The frequency (likely one survey) and duration (order of minutes for individual exposures and days for the general area) are both quite limited. While there is a level of uncertainty concerning specific mechanisms of potential effects, it is reasonable to conclude that, in general, EM surveys will not produce significant effects on the marine environment.

Other sources of EM emissions include natural sources (e.g., from sun and earth processes and anomalies, and ocean currents) and anthropogenic ones (e.g., underwater pumps and pipelines, telecommunication lines, and power transmission lines, both AC and DC). Due to the small area of influence of the EM surveys, the minor magnitude of effects, the infrequent nature, and the very short exposure durations, little or no cumulative effects are predicted for EM surveys.

7.2. Potential Mitigations

Potential mitigations that could be used to address some of the issues/effects identified in this EIA are provided in Table 7.1.

Table 7.1 Potential mitigations for EM surveys.

Potential Issues/Effects	Potential Mitigation
Bird attraction, strandings and mortalities	• Minimize attractions • Cover oily deck areas • Cover areas with netting where birds such as petrels may become trapped • Utilize bird handling/release protocols
Underwater noise disturbance	• Select low noise propellers and thrusters, if possible • Minimize use of thrusters in sensitive areas for marine mammals • Utilize marine mammal observers in particularly sensitive areas
Small oil spills (e.g. Isopar)	• Utilize solid flotation materials as opposed to hydrocarbons • Spill response plan • Cover oily areas such as winch oil pans with mesh to exclude birds • Onboard spill containment kits • Disperse small surface spills by workboat or ship's propellors
Ship strikes	• Use slower speeds when transiting sensitive cetacean congregation areas, especially right whale areas [Survey speeds are unlikely to be an issue.]
Electro-chemical emissions	• Turn off source when not actually collecting data
Electromagnetic emissions	• Turn off source when not actually collecting data • Use lowest field strengths required to successfully complete the survey • Minimize use over sensitive benthic habitats (e.g., corals, chemosynthetic communities) • Ramp up source • Utilize an exclusion area for marine mammals and sea turtles (e.g., 400 m, or perhaps more in a sensitive shallow area)
Habitat alteration	• Eliminate use of anchors over sensitive bottom habitat or at least use very precise placement techniques • Use compacted sand anchors that break down in 6-9 months • Avoid sargassum areas

8.0 SUMMARY AND CONCLUSIONS

Marine electromagnetic (EM) surveys are conducted using a towed electrical source accompanied by bottom-mounted or towed receivers. They have been more typically towed near bottom in deepwater (>500 m) but new techniques are being developed to allow towing near surface (e.g., 10 m) in water depths as shallow as 30 m. The resulting data allow measurement of differences in resistivity within the seabed which aids in discriminating between water and hydrocarbons. Such information can enhance offshore drilling success rates.

Equipment, materials, and activities with at least some potential to affect key members of the marine ecosystem and that may be characteristic of EM surveys include:

- Underwater noise emissions (from thrusters during extensive manuvering when bottom-mounted antennae are deployed and retrieved)
- Light emissions
- Accidental events such as ship strikes and small oil spills (e.g., small scale spills from flotation fluids such as Isopar™, if used), and
- EM emissions (electromagnetic, the primary focus of this EIA; and electrolysis at electrodes)

Fish, seabirds, and sea turtles are all capable of detecting underwater sound and may react to those sounds. In general, these groups are considered to be not nearly as sensitive as marine mammals, especially cetaceans. CSEM survey vessels may use thrusters extensively and intermittently when retrieving bottom-mounted receivers, which could number as many as 200 or so. The underwater noise generated by thrusters may be a source of disturbance to marine mammals, perhaps more so than the steady noise of ship propulsion noise when moving at a constant slow speed. There is no mitigation for this type of disturbance except to select quieter models of thruster if available and to minimize the use of thrusters where feasible. The underwater noise generated by the ship's thrusters has some potential to create some minor behavioral effects on cetaceans. However, there are many types of thrusters and there is little published information on this topic.

Light emissions from any work platform at sea have the potential to attract prey that in turn may attract predators such as fish, sea turtles, seabirds, and marine mammals. In the case of an EM survey vessel with work lights illuminated the decks, such attractions can be considered localized and transitory, and any effects are probably negligible. However, it is well documented that light emissions can attract birds at night and in some cases (e.g., on nights with poor visibility) birds may collide with the superstructure and become stranded and/or suffer mortality. In the NW Atlantic, this is a relatively common occurrence at certain times of the year. Small oil spills and light emissions could affect marine birds although most effects can be mitigated and all would be small scale (although arguably not the case for an endangered species).

Accidents such as ship strikes of sea turtles and marine mammals are unlikely given the slow speeds used during EM surveys and the abilities of most large animals to avoid the vessel and towed equipment. Accidental petroleum hydrocarbon spills (e.g., fuels, lubricants, hydraulic fluids, and flotation fluids) have the potential to affect all of the animal groups of interest. None of these types of fluids are unique to an EM survey with the possible exception of Isopar™, a floatation fluid used in geophysical cables. For seismic contractors, Isopar™ appears to be in the process of being phased out in favor of solid floatation. Small spills on the order of a few liters to a few hundred are possible when it is used. Such spills are of little concern for most marine animals with the exception of seabirds where even a small amount of oil can cause a loss of insulation and subsequent mortality. Mitigations for this situation include rapid clean-up materials and training, dispersal with ship's props, minimizing attractions, bird handling and release protocols, lighting modifications, and placing of mesh over dangerous areas where birds may become trapped or oiled.

The unique aspects of EM surveys are the electromagnetic emissions from a towed electrical source. The source may be towed near surface or near bottom in shallow or deep water. Electromagnetic energy obeys the diffusion equation which means that the signal strength falls off proportionally to r^2 (where r is the distance from the source) unlike seismic energy which obeys the wave equation where the signal strength falls off proportionally to r. Therefore, EM energy attenuates far more rapidly than seismic energy and thus its effect is much more localised. This is beneficial in that the EM source zone of influence is relatively localised and for a given transit speed the duration of any effects will be shorter.

The source emissions (single or multiple frequencies) have virtually no potential for causing health effects because they are very low frequency and because exposure times are of short duration. However, some marine animals such as elasmobranchs (sharks, skates and rays) have highly developed electroreceptive organs and most likely can detect EM emissions. Some animals may use naturally occurring electromagnetic information to navigate (e.g., young sea turtles) and others may use the information to detect less visible prey at close range. Elasmobranchs may be the most sensitive group to EM emissions since they have been shown to use them to detect prey at close range particularly in areas of low visibility. Based upon attenuation data provided by the EM industry, studies of the reactions of various animal groups to electric and magnetic fields, and some simple calculations by the authors, it can be concluded that the "zone of influence" of a typical source would be less than 400 m radius in most cases. In addition, the time of exposure would be on the order of minutes between a moving source and a mobile animal.

As noted above, some animals may use electric or magnetic fields for navigational purposes. However, it is highly likely that these fields would represent only one cue among a suite of navigational cues such as sun angle, olfactory, current strength, and possibly others. A total dependence upon geomagnetic cues likely would render the system useless during times (e.g., solar storms) or locations of anomalies. In addition, the Earth's electric field is DC whereas most EM surveys emit AC fields.

Several marine EM industry companies through IAGC provided attenuation data for their specific gear that were calculated using a standard set of parameters. These data were then compared to sensitivity data derived from published literature on elasmobranchs (electroreceptive sharks, skates and rays) which are likely the most sensitive group of large marine animals to EM fields. Thresholds of effects (primarily behavioral) suggest that any effects would only occur within radii of 400 m or less in most cases and only for a matter of minutes under any realistic scenario. As such, it was concluded that EM sources as presently used have no potential for significant effects on any of the important animal groups such as fish, seabirds, sea turtles, and marine mammals.

At present, there are no prescribed mitigations specific to EM surveys. In one special case, onboard environmental observers (to collect observations and handle stranded seabirds), source ramp-ups, and turning the source off when over the shelf have been used. Aside from potential accidents and light attraction/collision, any effects from EM surveys can be considered minimal. Based upon existing knowledge it is concluded that EM survey emissions are detectable by marine animals and may affect their behavior somewhat but that any effects will be localized, affect relatively few members of a population, and will be of relatively short duration. Therefore, in general and if local concerns are addressed, it is predicted that EM surveys will not produce significant effects on the marine environment. Cumulative effects with other EM sources, both natural and anthropogenic are also predicted to be not significant.

9.0 REFERENCES

Abgrall, P., A. L. Lang, and V. D. Moulton. 2008a. Marine mammal and seabird monitoring of Husky Energy's 3-D seismic program in the Jeanne d'Arc Basin, 2006 and 2005-2006 combined. LGL Rep. SA920, Rep. by LGL Limited, St. John's, NL, for Husky Energy Inc., St. John's, NL. 89 p.

Abgrall, P., B. D. Mactavish, and V. D. Moulton. 2008b. Marine Mammal and Seabird Monitoring of Orphan Basin Controlled Source Electromagnetic Survey Program, 2006-2007. LGL Rep. SA904/939, Rep. by LGL Limited, St. John's, NL, for ExxonMobil Canada Ltd., St. John's, NL. 96 p.

Able, K.P. 1982. Skylight polarization patterns at dusk influence migratory orientation in birds. Nature 288:550-551.

Able, K.P., and M.A. Able. 1990. Calibration of the magnetic compass of a migratory bird by celestial rotation. Nature 347:378-389.

Able, K.P., and M.A. Able. 1993. Daytime calibration of magnetic orientation in a migratory bird requires a view of skylight polarization. Nature 364:523-525.

Able, K.P., and M.A. Able. 1995. Interactions in the flexible orientation system of a migratory bird. Nature (in press).

Aguilar, J.S., Benvenuti, S., Dall'Antonia, L., McMinn-Grivé, M., and Mayol-Serra, J. 2003. Preliminary results on the foraging ecology of Balearic shearwaters (*Puffinus mauretanicus*) from bird-borne data loggers. Scientia Marina, 67(Suppl.2): 129-134.

Aguilar-Soto, N., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? Mar. Mamm. Sci. 22(3):690-699.

Ainley, D.G. and Sanger, G.A. 1979. Trophic relationships of seabirds in the northeastern Pacific Ocean and Bering Sea. p. 95-122. *In* Bartonek, J.C. and Nettleship, D.N. (eds.). Conservation of marine birds in northern North America. U.S. Department of International Wildlife Research Report, 11. 319p. *In* Briggs, K.T., Dettman, K.F., Lewis, D.B., and Tyler, Wm.B. 1984. Phalarope feeding in relation to autumn upwelling off California. p. 51-62. *In* Nettleship, G., Sanger, A., and Springer, P.F. (eds.). Marine birds: Their feeding ecology and commercial fisheries relationships. Canadian Wildlife Service, Ottawa.

Åkesson, S., J. Morin, R. Muheim, and U. Ottosson. 2001. Avian orientation at steep angles of inclination: experiments with migratory white-crowned sparrows at the magnetic North Pole. Proceedings of the Royal Society of London B 268-1907-1913.

Åkesson, S., J. Morin, R. Muheim, and U. Ottosson. 2005. Dramatic orientation shift of white-crowned sparrows displaced across longitudes in the high arctic. Current Biology 15:1591-1597.

Akoev, G.N., and O.B. Ilyinskii. 1972. Some functional characteristics of the electroreceptors of the ampullae of Lorenzini of black sea skates. Proceedings of the Academy of Sciences of the USSR 2905:499-501.

Akoev, G.N., N.N. Beller, P.M. Zhadan, O.B. Ilyinskii, and E.S. Titkov. 1975. Functional characteristics of the electroreceptors of some electric and nonelectric fish. Sechenov Physiology Journal USSR 61:391-399.

Akoev, G.N., P.M. Zhadan, O.B. Ilyinskii, and E.S. Titkov. 1974. Electrophysiological investigation of the electroreceptors (the ampullae of Lorenzini) in black sea skates. Neirofiziologiya (USSR) 6:426-433.

Allen, M.C., and A.J. Read. 2000. Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. Mar. Mamm. Sci. 16(4):815-824.

Alves, F., Dinis, A., Cascão, I., and Freitas, L. 2010. Bryde's whale (*Balaenoptera brydei*) stable associations and dive profiles: New insights into foraging behaviour. Marine Mammal Science, 26(1): 202-212.

Ancel, A., Kooyman, G.L., Ponganis, P.J., Gendner, J.P., Lignon, J., and Mestre, X. 1992. Foraging behavior of emperor penguins as a resource detector in winter and summer. Nature, 360: 336-339.

André, M., E. Degollada and A. Fernández. 2001. Hearing loss in long-term low frequency sounds [sic] exposed sperm whales. Abstract presented at the Fourteenth Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 2001, Vancouver, Canada. p. 6-7.

André, M., M. Terada and Y. Watanabe. 1997. Sperm whale (*Physeter macrocephalus*) behavioural response after the playback of artificial sounds. Rep. Int. Whal. Comm. 47:499-504.

Andrianov, G.N., H.R. Brown, and O.B. Ilyinsky. 1974. Responses of central neurons to electrical and magnetic stimuli of the ampullae of Lorenzini in the black sea skate. Journal of Comparative Physiology 93:287-299.

Andrulewicz, E., D. Napierska, and Z. Otremba. 2003. The environmental effects of the installation and functioning of the submarine *SwePol Link* HVDC transmission line: a case study of the Polish Marine Area of the Baltic Sea. Journal of Sea Research 49:337-345.

Anyamba, E., E. Williams, J. Susskind, A. Fraser-Smith, M. Fullekrug, 2000: The manifestation of the Madden–Julian Oscillation in Global Deep Convection and in the Schumann Resonance intensity. J. Atmos. Sci., 57, 1029–1044.

Arendse, M.C. 1978. Magnetic field detection is distinct from light detection in the invertebrates *Tenebrio* and *Talitrus*. Nature 274:358-362.

Atlantic States Marine Fisheries Commission. 1999. Fishery Management Council prohibits Sargassum seaweed harvest. Habitat Hotline Atlantic 6:1-2.

Au, W.W.L. and M. Green. 2000. Acoustic interaction of humpback whales and whale-watching boats. Mar. Environ. Res. 49(5, Jun.), 469-481.

Au, W.W.L. and M. Green. 1997. Acoustic interaction of humpback whales and whale-watching boats off Maui, Hawaii. J. Acoust. Soc. Am. 102(5, Pt. 2), 3177.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. Journal of the Acoustical Society of America 120(2):1103-1110.

Au, W.W.L., A.N. Popper, and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer Handbook of Auditory Res. Vol. 12. Springer-Verlag, New York, NY. 458 p.

Avins, L., and K.J. Lohmann. 2003. Use of multiple orientation cues by juvenile loggerhead sea turtles *Caretta caretta*. The Journal of Experimental Biology 206:4317-4325.

Avins, L., and K.J. Lohmann. 2004. Navigation and seasonal migratory orientation in 0juvenile sea turtles. The Journal of Experimental Biology 206:1771-1778.

Baird, R.W., Webster, D.L., McSweeney, D.J., Ligon, A.D., Schorr, G.S., and Barlow, J. 2006. Diving behavior of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawai'i. Canadian Journal of Zoology, 84: 1120-1128. *In* Auster, P.J. 2010. Beaked whale foraging areas inferred by gouges in the seafloor. Marine Mammal Science, 26(1): 226-233.

Baker, C.S. and L.M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. NPS-NR-TRS-89-01. Rep. by Kewalo Basin Mar. Mamm. Lab., Univ. Hawaii, Honolulu, HI, for U.S. Natl. Park Serv., Anchorage, AK. 50 p. NTIS PB90-198409.

Baker, C.S., L.M. Herman, B.G. Bays, and W.F. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Rep. by Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Natl. Mar. Fish. Serv., Seattle, WA. 78 p.

Baker, C.S., L.M. Herman, B.G. Bays, and G.B. Bauer. 1983. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska: 1982 season. Rep. by Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Natl. Mar. Mamm. Lab., Seattle, WA. 30 p. + fig., tables.

Balazs, G.H., R.K. Miya, and M.A. Finn. 1994. Aspects of green turtles in their feeding, resting, and cleaning areas off Waikiki Beach. Pages 15-18 *in Proceedings of the 13th Annual Workshop on Sea Turtle Biology and Conservation*. NOAA Technical Memorandum NMFS-SEFSC-341. U.S. Department of Commerce.

Bane, G. 1992. First report of loggerhead sea turtle from Alaska. Marine Turtle Newsletter 58: 1-2.

Barber, N., and M.S. Longeut-Higgins. 1948. Water movements and the earth's currents: electrical and magnetic effects. Nature 161:192-193.

Barr, D. 1997. Electromagnetic fields: Controversies-myth-policies. Volume 4, Number 3 in Technology and Standards Division, National Communication System. www.ncs.gov.n6/ content/technote/tnv4n3/tnv4n3.htm.

Bartlett, G. 1989. Loggerheads invade Baja Sur. Not. Cagu 22:2-10.

Bartol, S.M and D.R. Ketten. 2006. Turtle and tuna hearing. Pages 98-105 *in* Y. Swimmer and R. Brill, editors. Sea turtle and pelagic fish sensory biology: Developing techniques to reduce sea turtle bycatch in longline fisheries. NOAA Technical Memorandum NMFS-PIFSC-7.

Bartol, S.M. and J.A. Musick. 2003. Sensory biology of sea turtles. Pages 79-102 in P.L. Lutz, J.A. Music, and J. Wyneken. The biology of sea turtles, Volume II. CRC Press Boca Raton, Florida.

Bartol, S.M., J.A. Muick, and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Carette carette*). Copeia 1999(3):836-840.

Bazylinski, D.A., D.R. Schlezinger, B.H. Howes, R.B. Frankel, and S.S. Epstein. 2000. Occurrence and distribution of diverse populations of magnetic protists in a chemically stratified coastal salt pond. Chemical Geology 169:319-328. DOI:10.1016/S0009-2541(00)(00211-4).

Beanlands, G.E. and P.N. Duinker. 1984a. An ecological framework for environmental impact assessment. Journal of Environmental Management 18:267-277.

Beanlands, G.E. and P.N. Duinker. 1984b. Lessons from a decade of offshore environmental impact assessment. Ocean Management 9:157-175.

Beason, R.C. 1989. Use of an inclination compass during migratory orientation by the bobolink (*Dolichonyx oryzivorus*). Ethology 81:291-299.

Bejder, L., A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance with a longitudinal perspective. Animal Behav**.** 72:1149-1158.

Benfield, M.C. and R.F. Shaw. 2005. Potential spatial and temporal vulnerability of pelagic fish assemblages in the Gulf of Mexico to surface oil spills associated with deepwater petroleum development. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 2005-012. 158 p.

Bengston, J.L., Croll, D.L., and Goebel, M.E. 1993. Diving behavior of chinstrap penguins at Seal Island. Antarctic Science, 5: 9-15. *In* Wanless, S., Barton, T.R., and Harris, M.P. 1997. Blood hematocrit measurements of 4 species of North Atlantic seabirds in relation to levels of infestation by the tick *Ixodes uriae*. Colonial Waterbirds, 20(3): 540-544.

Benhamou, S., F. Bonadonna, and P. Jouventin. 2003. Successful homing of magnet-carrying white-chinned petresl released in the open sea. Animal Behaviour 65:729-734.

Berkson, H. 1967. Physiological adjustments to deep diving in the Pacific Green turtle (*Chelonia mydas agassizii*), Comp. Biochem. Physiol. 21:506.

Berta, A., R. Racicot and T. Deméré. 2009. The comparative anatomy and evolution of the ear in *Balaenoptera* mysticetes. p. 33 *In*: Abstracts of the 18th Biennial Conference of The Biology of Marine Mammals, Québec, Oct. 2009. 306 p.

Bingman, V.P. 1983. Magnetic field orientation of migratory savannah sparrows with different first summer experience. Behaviour 87:43-53.

Bingman, V.P. 1987. Earth's magnetism and the nocturnal orientation of migratory European robins. Auk 104:523-525.

Bingman, V.P., and W. Wiltschko. 1988. Orientation of dunnocks (*Prunella modularis*) at sunset. Ethology 77:1-9.

Bird Forum. 2009. European shag. Available at: http://www.birdforum.net/opus/European_Shag. Accessed: March 2011.

Bjorndal, K.A. 1997. Reproduction in sea turtles. Pages 199-231 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Black, A. 2005. Light induced seabird mortality on vessels operating in the Southern Ocean: incidents and mitigation measures. Antarctic Science 17:67-68.

Blakemore, R. 1975. Magnetic bacteria. Science 190:377-379.

Blackwell, S.B., J.W. Lawson and M.T. Williams. 2004. Tolerance by ringed seals (Phoca hispida) to impact pipe-driving and construction sounds at an oil production island. Journal of the Acoustical Society of America 115(5, Pt. 1):2346-2357.

Bleckman, H., and M.H. Hofmann. 1999. Special senses. Pages 300-328 *in* W.C. Hamlett, editor. Sharks, Skates, and Ray: The Biology of Elasmobranch Fishes. The Johns Hopkins University Press, Baltimore.

Blix, A.S., and Folkow, L.P. 1995. Daily energy expenditure in free living minke whales. Acta Physiologica Scandinavica, 153: 61-66.

Bocetti, C. I. 2011. Cruise ships as a source of avian mortality during fall migration. Wilson Journal of Ornithology 123:176-178.

Bodznick, D. 1978a. Water source preference and lakeward migration of sockeye salmon fry (*Oncorhynchus nerka*). Journal of Comparative Physiology 127:139-146.

Bodznick, D. 1978b. Characterization of olfactory bulb units of sockeye salmon with behaviorally relevant stimuli. Journal of Comparative Physiology 127:147-155.

Bodznick, D., J. Montgomery, and T.C. Tricas 2003. Electroreception: extracting behaviorally important signals from noise. Chapter 20. Pages 389-403 *in* S.P. Collins and N.J. Marshall, editors. Sensory Processing in Aquatic Environments. Springer.

Bolton, A.B. 2003. Variation in sea turtle life history patterns: neritic vs. oceanic developmental stages. Pages 243-257 *in* P.L. Lutz, J.A. Musick, and Wyneken, editors. The Biology of Sea Turtles, Volume II. CRC Press, Boca Raton.

Bolton, A.B., C. Santana, and K.A. Bjorndal. 1992. Transatlantic crossing by a loggerhead turtle. Marine Turtle Newsletter 59:7.

Bolton, A.B., H.R. Martins, M.L. Watali, J.C. Thomas, and M.S. Marcovaldi. 1990. Loggerhead released in Brazil recaptured in Azores. Marine Turtle Newsletter 48:24.

Bonadonna, F., C. Bajzak, S. Benhamou, K. Igloi, P. Jouventin, H. P. Lipp, and G. Dell'Omo. 2005. Orientation in the wandering albatross: interfering with magnetic perception does not affect orientation performance. Proceedings of the Royal Society B: Biological Sciences 272:489-495.

Bonadonna, F., S. Chamaille-Jammes, D. Pinaud, and H. Weimerskirch. 2003. Magnetic cues: are they important in black-browed albatross *Diomedea melanophris* orientation? Ibis 145:152-155.

Born, E.W., F.F. Riget, R. Dietz and D. Andriashek. 1999. Escape responses of hauled out ringed seals (*Phoca hispida*) to aircraft disturbances. Polar Biol. 21(3):171-178.

Bowen, B.W., F.A. Abreu-Grobois, G.H. Balazs, N. Kamezaki, C.J. Limpus, and R.J. Ferl. 1995. Trans-Pacific migrations of the loggerhead turtle (*Caretta caretta*) in the northwestern Atlantic Ocean and Mediterranean Sea. Conservation Biology 7:834.

Boyles, L.C., and K.J. Lohmann. 2003. True navigation and magnetic maps in spiny lobsters. Nature. 421:60-63.

Brabyn, M., and R. Frew. 1994. New Zealand herd stranding sites do not relate to geomagnetic topography. Marine Mammal Science 10:195-207.

Braidwood, J. 2009. Breeding biology and threats to the blue penguin (*Eudyptula minor*) in South Westland, New Zealand. Master of International Nature Conservation thesis. 87p.

Brannon, E.L. 1967. Genetic control of migrating behavior of newly emerged sockeye salmon fry. International Pacific Salmon Fishery Commission Progress Report 16:31.

Brannon, E.L. 1972. Mechanisms controlling migration of sockeye salmon fry. International Pacific Salmon Fishery Commission Bulletin 21:86.

Brannon, E.L., T.P. Quinn, G.L. Lucchetti, and B.D. Ross. 1981. Compass orientation of sockeye salmon fry from a complex river system. Canadian Journal of Zoology 59:1548-1553.

Branover, G.G., A.S. Vasil'yev, S.I. Gleyzer, and A.B. Tsinober. 1970. A study of the behavior of the eel in natural and artificial and magnetic fields and an analysis of its reception mechanism. Journal of Ichthyology 11:608-614.

Bratton, B. and J. Ayers. 1987. Observations on the electric organ discharge of two skate species (Chondrichthyes: Rajidae) and its relationships to behavior. Environmental Biology of Fishes 20:241-254.

Brabyn, M., and R. Frew. 1994. New Zealand herd stranding sites do not relate to geomagnetic topography. Marine Mammal Science 10:195-207.

Bretagnolle, V. 1990. Effet de la lune sur l'activité des pétrels (classe Aves) aux îles Salvages (Portugal). Canadian Journal of Zoology 68:1404-1409.

Briggs, K.T., Dettman, K.F., Lewis, D.B., and Tyler, Wm.B. 1984. Phalarope feeding in relation to autumn upwelling off California. p. 51-62. *In* Nettleship, G., Sanger, A., and Springer, P.F. (eds.). Marine birds: Their feeding ecology and commercial fisheries relationships. Canadian Wildlife Service, Ottawa.

Brill, R.W., G.H. Balazs, K.N. Holland, R.K.C., Chang, S. Sullivan, and J. George. 1995. Daily movements, habitat use, and submergence intervals of normal and tumor-bearing juvenile green turtles (*Chelonia mydas* L.) within foraging area in the Hawaiian islands, Journal of Experimental Marine Biology and Ecology 185:203.

British Geological Survey. 2010. http://www.geomag.bgs.ac.uk/

British Geological Survey. 2011. The Earth's magnetic field: An overview. http://www.geomag.bgs.ac.uk/education/earthmag.html

Brock, L.G., M.E. Eccles, and R.D. Keynes. 1953. The discharge of individual electroplates in *Raja clavata*. Journal of Physiology 122:4-5.

Brown, H.R., Il'Inskii, O.B. and Krylov, B.V. 1979. Responses of the Lorenzini ampullae in a uniform electric field. Neirofiziologiya 11: 158-166.

Brown, R.G.B., Bourne, W.R.P., and Wahl, T.R. 1978. Diving by shearwaters. Condor, 80: 123-125. *In* Ronconi, R.A., Koopman, H.N., McKinstry, C.A.E., Wong, S.N.P, and Westgate, A.J. 2010b. Inter-annual variability in diet of non-breeding pelagic seabirds *Puffinus* spp. at migratory staging areas: evidence from stable isotopes and fatty acids. Marine Ecology Progress Series, 419: 267-282.

Burger, A.E. 2003. Effects of the Juan de Fuca Eddy and upwelling of densities and distributions of seabirds off Southwest Vancouver Island, British Columbia. Marine Ornithology, 31: 113-122.

Burke, V.J., S.J. Morreale, P. Logan, and E.A. Standora. 1992. Diet of green turtles (*Chelonia mydas*) in the waters of Long Island, N.Y. Pages 140-142 *in: Proceedings of the 11th Annual Workshop on Sea Turtle Biology and Conservation*. NOAA Technical Memorandum NMFS-SEFSC-302. U.S. Department of Commerce.

Byles, R.A., 1988. Behavior and ecology of sea turtles from Chesapeake Bay, Virginia. Ph.D. Dissertation, College of William and Mary, Williamsburg, Va.

Camhi, M.D., S.V. Valenti, S.V. Fordham, S.L. Fowler, and C. Gibson. 2009. The conservation status of pelagic sharks and rays: Report of the IUCN shark specialist group pelagic shark red lis workshop. IUCN species survival commission shark specialist group. Newberry, U.K. 78p.

Campbell, N.A. 1990. Biology. The Benjamin/Cummings Publishing Company, Inc. Redwood City, California.

Camphuysen, K.C.J. and Webb, A. 1999. Multi-species feeding associations in North Sea seabirds: Jointly exploiting a patchy environment. Ardea, 87(2): 177-198.

Cannon, A.C. 1998. Gross necropsy results of sea turtles stranded on the upper Texas and western Louisiana coasts, 1 January-31 December 1994. United States Department of Commerce, NOAA Tech. Rep. NMFS 143: 81-85.

Carey, F.G., and J.V. Scharold. 1990. Movements of blue sharks (*Prionace glauca*) in depth and course. Marine Biology 106:329-342.

Carl, G.C. 1955. The green turtle in British Columbia. Pages B77-B78 *in* Report of the Provincial Museum of British Columbia for 1954. Victoria, B.C.

Carr, A. 1982. Notes on the behavioral ecology of sea turtles. *In* Biology and Conservation of Sea Turtles, Bjorndal, K.A., Ed., Smithsonian Institution Press, Washington, D.C.

Carr, A. 1986. Rips, FADS and little loggerheads. Bioscience 36:92-100.

Carr, A. 1987. New perspectives on the pelagic stage of sea turtle development. Conservation Biology 1(2):103.

Carr, A., and A.B. Meylan. 1980. Evidence of passive migration of green turtle hatchlings in Sargassum. Copeia 2:366.

Carr, A.F. 1952. Handbook of turtles. Cornell University Press, Ithaca, N.Y.

Carr, A.F. Jr. 1980. Some problems of sea turtle ecology. American Zoologist 20: 489-498.

Carwardine, M. 1995. Dorling Kindersley Handbooks: Whales, dolphins, and porpoises. Evans, P. and Weinrich, M. (eds.). Dorling Kindersley Limited, London. 256p.

Cawthorn, M.W. 1992. New Zealand progress report on cetacean research. Rep. Int. Whal. Comm. 42:357-360.

CENTRA Technology, Inc. 2011. Geomagnetic storms. Report for Office of Risk Management and Analysis, United States Department of Homeland Security. 69 p.

Chave, A.D., and C.S Cox. 1982. Controlled electromagnetic sources for measuring electrical conductivity beneath the oceans. 1. Forward Problem and Model Study. Journal of Geophysical Research 87:5327-5338.

Cherry, N. 2002. Schumann Resonance and sunspot relations to human health effects in Thailand. Human Sciences Department, P.O. Box 84, Lincoln University, Canterbury, New Zealand.

Chew, G.L., and G.E. Brown. 1987. Orientation of rainbow trout (*Salmo gairdneri*) in normal and null magnetic fields. Canadian Journal of Zoology 67:641-643.

Chung-Davidson, Y.W., S.S. Yun, J. Teeter, and W.M. Li. 2004. Brain pathways and behavioral responses to weak electric fields in parasitic sea lampreys (*Petromyson marinus*). Behavioral Neuroscience 118:611-619.

Clark, C.W., and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: Evidence from models and empirical measurements. p. 564-589 *In:* J.A. Thomas, C.F. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. Univ. Chicago Press, Chicago, IL. 604 p.

Cliver, E.W., and L Svalgaard. 2004. The 1959 solar terrestrial disturbance and the current limits of extreme weather activity. Solar Physics 224:407-422.

Collard, S.B. 1987. Review of oceanographic features relating to neonate sea turtle distribution and dispersal in the pelagic environment: Kemp's ridley (*Lepidochelys kempii*) in the Gulf of Mexico. Final Report, NOAA-NMFS No. 40-GFNF-5-00193. National Marine Fisheries Service. 70 p.

Collard, S.B., and L.H. Ogren. 1990. Dispersal scenarios for pelagic post-hatchling sea turtles. Bulletin of Marine Science. 47:233.

Collin, S.P., and D. Whitehead. 2004. The functional roles of passive electroreception in non-electric fishes. Animal Biology 54:1-25.

Constantine, R., D.H. Brunton and T. Dennis. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. Biol. Cons. 117:299-307.

Cook, M.L.H., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser, and A. Mann. 2006. Beaked whale auditory evoked potential hearing measurements. Journal of Comparative Physiology A 192:489-495.

Cope, M., D. St. Aubin and J. Thomas. 1999. The effect of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Hilton Head, South Carolina. Presented at the 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 1999, Wailea, Hawaii. p. 37-38.

Corkeron, P.J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: behaviour and responses to whale-watching vessels. Can. J. Zool. 73(7):1290-1299.

Cornelius, S.E. 1995. Status of sea turtles along the Pacific coast of middle America. Pages 211-219 *in* K. Bjorndal (ed.), The Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, D.C.

Costa, D.P., Huckstadt, L.A., Crocker, D.E., McDonald, B.I., Goebel, M.E., and Fedak, M.A. 2010. Approaches to studying climatic change and its role on the habitat selection of Antarctic pinnipeds. Integrative and Comparative Biology, 50(6): 1018-1030. Available at: http://icb.oxfordjournals.org.qe2a-proxy.mun.ca/content/50/6/1018.full.

Coston-Clements, L., L.R. Settle, D.E. Hoss, and F.A Cross 1991. Utilization of the Sargassum habitat by marine invertebrates – a review. NOAA Technical Memorandum NMFS-SEFSC-296. 36 p.

Croll, D.A., Gaston, A.J., Burger, A.E., and Konnoff, D. 1992. Foraging behavior and physiological adaptation for diving in thick-billed murres. Ecology, 73(1): 344-356. *In* Wanless, S., Barton, T.R., and Harris, M.P. 1997. Blood hematocrit measurements of 4 species of North Atlantic seabirds in relation to levels of infestation by the tick *Ixodes uriae*. Colonial Waterbirds, 20(3): 540-544.

Croxall, J.P. and Prince, P.A. 1980. Food, feeding ecology and ecological segregation of seabirds at South Georgia. Biological Journal of the Linnean Society, 14: 103-131.

Dahlheim, M.E. and C.O. Matkin. 1994. Assessment of injuries to Prince William Sound killer whales. pp. 163-171. *In:* T.R. Loughlin (ed.), Marine mammals and the Exxon Valdez. Academic Press, San Diego. 395 p.

David Balloch and Associates. 2003. Potential effects of OHM's active electromagnetic sounding on marine life. Preliminary report for Offshore Hydrocarbon Mapping Limited. 80 p.

Davis, R.A. 2006. Assessment of the effects of underwater noise from the proposed Neptune LNG project – A supplementary biological effects report. Report by LGL Limited, King City, ON for Ecology and Environment, Inc., Arlington, VA. 10 p.

Davis, R.A. 2009. Assessment of the effects of underwater noise from the proposed Neptune LNG project – 2nd supplementary biological effects report. Report by LGL Limited, King City, ON for Ecology and Environment, Inc., Arlington, VA. 9 p.

de Graaf, R.M., Tilghman, N.G., and Anderson, S.H. 1985. Research: Foraging guilds of North American birds. Environmental Management, 9(6): 493-536.

DeJong, D. 1982. Orientation of comb building by honeybees. Journal of Comparative Physiology 147:495-501.

Dell'Omo, G., D. Costantini, V. Lucini, G. Antonucci, R. Nonno, and A. Polichetti. 2009. Magnetic fields produced by power lines do not affect growth, serum melatonin, leukocytes and fledging success in wild kestrels. Comparative Biochemistry and Physiology - C Toxicology and Pharmacology 150:372.

Dennis, T.E., M.J. Rayner, and M.M. Walker. 2007. Evidence that pigeons orient to geomagnetic intensity during homing. Proceedings of the Royal Society B 274:1153-1158.

Dick, M. H. and W. Donaldson. 1978. Fishing vessel endangered by Crested Auklet landings. Condor 80:235-236.

Diebel, C.E., R. Proksch, C.R. Green, P. Neilson, and M.M. Walker. 2000. Magnetite defines a vertebrate magnetoreceptor. Nature. 406:299-301.

Diego-Rasilla, F.J., R.M. Luengo, and J.B. Phillips. 2010. Light-dependent magnetic compass in Iberian green frog tadpoles. Naturwissenschaften 97:1077-1088.

Dijkgraaf, S., and A.J. Kalmijn. 1962. Verhaltensversuche sur Funktion der Lorenzinische Ampullen. Naturwissenschaflen 49:400.

Dijkgraaf, S., and A.J. Kalmijn. 1963. Untersuchungen über die Funktion der Lorenzinischen Ampullen an Haifischen. Zeitschrift für vergleichende Physiologie 47:438-456.

Dijkgraaf, S., and A.J. Kalmijn. 1966. Versuche zur biologischen Bedeutung der Lorenzinischen Ampullen bei den Elasmobranchiern. Zeitschrift für vergleichende Physiologie 53:187-194.

Divoky, G.T. 1976. The pelagic feeding habits of ivory and Ross` gulls. The Condor, 78(1): 85-90.

Dodd, C.K., Jr., 1988. Synopsis of the biological data on the loggerhead sea turtle, *Caretta caretta* (Linnaeus 1758). U.S. Fish and Wildlife Service Report 88. 110 p.

Dooley, J.K. 1972. Fishes associated with the pelagic *Sargassum* complex, with a discussion of the *Sargassum* community. Contributions in Marine Science 16:1-32.

Doving, K.B., and O.B. Stabell. 2003. Trails in open water: Sensory cues in salmon migration. Chapter 2. Pages 39-52 *in* S.P. Collins and N.J. Marshall, editors. Sensory Processing in Aquatic Environments. Springer.

Dufault, S., and R.A. Davis. 2003. Whale monitoring aboard The Cat, summer 2002. LGL Rep. 2741. Rep. from LGL Ltd., King City, Ont. for Bay Ferries Ltd., Charlottetown, P.E.I. 33 p. + Appendices.

Dutton, P., and D. McDonald. 1990a. Status of sea turtles in San Diego Bay. Sea World Research Institute. Technical Report No. 90-225. 17 p.

Dutton, P., and D. McDonald. 1990b. Sea turtles present in San Diego Bay. Pages 139-141 *in* Proceedings of the 10th Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical Memorandum. NMFS-SEFSC-278. U.S. Department of Commerce.

Dutton, P., and D. McDonald. 1992. Tagging studies of sea turtles in San Diego Bay, 1990-1991. Pages 35-37 *in* Proceedings of the 11th Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical memorandum, NMFS-SEFSC-302. U.S. Department of Commerce.

Dutton, P., S.K. Davis, D.L. McDonald, and T. Guerra. 1994. A genetic study to determine the origin of the sea turtles in San Diego Bay, California. p. 55-56 *In: Proc. 13th annual workshop on sea turtle biology and conservation*. NOAA Technical Memorandum NMFS-SEFSC-341. U.S. Dep. Commerce

Eckert, K.L. 1993. The biology and population status of marine turtles in the northern Pacific Ocean. NOAA Technical memorandum, NMFS-SEFSC-186. U.S. Department of Commerce.

Eckert, S.A. 1998. Perspectives on the use of satellite telemetry and other electronic technologies for the study of marine turtles, with reference to the first year long tracking of leatherback sea turtles. Pages 46-48 *in* S. Epperly and J. Braun, compilers. Proceedings of the Seventeenth Annual Sea Turtle Symposium. NOaA Technical memorandum NMFS-SEFSC-415.

Eckert, S.A. 1999. Global distribution of juvenile leatherback sea turtles. Hubbs Sea World Research Institute Technical Report 99-294.

Eckert, S.A. 2002. Swim speed and movement patterns of gravid leatherback sea turtles (*Dermochelys coriacea*) at St Croix, US Virgin Islands. The company of Biologists limited.

Eckert, S.A., and H.R. Martins. 1989. Transatlantic travel by a juvenile loggerhead turtle. Marine Turtle Newsletter 59:7.

Eckert, S.A., and M.L. Sarti. 1997. Distant fisheries implicated in the loss of the world’s largest leatherback nesting population. Marine Turtle Newsletter 78:2-7.

Eckert, S.A., D.W. Nellis, K.L. Eckert, and G.L. Kooyman. 1986. Diving patterns of two leatherback sea turtles (*Dermochelys coriacea*) during interesting intervals at Sandy Point, St. Croix, U.S. Virgin Islands. Herpetology 42:381-388.

Eckert, S.A., K.L. Eckert, P. Ponganis, and G.L. Kooyman. 1989. Diving and foraging behavior of leatherback sea turtles (*Dermochelys coriacea*). Canadian Journal of Zoology 67:2834-2840.

Edwards, R.N., L.K. Law, and J.M. DeLaurier. 1981. On measuring the electrical conductivity of the oceanic crust by a modified magnetometric resistivity method. Journal of Geophysical Research 86:11,609-11,615.

Elliott, J.E., Scheuhammer, A.M., Leighton, F.A., and Pearce, P.A. 1992. Heavy metal and methallothionein concentrations in Atlantic Canadian seabirds. Archives of Environmental Contamination and Toxicology, 22: 63-73.

EMGS. 2011. EMGS website at http://EMGS.com.

Emlen, S.T. 1970. Celestial rotation: its importance in the development of migratory orientation. Science 170:1198-1201.

Engelhardt, F.R. 1982. Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, *Phoca hispida*. Comp. Biochemistry and Physiology 72C:133-136.

Erikstad, K.E. 1990. Winter diets of four seabird species in the Barents Sea after a crash in the capelin stock. Polar Biology, 10: 619-627.

Evans, P.G.H. 1982. Associations between seabirds and cetaceans: A review. Mammal Review, 12(4): 187-206.

ExxonMobil. 2011. http://www.exxonmobilchemical.com/Chem-English/brands/hydrocarbon-oxygenated-fluids-products-isopar.aspx?

Facey, D.E., and M.J. Van Den Avyle. 1987. American eel. *In*: Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic). USFWS-SEFSC Biological Report 82, TR EL-82-4.

Falk, K., Pedersen, C.E., and Kampp, K. 2000. Measurements of diving depth in dovekies (*Alle alle*). The Auk, 117(2): 522-525.

Falkenberg, G., G. Fleissner, K. Schuchardt, M. Kuehbacher, P. Thalau, H. Mouritsen, D. Heyers, G. Wellenreuther, and G. Fleissner. 2010. Avian magnetoreception: elaborate iron mineral containing dentrides in the upper beak seem to be a common feature of birds. PLoS One 2010, 5:e9231.

FAO (Food and Agriculture Organization). 2009. FISHSTAT Plus (v. 2.30), capture production database, 1950-2007, and commodities trade and production database 1976-2007. FAO, Rome, Italy.

Fernie, K. J., and S. J. Reynolds. 2005. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: A review. Journal of Toxicology and Environmental Health - Part B: Critical Reviews 8:127-140.

Fields, RD., T.H. Bullock, and G.D. Lange. 1993. Ampullary sense organs, peripheral, central and behavioral electroreception in chimeras (*Hydrolagus, Holocephali, Chondrichthyes*). Brain, Behavior and Evolution 41:269-289.

Findley, L.T., and O. Vidal. 2002. Gray whale (*Eschrichtius robustus*) at calving sites in the Gulf of California, Mexico. J. Cetacean Res. Manage. 4(1):27-40.

Finneran, J.J., D.S. Houser, B. Mase-Guthrie, R.Y. Ewing and R.G. Lingenfelser. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). Journal of the Acoustical Society of America 126(1):484-490.

Fleissner, G., E. Holtkamp-Rötzler, M. Hanzlik, M. Winklhofer, G. Fleissner, N. Petersen, and W. Wiltschko. 2003. Ultrastructural analysis of a putative magnetoreceptor in the beak of homing pigeons. Journal of Comparative Neurology 458:350-360.

Fletmeyer, J.R. 1978. Underwater tracking evidence that neonate loggerhead sea turtles seek shelter in drifting Sargassum. Copeia 1:148.

Fletmeyer, J.R. 1990. Kemp’s ridley sea turtle nests in Palm Beach. Florida Naturalist 63:5.

Forbes, G.A. 1994. The diet of the green turtle in an algal-based coral reef community—Heron Island, Australia. Pages 57-59 *in Proceedings of the 13th Annual Symposium on Sea Turtle Biology and Conservation*. NOAA Technical Memorandum NMFS-SEFSC-341. U.S. Department of Commerce.

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. p. 97 *In*: Abstracts of the 16th Biennial Conference of The Biology of Marine Mammals, San Diego, CA, Dec. 2005. 306 p.

Frankel, R.B., R.P. Blakemore, and R.S. Wolfe. 1979. Magnetite in freshwater magnetotactic bacteria. Science. 203:1355-1356.

Freake, M.J., R. Muheim, and J.B. Phillips. 2006. Magnetic maps in animals: a theory comes of age? The Quarterly Review of Biology 81(4):327-347.

Frick, J. 1976. Orientation and behavior of hatchling green sea turtles (*Chelonia mydas*) in the sea. Animal Behavior 24:849-857.

Fritts, T.H., M.L. Stinson, and R. Marquez. 1982. Status of sea turtle nesting in southern Baja California, Mexico. Bulletin of Southern California Academy of Science 81:51-60.

Frost, K.J., L.F. Lowry E. Sinclair, J. Ver Hoef and D.C. McAllister. 1994. Impacts on distribution, abundance, and productivity of harbor seals. pp. 97-118. *In:* T.R. Loughlin (ed.), Marine mammals and the Exxon Valdez. Academic Press, San Diego. 395 p.

Fulling, G.L. and J.C. Salinas Vega. 2009. Unique sperm whale (*Physeter macrocephalus*) encounter in the Mariana Islands. *In*: Abstracts 18th Bienn. Conf. Biol. Mar. Mamm., 12–16 October 2009. Quebec City, Quebec.

Gallaway, B.J. (Editor) 1988a. Northern Gulf of Mexico continental slope study, final report: Year 4. Volume I: Executive summary. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region New Orleans, Louisiana. OCS Study MMS 88-0052. 69 p.

Gallaway, B.J. (Editor) 1988b. Northern Gulf of Mexico continental slope study, final report: Year 4. Volume II: Synthesis report. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region New Orleans, Louisiana. OCS Study MMS 88-0053. 318 p.

Gallaway, B.J. (Editor) 1988c. Northern Gulf of Mexico continental slope study, final report: Year 4. Volume III: Appendices. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region New Orleans, Louisiana. OCS Study MMS 88-0054. 378 p.

Gauthreaux, S. A., Jr. and C. G. Belser. 2006. Effects of artificial night lighting on migrating birds. pp. 67-93 *in* C. Rich and T. Longcore (editors), Ecological Consequences of Artificial Night Lighting, Island Press, Washington, D.C. 478 p.

Gegeer, R.J., A. Casselman, A Waddell, and S.M. Reppert. 2008. Cryptochrome mediates light-dependent magnetosensitivity in Drosophila. Nature 454:1014-1018.

Geraci, J.R. 1990. Cetaceans and oil: physiologic and toxic effects. pp. 167-197. *In:* J.R. Geraci and D.J. St. Aubin (eds.), Sea mammals and oil: confronting the risks. Academic Press, San Diego. 282 p.

Geraci, J.R. and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. Journal of the Fisheries Research Board of Canada 33:1976-1984.

Ghoul, A., C. Reichmuth, and J. Mulsow. 2009. Source levels and spectral analysis of southern sea otter (*Enhydra lutris nereis*) scream vocalizations. p. 90 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A. 2005. The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms – a review. COWRIE 1.5 Electromagnetic Fields Review. 57 p. + App.

GMFMC (Gulf of Mexico Fisheries Management Council). 2004. Draft final environmental impact statement for the generic essential fish habitat amendment to the [current] fishery management plans of the Gulf of Mexico. Gulf of Mexico Fisheries Management Council, Tampa, Florida. 680 p.

Goff, M., M. Salmon, and K.J. Lohmann. 1995. The magnetic compass of loggerhead sea turtle hatchlings: calibration by surface waves. Page 105 *in* Proceedings of the Fifteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical memorandum NMFS-SEFCS-387.

Goff, M., M. Salmon, and K.J. Lohmann. 1998. Hatchling sea turtles use surface waves to establish a magnetic compass direction. Animal Behavior 55:69-77.

Gordon, D., P. Schwinghamer, T.W. Rowell, J. Prena, K. Gilkinson, W.P Vass and D.L. McKeown. 1998. Studies in Eastern Canada on the impact of mobile fishing gear on benthic habitat and communities. *In:* Dorsey, E.M. and J. Pederson (eds.), Effects of fishing gear on the sea floor of New England. Conservation Law Foundation, Boston, Massachusetts.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Mar. Technol. Soc. J. 37(4):16-34.

Gould, J.L. 1980. The case for magnetic sensitivity in birds and bees (such as it is). American Scientist 68:256-267.

Gould, J.L. 1998. Sensory bases of navigation. Current Biology 8:R731-R738.

Grémillet, D., Tuschy, I., and Kierspel, M. 1998. Body temperature and insulation in diving great cormorants and European shags. Functional Ecology, 12: 386-394.

Greene Jr., C.R. 1985. Characteristics of waterborne industrial noise, 1980-84. p. 197-253. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1980-84. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p. NTIS PB87-124376.

Greene Jr., C.R. 1987. Characteristics of oil industry dredge and drilling sounds in the Beaufort Sea. J. Acoust. Soc. Am. 82: 1315-1324.

Griffin, D.R. 1952. Bird navigation. Biological Reviews 27359-400.

Gubbins, D. 2008. Earth science: Geomagnetic reversals. Nature 452:165-167.

Guess, R.C. 1981a. A Pacific loggerhead captured off California's northern Channel Islands. Herpetology Review 12: 1-15.

Guess, R.C. 1981b. Occurrence of a Pacific loggerhead turtle, *Caretta caretta gigas* Deraniyagala, in the waters off Santa Cruz, California. California Fish and Game Notes 68: 122-123.

Guilford, T.C., Meade, J., Freeman, R., Biro, D., Evans, T., Bonadonna, F., Boyle, D., Roberts, S., and Perrins, C.M. 2008. GPS tracking of the foraging movements of manx shearwaters *Puffinus puffinus* breeding on Skomer Island, Wales. Ibis, 150: 462-473.

Hahn, S., Ritz, M.S., and Reinhardt, K. 2008. Marine foraging and annual fish consumption of a south polar skua population in the maritime Antarctic. Polar Biology, 31: 959-969.

Haine, O.S., P.V. Ridd, and R.J. Rowe. 2001. Range of electrosensory detection of prey by *Carcharhinus melanopterus* and *Himantura granulate*. Marine and Freshwater Research 52:291-296.

Hansen, L.P., and J.A. Jacobsen. 2000. Distribution and migration of Atlantic salmon, Salmo salar L., in the sea. Pages 75-97 *in* The Ocean Life of Atlantic Salmon, D. Mills, editor. Blackwell Science, Oxford.

Hanson, M., G. Wirmark, M. Oblad, and L. Strid. 1984b. Iron-rich particles in European eel *anguilla anguilla* L). Comparative Biochemistry and Physiology A 79:311-316.

Hanson, M., L. Karlsson, and H. Westerberg. 1984a. Magnetic material in European eel (*Anguilla anguilla* L). Comparative Biochemistry and Physiology A 77:221-224.

Harvey, J.T. and M.E. Dahlheim. 1994. Cetaceans in oil. pp. 257-264. *In:* T.R. Loughlin (ed.), Marine mammals and the Exxon Valdez. Academic Press, San Diego. 395 p.

Harwood, L.A., F. McLaughlin, R.M. Allen, J. Lillasiak, Jr., and J. Alikamik. 2005. First-ever marine mammal and bird observations in the deep Canada Basin and Beaufort/Chukchi seas: expeditions during 2002. Polar Biol. 28:250-253.

Hastie, G.D., B. Wilson, L.H. Tufft and P.M. Thompson. 2003. Bottlenose dolphins increase breathing synchrony in response to boat traffic. Marine Mammal Science 19(1): 74-84.

Hayakawa, M., K. Ohta, A.P. Nickolaenko, and Y. Ando. 2005. Anomalous effect in Schumann resonance phenomena observed in Japan, possibly associated with the Chi-chi earthquake in Taiwan. Annales Geophysicae 23:1335-1346.

Hays, G.C., P. Luschi, F. Papi, C. del Seppia, and R. Marsh. 1999. Changes in behaviour during the inter-nesting period and post-nesting migration for Ascension Island green turtles. Marine Ecology Progress Series 189:263-273.

Heckel, G. S.B. Reilly, J.L. Sumich and I Espejel. 2001. The influences of whalewatching on the behaviour of migrating gray whales (*Eschirichtius robustus*) in Todos Santos Bay and surrounding waters, Baja California, Mexico. J. Cetacean Res. Manage. 3(3):227-237.

Helfman, G., B. Collette, and D. Facey. 2002. The Diversity of Fishes. Wiley-Blackwell, 544 p.

Henshaw, I., T. Fransson, S. Jakobsson, and C. Kullberg. 2010. Geomanetic field affects spring migratory direction in a long distance migrant. Behavior Ecology and Sociobiology 64:1317-1323.

Hildebrand, H.H. 1995. A historical review of the status of sea turtle populations in the western Gulf of Mexico. Pages 447-453 *in* K. Bjorndal, editor. The biology and conservation of sea turtles. Smithsonian Institution Press, Washington, D.C.

Hjermann, D.Ø., A. Melsom, G.E. Dingsør, J.M. Durant, A.M. Eikeset, L.P. Røed, G. Ottersen, G. Storvik, and N.C. Stenseth. 2007. Fish and oil in the Lofoten-Barents Sea system: synoptic review of the effect of oil spills on fish populations. Mar. Ecol. Prog. Ser. 339:283-299.

Hodge, R.P. 1982. *Carette carette gigas* (Pacific loggerhead). USA Washington. Herpetology Review 13: 24.

Hodge, R.P. 1981. *Chelonia mydas agassizi* (Pacific green turtle). USA Alaska. Herpetology Review 12:83.

Hoffman, W., Heinemann, D., and Wiens, J.A. 1981. The ecology of seabird feeding flocks in Alaska. The Auk, 98(3): 437-456.

Hoover-Miller, A., K.R. Parker and J.J. Burns. 2001. A reassessment of the impact of Exxon Valdez oil spill on harbor seals (*Phoca vitulina richardsi*) in Prince William Sound, Alaska. Marine Mammal Science 17(1):111-135.

Houghton, J.D.R., A. Cedras, A.E. Myers, N. Liebsch, J.D. Metcalfe, J.A. Mortimer, and G.C. Hays. 2008. Measuring the state of consciousness in a free-living diving sea turtle. Journal of Experimental Marine Biology and Ecology 356:115-120. http://www.nmfs.noaa.gov/pr/species/turtles/green.htm

Hui, C. 1994. Lack of association between magnetic patterns and the distribution of free-ranging dolphins. Journal of Mammology 75:399-405.

Hull, C.L. 2000. Comparative diving behavior and segregation of the marine habitat by breeding royal penguins, *Eudyptes schlegeli*, and eastern rockhopper penguins, *Eudyptes chrysocome filholi*, at Macquarie Island. Canadian Journal of Zoology, 78: 333-345.

ICNIRP (International Commission on Non-Ionizing Radiation Protection). 2009. Guidelines on limits of exposure to static magnetic fields. Health Physics 96:504-514.

ICNIRP. 2010. Guidelines on limits of exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Physics 99:818-836.

Imber, M. J. 1975. Behaviour of petrels in relation to the moon and artificial lights. Notornis 22:302-306.

IOC. 2010. 25th International Ornithological Congress. http://www.acquaviva.com.br/ioc2010.

Irwin, W.P. and K. Lohmann. 2002. Magnet-induced distortion in hatchling loggerhead sea turtles. The Journal of Experimental Biology 206:497-501.

IUCN (*International Union for Conservation of Nature*). 2010. The IUCN red list of threatened species. http://www.iucnredlist.org.

Jacklyn, P.M. 1992. Solar engineering for the blind: magnetic termite mounds of the Top End. North Territory Naturalist 13:9-15.

Jacob, B.A, J.D. McEachran, and P.L. Lyons. 1994. Electric organs in skates: Variation and phylogenetic significance (Chondrichthyes: Rajoidei). Journal of Morphology 221:45-63.

Jahoda, M., C.L. Lafortuna, N. Biassoni, C. Almirante, A. Azzellino, S. Panigada, M. Zanardelli and G. Notarbartolo Di Sciara. 2003. Mediterranean fin whales (*Balaenoptera physalus*) response to small vessels and biopsy sampling assessed through passive tracking and timing of respiration. Mar. Mamm. Sci. 19(1):96-110.

Janik, V.M. and P.M. Thompson. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Mar. Mamm. Sci. 12(4):597-602.

Jennings, S., M.J. Kaiser, and J.D. Reynolds. 2001. Marine Fisheries Ecology. Blackwell Science, Oxford.

Jensen, A.S. and G.K. Silber. 2003. Large whale ship strike database. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-OPR-. 37 p.

Johnson, C.S., B.L. Scronce, and M.W. McManus. 1984. Detection of DC electric dipoles in background fields by the nurse shark. Journal of Comparative Physiology A 155:681-687.

Jurasz, C.M. and V.P. Jurasz. 1979. Ecology of humpback whale. Draft report for U.S. Natl. Park Serv. Contr. No. CX-9000-7-0045.

Kajiura, S.M. 2003. Electroreception in neonatal bonnethead sharks, *Sphyrna tiburo*. Marine Biology 143:603-611.

Kajiura, S.M., and K.N. Holland. 2002. Electroreception in juvenile scalloped hammerhead and sandbar sharks. Journal of Experimental Biology 205:3609-3621.

Kalmijn, A.J. 1966. Electro-perception in sharks and rays. Nature (London) 212:1232-1233.

Kalmijn, A.J. 1971. The electric sense of sharks and rays. Journal of Experimental Biology 55:371-383.

Kalmijn, A.J. 1978. Experimental evidence of geomagnetic orientation in elasmobrach fishes. Pages 347-353 *in* K. Schmidt-Koenig and W.T. Keeton, editors. Animal Migration, Navigation and Homing. Heidelberg: Springer-Verlag.

Kalmijn, A.J. 1982. Electric and magnetic field detection in elasmobranch fishes. Science 218:916-918.

Kalmijn, A.J. 1984. Theory of electromagnetic orientation: a further analysis. Pages 525-560 *in* A. Bolis, R.D. Keynes, and S.H.P. Madrell, editors. Comparative Physiology of Sensory Systems. Cambridge University Press, Cambridge.

Kalmijn, A.J. 1987. Detection of weak electric fields. Pages 151-186 *in* J. Atema, R.R. Fay, A.N. Popper, and W.N. Tavolga, editors. Social Communication in Aquatic Environments. Springer-Verlag, New York.

Kalmijn, A.J. 2000. Detecting and processing of electromagnetic and near-field acoustic signals in elasmobranch fishes. Philosophical Transactions of the Royal Society of London B 355:1135-1141.

Kalmjin, A.J. 2003. Physical principals of electric, magnetic, and near-field acoustic orientation. Chapter 4. Pages 77-91 *in* S.P. Collins and N.J. Marshall, editors. Sensory Processing in Aquatic Environments. Springer.

Karlsen, J.D., A. Bisther, C. Lydersen, T. Haug and K.M. Kovacs. 2002. Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. Polar Biol. 25:808-817.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise and ecology. Journal of the Acoustical Society of America 103(4):2216-2228.

Kastak, D. and R.J. Schusterman. 1999. In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). Canadian Journal of Zoology 77(11):1751-1758.

Kastelein, R.A., P. Mosterd, B. van Santen, M. Hagedoorn, and D. de Haan. 2002. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. Journal of the Acoustical Society of America 112(5):2173-2182.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). Journal of the Acoustical Society of America 125(2):1222-1229.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. **Sci.** Rep. Whales Res. Inst. 37:61-83.

Keeton, W.T., T.S. Larkin, and D.M. Windsor. 1974. Normal fluctuations in the earth’s magnetic field influence pigeon orientation. Journal of Comparative Physiology 95:95-103.

Keinath, J.A., and J.A. Musick. 1993. Movements and diving behavior of a leatherback turtle, *Dermochelys coriacea, Copeia* 1993:1010.

Keitt, B.S., Croll, D.A., and Tershy, B.R. 2000b. Dive depth and diet of the black-vented shearwater (*Puffinus opithomelas*). Auk, 117: 507-510. *In* Keitt, B.S., Tershy, B.R., and Croll, D.A. 2000a. Black-vented shearwater (*Puffinus opisthomelas*). The Birds of North America, 521: 16p.

Keitt, B.S., Tershy, B.R., and Croll, D.A. 2000a. Black-vented shearwater (*Puffinus opisthomelas*). The Birds of North America, 521: 16p.

Ketten, D.R. 1991. The marine mammal ear: specializations for aquatic audition and echolocation. p. 717-750 *In:* D. Webster, R. Fay and A. Popper (eds.), The Biology of Hearing. Springer-Verlag, Berlin.

Ketten, D.R. 1992. The cetacean ear: form, frequency, and evolution. p. 53-75 *In:* J.A. Thomas, R.A. Kastelein, and A. Ya Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York, NY.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. IEEE Proc. Underwater Acoustics 1:264-270.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 *In:* W.W.L. Au, A.N. Popper, and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 485 p.

Ketten, D.R., and S.M. Bartol. 2006. Functional measures of sea turtle hearing. Final Report to Office of Naval Research, Boston, MA.

King, F.W. 1995. Historical review of the decline of the green turtle and the hawksbill. Pages 183-188 *in* K. Bjorndal, editor. The biology and conservation of sea turtles. Smithsonian Institution Press, Washington, D.C.

Kirschvink, J.L. 1990. Geomagnetic sensitivity in cetaceans: an update with live stranding records in the United States. Pages 639-649 *in* J.A. Thomas and R.A. Kastelein, editors. Sensory Abilities of Cetaceans: Laboratory and Field Evidence. Plenum Press, New York.

Kirschvink, J.L., A. Kobayashi-Kirschvink, and B.J. Woodford. 1992. Magnetite biomineralization in the human brain. Proceedings of the National Academy of Sciences 89:7683-7687.

Kirschvink, J.L., A.E. Dizon, and J.A. Westphal. 1986. Evidence from strandings for geomagnetic sensitivity in cetaceans. Journal of Experimental Biology 120:1-24.

Kirschvink, J.L., and J.L. Gould. 1981. Biogenic magnetite as a basis for magnetic field detection in animals. Biosystems 13:181-201.

Kirschvink, J.L., and M.M. Walker. 1985. Particles size considerations for magnetite-based magnetoreceptors. Pages 243-256 *in* J.L. Kirschvink, D.S. Jones, and B.J. MacFadden, editors. Magnetite Biomineralization and Magnetoreception in Organisms. Plenum Press, New York.

Kirschvink, J.L., M.M. Walker, S-B Chang, A.E. Dizon, and K.A. Peterson. 1985. Chains of single-domain magnetite particles in Chinook salmon, *Oncorhynchus tshawytscha*. Journal of Comparative Physiology. 157:375-381.

Kirschvink. J.L. 1980. South seeking magnetic bacteria. Journal of Experimental Biology 86:345-347.

Kirschvink. J.L. 1997. Homing in on vertebrates. Nature 390:339-340.

Klimley, A.P. 1993. Highly directional swimming by scalloped hammerhead sharks, *Sphbyrna lewini*, and subsurface Irradiance, temperature, bathymetry, and geomagnetic field. Marine Biology 117:1-22.

Klinowska, M. 1985. Cetacean live stranding sites relate to geomagnetic topography. Aquatic Mammals 1:27-32.

Klinowska, M. 1986. Cetacean live stranding dates relate to geomagnetic disturbances. Aquatic Mammals 11.3:109-199.

Komerovsky, I. 1993. Magnetite: Geomagnetic field receptors in *Meriones* (Rodentia Gerbillidae). Comptes Rendus de L'Academie des Sciences Serie III Sciences de la Vie 316:572-574.

Krieger, K.J. and B.L. Wing. 1984. Hydroacoustic surveys and identification of humpback whale forage in Glacier Bay, Stephens Passage, and Frederick Sound, southeastern Alaska, summer 1983. NOAA Tech. Memo. NMFS F/NWC-66. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 60 p. NTIS PB85-183887.

Krieger, K.J. and B.L. Wing. 1986. Hydroacoustic monitoring of prey to determine humpback whale movements. NOAA Tech. Memo. NMFS F/NWC-98. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 63 p. NTIS PB86-204054.

LGL and JASCO Research. 2005. Assessment of the effects of underwater noise from the proposed Neptune LNG Project. Report by LGL Limited, King City, ON and JASCO Research Ltd. Halifax, NS for Ecology and Environment, Inc., Arlington, VA. 234 p.

Laist, D.W., A.R. Knowlton, J.G. Mead, A.S. Collet and M. Podesta. 2001. Collisions between ships and whales. Marine Mammal Science 17(1):35-75.

Le Corre, M., A. Ollivier, S. Ribes, and P. Jouventin. 2002. Light-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). Biological Conservation 105:93-102.

Lenhardt, M. 2002. Sea turtle auditory behavior (A). Acoustical Society of America 112(5):2314-2314.

Lenhardt, M.L. 1994. Seismic and very low frequency induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). Pages 238-241 *in*: Bjorndal, K.A., A.B. Bolten, D.A. Johnson, and P.J. Eliazar, compilers. Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAa Technical Memorandum NMFS-SEFSC351.

Lenhardt, M.L., S. Bellmund, R.A. Byles, S.W. Harkins, and J.A. Musick. 1983. Marine turtle reception of bone-conducted sound. Journal of Auditory research 23:119-125.

Lesage, V., C. Barrette, M.C.S. Kingsley and B. Sjare. 1999. The effect of vessel noise on the vocal behaviour of belugas in the St. Lawrence River Estuary, Canada. Mar. Mamm. Sci. 15: 65-84.

Lewis, S., Benvenuti, S., Dall'Antonia, L., Griffiths, R., Money, L., Sherratt, T.N., Wanless, S., and Hamer, K.C. 2002. Sex-specific foraging behavior in a monomorphic seabird. Proceedings of the Royal Society of London B, 269: 1687-1693.

Light, P., M. Salmon, and K.J. Lohmann. 1993. Geomagnetic orientation of loggerhead sea turtles: evidence for an inclination compass. Journal of Experimental Biology 182:1-10.

Limpus, C. 1971. Sea turtle ocean finding behavior. Search 2(10):385-387.

Linton, A. 1978. The food and feeding habits of Leach's storm-petrel (*Oceanodrama leucorhoa*) at Pearl Island, N.S. and Middle Lawn Island, Newfoundland. M.Sc. thesis, Dalhousie University, Halifax, Canada. *In* Elliott, J.E., Scheuhammer, A.M., Leighton, F.A., and Pearce, P.A. 1992. Heavy metal and methallothionein concentrations in Atlantic Canadian seabirds. Archives of Environmental Contamination and Toxicology, 22: 63-73.

Lohmann, K.J. 1985. Geomagnetic field detection by the western Atlantic spiny lobster, *Panulirus argus*. Marine Behavior and Physiology 12:1-17.

Lohmann, K.J. 1991. Magnetic orientation by hatching loggerhead sea turtles (*Caretta caretta*). Journal of Experimental Biology 155:37-49.

Lohmann, K.J. and C.M.F. Lohmann. 1994b. Acquisition of magnetic directional preference in hatchling loggerhead sea turtles. The Journal of Experimental Biology 190:1-8.

Lohmann, K.J., A.O. D. Willows, and R.B Pinter. 1991. An identifiable molluscan neuron responds to changes in earth-strength magnetic fields. Journal of Experimental Biology 161:1-24.

Lohmann, K.J., A.W. Swartz, and C.M.F. Lohmann. 1995a. Perception of ocean wave direction by sea turtles. The Journal of Experimental Biology 198:1079-1085.

Lohmann, K.J., and A.O.D. Willows. 1987. Lunar-modulated geomagnetic orientation by a marine mollusk. Science 235:331-334.

Lohmann, K.J., and C.M.F. Lohmann. 1992. Orientation to oceanic waves by green turtle hatchlings. Journal of Experimental Biology 171:1-13.

Lohmann, K.J., and C.M.F. Lohmann. 1993. A light-independent magnetic compass in the leatherback sea turtle. Biological Bulletin 185:149-151.

Lohmann, K.J., and C.M.F. Lohmann. 1994a. Detection of magnetic inclination angles by sea turtles: a possible mechanism for determining latitude. Journal of Experimental Biology 194:23-32.

Lohmann, K.J., B.E. Witherton, C.M.F. Lohmann, and M. Salmon. 1997. Orientation, navigation, and natal beach homing in sea turtles. Pages 107-163 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Lohmann, K.J., M. Salmon, and J. Wyneken. 1990. Functional autonomy of land and sea orientation systems in sea turtle hatchlings. Biological Bulletin 79:214-218.

Lohmann, K.J., N.D. Pentcheff, G.A. Nevitt, G.D. Stetten, R.K. Zimmer-Faust, H.E. Jarrard, and L.C. Boles. 1995b. Magnetic orientation of spiny lobsters in the ocean: experiments with undersea coil systems. The Journal of Experimental Biology 198:2041-2048.

Lohmann, K.L., and C.M.F. Lohmann. 1996a. Orientation and open-sea navigation in sea turtles. The Journal of Experimental Biology 199:73-81.

Lohmann, K.L., and C.M.F. Lohmann. 1996b. Detection of magnetic field intensity by sea turtles. Nature. 380:59-61.

López-Mendilaharsu, M., C.F.D. Rocha, P. Miller, A. Domingo, and L. Prosdocimi. 2009. Insights on leatherback turtle movements and high use areas in the Southwest Atlantic Ocean. Journal of Experimental Marine Biology and Ecology 378:31-39.

Lu, J., and H.M. Fishman. 1994. Linear properties of electroreceptive ampullary epithelium isolated from skates show underlying negative conductance behavior. Biophysical Journal 66:6-10.

Luschi, P., S Akesson, C. Broderick, F. Glen, B.J. Godley, F. Papi, and G.C. Hays. 2001. Testing the navigational abilities of ocean migrants: displacement experiments on green sea turtles (*Chelonia mydas*). Behavioral Ecology and Sociobiology 50:528-534.

Luschi, P., S. Benhamou, C. Girard, S. Ciccione, D. Roos, J. Sudre, and S. Benvenuti. 2007. Marine turtles use geomagnetic cues during open-sea homing. Current Biology 17: 126–133.

Lusseau, D. 2003. Effects of tour boats on the behavior of bottlenose dolphins: using Markov chains to model anthropogenic impacts. Conserv. Biol. 17(6):1785-1793.

Lusseau, D. 2004. The hidden cost of tourism: detecting long-term effects of tourism using behavioral information. Ecol. Soc. 9(1):2.

Lusseau, D. 2005. The residency patterns of bottlenose dolphins (*Tursiops* spp.) have different strategies to avoid interactions with tour boats in Doubtful Sound, New Zealand. Mar. Ecol. Prog. Ser. 257:265-272.

Lusseau, D., D.E. Bain, R. Williams and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. Endangered Species Research 6:211-221

Lutcavage, M.E., and P.L. Lutz. 1997. Diving physiology. Pages 277-296 in P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Lutcavage, M.E., P. Plotkin, B. Witherington and P.L. Lutz. 1997. Human impacts on sea turtle survival. p. 387-409 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Macdonald, R.W. 1978. The interaction of chlorine and seawater with special reference to the four liquid chlorine tank cars lost in British Columbia coastal waters. Journal of Hazardous Materials 2:51-75.

McEachran, J.D., and J.D. Fechhelm. 1998. Fishes of the Gulf of Mexico. Volume 1: Myxiniformes to Gasterosteiformes. University of Texas Press, Austin, Texas.

Magalhães, S., R. Prieto, M.A. Silva, J. Gonçalves, M. Afonso-Dian and R.S. Santos. 2002. Short-term reactions of sperm whales (*Physeter macrocephalus*) to whale-watching vessels in the Azores. Aquat. Mamm. 28(3):267-274.

Maguire, J., M. Sissenwine, J. Csirke, R. Grainger, and S. Garcia. 2006. The state of world highly migratory, straddling, and other high seas fishery resources and associated species. FAO Fisheries Technical Paper No. 495. FAO, Rome, Italy.

Mann, S., N.C.H. Sparks, M.M. Walker, and J.L. Kirschvink. 1988. Ultrastructure, morphology and organization of biogenic magnetite from sockeye salmon, *Oncorhynchus nerka*: implications for magnetoreception. Journal of Experimental Biology 140:35-49.

Manning, E.L., H.S. Cate, and K.J. Lohmann. 1997. Discrimination of ocean wave features by hatchling loggerhead sea turtles, *Caretta caretta*. Marine Biology 127:539-544.

Manzella, S.A., and C.T. Fontaine. 1988. Loggerhead sea turtle travels from Padre Island, Texas to the mouth of the Adriatic Sea. Marine Turtle Newsletter 42:7.

Manzella, S.A., J.A. Williams, B. Schroeder, and W. Teas. 1991. Juvenile head-started Kemp's ridleys found in floating grass mats. Marine Turtle Newsletter 52:5.

Marcotte, M.M. and C.G. Lowe. 2008. Behavioral responses of two species of sharks to pulsed, direct current electrical fields: Testing a potential shark deterrent. Marine Technology Society Journal 42 (2):53-61.

Matkin, C.O., G.M. Ellis, M.E. Dahlheim and J. Zeh. 1994. Status of killer whales in Prince William Sound, 1985-1992. pp. 141-162. *In:* T.R. Loughlin (ed.), Marine Mammals and the Exxon Valdez. Academic Press, San Diego. 395 p.

Mattern, T., Ellenberg, U., Houston, D.M., and Davis, L.S. 2007. Consistent foraging routes and benthic foraging behavior in yellow-eyed penguins. Marine Ecology Progress Series, 343: 295-306.

Mazzuca, L., S. Atkinson, B. Keating, and E. Nitta. 1999. Cetacean mass strandings in the Hawaii Archipelago, 1957-1998. Aquatic Mammals 25:105-114.

McCauley, R.D. and D.H. Cato. 2001. The underwater noise of vessels in the Hervey Bay (Queensland) whale watch fleet and its impact on humpback whales. J. Acoust. Soc. Am. 109(5, Pt. 2):2455.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Penrose, R.I.T. Prince, A. Adhita, J. Murdoch, and K. McCabe. 2000. Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. A Report prepared for the Australian Production Exploration Association. Project CMST 163, report R99-15. 198 pp.

McCleave, J.D., and J.H. Power. 1978. Influence of weak electric and magnetic fields on turning behavior in elvers of the American ell *Anguilla rostrata*. Marine Biology 46:29-34.

McMahon, C.R., C.J.A. Bradshaw, and G.C. Hays. 2007. Satellite tracking reveals unusual diving characteristics for a marine reptile, the olive ridley turtle *Lepidochelys olivacea*. Marine Ecology Progress Series 329:239-252.

Mehta, K, M. Nabighian, Y. Li, and Doug Oldenburg. 2000. Controlled Source Electromagnetic (CSEM) technique for detection and delineation of hydrocarbon reservoirs: an evaluation. Center for Gravity, Electrical & Magnetic Studies, Colorado School of Mines and UBC-GIF, University of British Columbia.

Mendonca, M.T., and P.C.H. Pritchard. 1986. Offshore movements of post-nesting Kemp's ridley sea turtles (*Lepidochelys kempi*), Herpetologica 42:373.

Merkel, F. R. 2010. Light-induced bird strikes on vessels in Southwest Greenland. Greenland Institute of Natural Resources, Teknisk Rapport Pingortitaleriffik 84, 2010. 26 p.

Meyer, C.G., K.N. Holland, and Y.P. Papastamatiou. 2004. Sharks can detect changes in the geomagnetic field. Journal of the Royal Society Interface. Published online.

Meylan, A., P. Castaneda, C. Coogan, T. Lozon, and J. Fletmeyer. 1990. First recorded nesting of Kemp's ridley in Florida, USA. Marine Turtle Newsletter 48:8-9.

Miles, W., S. Money, R. Luxmoore, and R. W. Furness. 2010. Effects of artificial lights and moonlight on petrels at St Kilda. Bird Study 57:244-251.

Miller, J.D. 1997. Reproduction in sea turtles. Pages 51-81 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Moein, S.E. et al. 1995. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Sea turtle research program summary report. Prepared for U.S. Army Engineer Division, South Atlantic, Atlanta, Georgia and U.S. Naval Submarine Base, Kings Bay, Georgia. Technical Report CERC-95-31.

Montague, T.L. 1985. A maximum dive recorder for little penguins. Emu, 85: 264-267.

Montevecchi, W. A. 2006. Influences of artificial light on marine birds. pp. 94-113 *in* C. Rich and T. Longcore (editors), Ecological Consequences of Artificial Night Lighting, Island Press, Washington, D.C. 478 p.

Montevecchi, W. A., F. K. Wiese, G. K. Davoren, A. W. Diamond, F. Huettmann, and J. Linke. 1999. Seabird attraction to offshore platforms and seabird monitoring from offshore support vessels and other ships: Literature review and monitoring designs. Prepared for the Canadian Association of Petroleum Producers. 56 p.

Montgomery, J.C., and M.M. Walker. 2001. Orientation and navigation in elasmobranchs: which way forward? Environmental Biology of Fishes 60:109-116.

Moore, A., S.M. Freake, and I.M. Thomas. 1990. Magnetic particles in the lateral line of the Atlantic salmon (*Salmo salar* L.). Philosophical Transaction of the Royal Society of London B 329:11-15.

Moore, B.R. 1980. Is the homing pigeon’s map geomagnetic? Nature 285:69-70.

Moore, F. R. 1975. Influence of solar and geomagnetic stimuli on the migratory orientation of Herring Gull chicks. Auk 92:655-664.

Moore, S.E. and J.T. Clarke. 2002. Potential impact of offshore human activities on gray whales (*Eschrichtius robustus*). J. Cetacean Res. Manage. 4(1):19-25.

Mortimer, J.A. 1995. Feeding ecology of sea turtles. Pages 103-109 *in* K. Bjorndal (ed.), The Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, D.C.

Mougeot, F. and V. Bretagnolle. 2000. Predation risk and moonlight avoidance in nocturnal seabirds. Journal of Avian Biology 31:376-386.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48. *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco’s open water seismic program in the Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. LGL Rep. TA2564-4.

Mrosovsky, N. 1972. The water-finding ability of sea turtles. Behavioral studies and physiological speculations. Brain Behavior and Evolution 5:202-225.

Mrosovsky, N., and S.J. Shettleworth. 1968. Wavelength preferences and brightness cues in the water finding behavior of sea turtles. Behavior 32:211-257.

Muheim, R., F.R. Moore, and J.B. Phillips. 2006. Calibration of magnetic and celestial compass cues in migratory birds—a review of cue conflict experiments. Journal of Experimental Biology 209:2-17.

Muheim, R., J. Bäckman, and S. Åkesson. 2002. Magnetic compass orientation in European Robins is dependent on both wavelength and intensity of light. Journal of Experimental Biology 205:3845-3856.

Murray, R.W. 1960. Electrical sensitivity of the ampullae of Lorenzini. Nature (London) 187:957.

Murray, R.W. 1962. The response of ampullae of Lorenzini of elasmobranchs to electrical stimulation. Journal of Experimental Biology 39:119-128.

Musick, J.A., and C.J. Limpus. 1997. Habitat utilization and migration in juvenile sea turtles. Pages 137-164 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Nachtigall, P.E., A.Y. Supin, M. Amundin, B. Röken,,T. Møller, A. Mooney, K.A. Taylor, and M. Yuen. 2007. Polar bear *Ursus maritimus* hearing measured with auditory evoked potentials. Journal of Experimental Biology 210(7):1116-1122.

National Institute of Environmental Health Sciences/National Institute of Health. 2001. Electric Power Background: Information Fact Sheet. http://www.neihs.nih.gov/oc/fact sheets/emf/epbasics.htm.

Neff, J.M. and J.W. Anderson. 1981. Response of marine animals to petroleum and specific petroleum hydrocarbons. Applied Science Publishers, Essex, pp. 177.

NMFS/USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1996a. Recovery Plans for U.S. Pacific Populations of the Hawksbill Turtle (*Eretmochelys imbricata*). National Marine Fisheries Service, Silver Spring, MD.

NMFS/USFWS. 1996b. Recovery Plans for U.S. Pacific Populations of the Loggerhead Turtle (*Caretta caretta*). National Marine Fisheries Service, Silver Spring, MD.

NMFS/USFWS. 1996c. Recovery Plans for U.S. Pacific Populations of the Leatherback Turtle (*Dermochelys coriacea*). National Marine Fisheries Service, Silver Spring, MD.

NMFS/USFWS. 1996d. Recovery Plans for U.S. Pacific Populations of the Olive Ridley Turtle (*Lepidochelys olivacea*). National Marine Fisheries Service, Silver Spring, MD.

NMFS/USFWS. 1996e. Recovery Plans for U.S. Pacific Populations of the East Pacific Green Turtle (*Chelonia mydas*). National Marine Fisheries Service, Silver Spring, MD.

NOAA Fishery Service. 2011. Hawaiian green turtle: life history. http://www.fpir.noaa.gov/Library/PRD/Sea%20Turtles/Fishing%20around%20sea%20turtles%20page/seaturtle-lifehistoryFAQ.2-4-11-1.pdf.

NOAA. 2011. Green turtle fact sheet. Office of Protected Resources, National Oceanic and Atmospheric Administration.

NOAA. 2011. Space Weather Scale for Geomagnetic Storms. http://www.swpc.noaa.gov/NOAAscales/

Nowacek, D.P., Johnson, M.P., and Tyack, P.L. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London, B, 271: 227-231.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review 37(2):81-115.

Nowacek, D.P., M.P. Johnson and P.L. Tyack. 2004. North Atlantic right whales (Eubalaena glacialis) ignore ships but respond to alerting stimuli. Proceedings: Biological Sciences 271(1536):227-231.

Nowacek, S.M., R.S. Wells and A.R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Mar. Mamm. Sci. 17(4):673-688.

NRC (National Research Council). 1990. Decline of the sea turtle. National Academy Press, Washington, D.C.

O’Hara, J., and J.R. Wilcos. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia 1990(2):564-567.

Ogren, L.H. 1988. Biology of sea turtles. Prepared for National Marine Fisheries, Panama City Laboratory.

Ogura, M., M. Kato, N. Arai, T. Sasada, and Y. Sakaki. 1992. Magnetic particles in chum salmon (*Oncorhynchus keta*): extraction and transmission electron microscopy. Canadian Journal of Zoology 70:874-877.

Oliver, J.A. The natural history of North American amphibians and reptiles. Von Nostrand, New York. 359 p.

Oro, D., A. De León, E. Minguez, and R. W. Furness. 2005. Estimating predation on breeding European Storm-petrels (*Hydrobates pelagicus*) by Yellow-legged Gulls (*Larus michahellis*). Journal of Zoology (London) 265:421-429.

OSPAR. 2008. Background Document on potential problems associated with power cables other than those for oil and gas activities. OSPAR Commission. 50 p.

Ovchinnikov, V.V., S.I. Gleyzer, and C.Z. Galaktionov. 1973. Features of orientation of the European eel (*Anguilla anguilla* L.) at some stages of migration. Journal of Ichthyology 13:455-463.

Palka, D. 1996. Evidence of ship avoidance from harbour porpoises during line transect sighting surveys in the Gulf of Maine. Abstract SC/47/SM27. Rep. Int. Whal. Commn 46:675.

Pals, N., 1982 Local geoelectric fields at the bottom of the sea and their relevance for electrosensitive fish. Netherlands Journal of Zoology 32(4):479–494.

Papastavrou, V., S.C. Smith, and H. Whitehead. 1989. Diving behaviour of the sperm whale, *Physeter macrocephalus*, off the Galápagos Islands. **Can. J. Zool.** 67(4):839-846.

Papi, F., and P. Loalé. 1988. Pigeon navigation: new experiments on interaction between olfactory and magnetic cues. Comparative Biochemistry and Physiology 91A(1):87-89.

Papi, F., H.C. Chew, P. Luschi, and E.H. Chan. 1995. Long-range migratory travel of a green turtle tracked by satellite: evidence for navigational ability. Marine Biology 122:171-175.

Papi, F., P. Luschi, S. Akesson, S. Capogrossi, and G.C. Hays. 2000. Open-sea migration of magnetically disturbed sea turtles. The Journal of Experimental Biology 203:3435-3443.

Parks, S.E., D.R. Ketten, J.T. O'Malley and J. Arruda. 2007. Anatomical predictions of hearing in the North Atlantic right whale. Anat. Rec. 290(6):734-744.

Patenaude, N.J., W.J. Richardson, M.A. Smultea, W.J. Richardson, W.R. Koski, G.W. Miller, B. Würsig and C.R. Greene, Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 18(2):309-335.

Paulin, M.G. 1995. Electroreception and the compass sense of sharks. Journal of Theoretical Biology 174:325-339.

Payne, R. 1978. Behavior and vocalizations of humpback whales (*Megaptera* sp.). *In*: K.S Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. MCC-77/03. Rep. by Sea Life Inc., Makapuu Pt., HI, for U.S. Mar. Mamm. Comm., Washington, DC.

Peck, D.R. and Congdon, B.C. 2006. Sex-specific chick provisioning and diving behavior in the wedge-tailed shearwater *Puffinus pacificus*. Journal of Avian Biology, 37: 245-251.

Peck, D.R., Smithers, B.V., Krockenberger, A.K., and Congdon, B.C. 2004. Sea surface temperature constrains wedge-tailed shearwater foraging success within breeding seasons. Marine Ecology Progress Series, 281: 259-266.

Pedersen, H.T., M. Akmal Affendi B. Adnan, B. A. Manaf. 2010. Shallow water 3D CSEM: A case study from Malaysia. SEG Denver 2010 Annual Meeting. P. 848-852.

Perrin, W.F., Würsig, B., and Thewissen, J.G.M (eds.). 2002. Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414p.

Perry, E.A., D.J. Boness and S.J. Insley. 2002. Effects of sonic booms on breeding gray seals and harbor seals on Sable Island, Canada. J. Acoust. Soc. Am. 111(1):599-609.

Peters, R.C. and F. Bretschneider. 1972. Electric phenomena in the habitat of the catfish *Ictalurus nebulosus*. Journal of Comparative Physiology 81:345-362.

Peters, R.C., and H.-P Evers. 1985. Frequency selectivity in the ampullary system of an elasmobranch fish (*Scyliorhinus canicula*) Journal of Experimental Biology 118:99-109.

Peters, R.C., B. Lonneke, M. Eeuwes, and F. Bretschneider. 2007. On the electrodetection threshold of aquatic vertebrates with ampullary or mucus gland electroreceptor organs. Biological Review 82:361-373.

PGS (Petroleum Geo-Services). 2007. Multi-transient EM technology at PGS. http://www.pgs.com.techlink.

Phillips, J.B. 1986. Two magnetoreception pathways in a migratory salamander. Science 233:765-767.

Phillips, J.B. 1996. Magnetic navigation. Journal Theor. Biology 180:309-319.

Phillips, J.B., and M.E. Deutschlander. 1997. Magnetoreception in terrestrial vertebrates: implications for possible mechanisms of EMF interaction with biological systems. Pages 111-172 *in* The Melatonin Hypothesis: Breast Cancer and Use of Electric Power. Edited by R.G. Stevens, B.W. Wilson, and L.E. Andrews. Columbus, OH: Battelle Press.

Phillips, J.B., K. Schmidt-Koenig, and R. Muheim. 2006. True navigation: sensory bases of gradient maps. Animal Spatial Cognition: Comparative, Neural and Computational Approaches. Edited by M.F. Brown and R.G. Cook, in cooperation with Comparative Cognition Press, Medford, MA. http://www.pigeon.psy.tufts.edu/asc/Phillips.

Piatt, J.F. and Nettleship, D.N. 1985. Diving depths of four alcids. Auk, 102(2): 293-297. *In* Elliott, J.E., Scheuhammer, A.M., Leighton, F.A., and Pearce, P.A. 1992. Heavy metal and methallothionein concentrations in Atlantic Canadian seabirds. Archives of Environmental Contamination and Toxicology, 22: 63-73. *Also In* Wanless, S., Barton, T.R., and Harris, M.P. 1997. Blood hematocrit measurements of 4 species of North Atlantic seabirds in relation to levels of infestation by the tick *Ixodes uriae*. Colonial Waterbirds, 20(3): 540-544.

Pitman, R.L. 1990. Pelagic distribution and biology of sea turtles in the eastern tropical Pacific. Pages 143-144 *in* proceedings of the 10th Annual Workshop on Sea Turtle Biology and Conservation. NOAA Technical Memorandum, NMFS-SEFC-278. U.S. Department of Commerce.

Plotkin, P.T. 1994. The migratory and reproductive behavior of the olive ridley, *Lepidochelys olivacea* (Eschscholtz, 1829) in the Eastern Pacific Ocean, Ph.D. Dissertation, Texas A&M University, College Station.

Polovina, J.J., Howell, E., and Parker, D.M. 2003. Dive-depth distribution of loggerhead (*Carretta carretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific: Might deep longline sets catch fewer turtles? Fishery Bulletin 101 (1):189–193.

Poot, H., B. J. Ens, H. de Vries, M. A. H. Donners, M. R. Wernand, and J. M. Marquenie. 2008. Green Light for Nocturnally Migrating Birds. Ecology and Society 113:47. Available at: http://www.ecologyandsociety.org/vol13/iss2/art47/. Accessed: 1 January 2011.

Prange, H.D. 1976. Energetics of swimming of a sea turtle. Journal of Experimental Biology 64:1-12.

Prinz, K., and W. Wiltschko. 1992. Migratory orientation of pied flycatchers: Interaction of stellar and magnetic information during ontogeny. Animal Behaviour 44:539-545.

Pritchard, C.P.H. 1971. Galapagos sea turtles—preliminary findings. Journal of Herpetology 5:1-9.

Pritchard, C.P.H.. 1997. Evolution, phylogeny, and current status. Pages 1-28 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Proctor, N.S. and Lynch, P.J. 2005. A field guide to North Atlantic wildlife: Marine mammals, seabirds, fish, and other sea life. Yale University Press, New Haven and London. 221p.

Quinn, T.P. 1980. Evidence for celestial and magnetic compass orientation in lake migrating sockeye salmon fry. Journal of Comparative Physiology. 137:243-248.

Quinn, T.P., and C. Groot. 1983. Orientation of chum salmon (*Oncorhynchus keta*) after internal and external magnetic field alteration. Canadian Journal of Fisheries and Aquatic Science 40:1598-1606.

Quinn, T.P., and E.L. Brannon. 1982. The use of celestial and magnetic cues by orienting sockeye salmon smolts. Journal of Comparative Physiology. 147:547-552.

Raleigh, R.F. 1967. Genetic control in the lakeward migrations of sockeye salmon (*Oncorhynchus nerka*) fry. Canadian Journal of the Fisheries Research Board of Canada 24:2613-2622.

Raleigh, R.F., 1971. Innate control of migrations of salmon and trout from natal gravels to rearing areas. Ecology 52:291-297.

Rao, N.V, T.Madhu, T., and Kishore, K.L. 2010. Geomagnetic Storm Effects on GPS Aided Navigation over Low Latitude South Indian Region. IJCSNS International Journal of Computer Science and Network Security 10 (3):37-42.

Raschi, W. 1986. A morphological analysis of the ampullae of Lorenzini in selected skates (Pisces, Rajoidei). Journal of Morphology 189:225-247.

Raschi, W., and W.H. Adams. 1988. Depth-related modifications in the electroreceptive system of the eurybathic skate, Raja radiata (Chondrichthyes: Rajidar). Copeia 1988:116-123.

Reed, J. R., J. L. Sincock, and J. P. Hailman. 1985. Light attraction in endangered Procellariiform birds: reduction by shielding upward radiation. Auk 102:377-383.

Reeves, R.R., Stewart, B.S., Clapham, P.J. and Powell, J.A. 2002. National Audubon Society: Guide to marine mammals of the world. Alfred A. Knopf, Inc. and Chanticleer Press, Inc., New York, NY. 527p.

Reilly, J. 1998. Applied bioelectricity: from electrical stimulation to electropathogy. Springer-Verlag, New York.

Reilly, J.P. 2002. Neuroelectric mechanisms applied to low frequency and electric and magnetic field exposure guidelines—part I: sinusoidal waveforms. Health Physics 83:341-355.

Rice, M.R., and G.H. Balazs. 2008. Diving behavior of the Hawaiian green turtle (*Chelonia mydas*) during oceanic migrations. Journal of Experimental Marine Biology and Ecology. 356(1-2):121-127.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego. 576 p.

Richter, C.F., S.M. Dawson and E. Slooten. 2003. Sperm whale watching off Kaikoura, New Zealand: effects of current activities on surfacing and vocalisation patterns. Science for Conservation 219. Department of Conservation, Wellington. 78 p. Available at http:// www.doc.govt.nz/Publications/004~Science-and-Research/Science-for-Conservation/PDF/SFC219.pdf.

Ridgway, S.H., E.G. Wever, J.G. Mccormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. Proceedings of the National Academy of Sciences 64:884-890.

Ritz, T., D.H. Dommer, and J.B. Phillips. 2002. Shedding light on vertebrate magnetoreception. Neuron:503-506.

Ritz, T., P. Thalau, J.B. Phillips, R. Wiltschko, and W. Wiltschko. 2004. Resonance effects indicate a radical-pair mechanism for avian magnetic compass. Nature 429:177-180.

Ritz, T., S. Adem, and K. Schulten. 2000. A model for photoreceptor-based magnetoreception in birds. Biophysical Journal 78:707-718.

Riveros, A.J and R.B. Srygley. 2010. Magnetic compasses in insects. Encyclopedia of Animal Behavior 2:305-313.

Rodgers, C.T., and P.J. Hore. 2009. Chemical magnetoreception in birds: The radical pair mechanism. www.pnas.org/cgi/doi/10.1073/pnas.0711968106.

Rodríguez, A. and B. Rodríguez. 2009. Attraction of petrels to artificial lights in the Canary Islands: effects of the moon phase and age class. Ibis 151:299-310.

Rogan, E, J.R. Baker, P.D. Jepson, S. Berrow, and O. Kiely. 1997. A mass stranding of white-side dolphins (*Lagenorhynchus acutus*) in Ireland: biological and pathological studies. Journal of Zoology 242:217-227.

Rommel, S.A., and J.D. McCleave. 1973. Sensitivity of American eels (*Anguilla rostrata*) and Atlantic salmon (*Salmo salar*) to weak electric and magnetic fields. Journal of the Fisheries Research Board of Canada 30:657-663.

Rommel, S.A., Jr. and J.D. McCleave. 1973. Prediction of oceanic electric fields in relation to fish migration. ICES Journal of Marine Science 35:27-31.

Ronconi, R.A., Koopman, H.N., McKinstry, C.A.E., Wong, S.N.P, and Westgate, A.J. 2010b. Inter-annual variability in diet of non-breeding pelagic seabirds *Puffinus* spp. at migratory staging areas: evidence from stable isotopes and fatty acids. Marine Ecology Progress Series, 419: 267-282.

Ronconi, R.B., Ryan, P.G., and Ropert-Coudert, Y. 2010a. Diving of great shearwaters (*Puffinus gravis*) in cold and warm water regions of the South Atlantic Ocean. PLos One, 5(11; e15508): 7p.

Ross, G.L. and H. Markowitz. 2001. Behavioral responses of Hawaiian spinner dolphins, *Stenella longirostris*, to vessel presence at midway atoll, National Wildlife Refuge. Abstract presented at the Fourteenth Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 2001, Vancouver, Canada. p. 184.

Ross, J.P., S. Beavers, D. Mundell, and M. Airth-Kindree. 1989. The status of Kemp’s ridley. Center for Marine Conservation, Gainsville, Florida. 51 p.

Rowe, G.T. and M.C. Kennicutt. 2001. Deepwater program: Northern Gulf of Mexico continental slope habitat and benthic ecology. Year 1: Interim report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS-2001-091. 166 p.

Rowe, G.T. and M.C. Kennicutt. 2002. Deepwater program: Northern Gulf of Mexico continental slope habitat and benthic ecology. Year 2: Interim report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS-2002-063. 158 p.

Russell, R. W. 2005. Interactions between migrating birds and offshore oil and gas platforms in the northern Gulf of Mexico: Final Report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2005-009. 348 p.

Sakaki, Y., T. Motomiya, M. Kato., and M. Ogure. 1990. Possible mechanism of biomagnetic sense organ extracted from sockeye salmon. IEEE Trans. Magn. 26:1554-1556.

Sakamoto, W., I. Uchida, Y. Naito, K. Kureha, M. Tujimura, and K. Sato. 1990a. Deep diving behavior of loggerhead turtle near the frontal zone. Nippon Suisan Gakkaishi 56: 435-442.

Sakamoto, W., Y. Naito, I. Uchida, K. Kureha. 1990b. Corcadian rhythm on diving motion of the loggerhead turtle *Carette carette* during internesting and its fluctuations induced by the oceanic environmental events. Nippon Suisan Gakkaishi 56: 263.

Salden, D.R. 1993. Effects of research boat approaches on humpback whale behavior off Maui, Hawaii, 1989–1993. p. 94 *In*: Abstr. 10th Bienn. Conf. Biol. Mar. Mamm., Galveston, TX, Nov. 1993. 130 p.

Salmon, M., and J. Wyneken. 1987. Orientation and swimming behavior of hatchling loggerhead turtles (*Caretta caretta* L. during their offshore migration. Journal of Experimental Marine Biology and Ecology 109:137-153.

Salmon, M., and K.J. Lohmann. 1989. Orientation cues used by hatchling loggerhead sea turtles (*Caretta caretta*) during their offshore migration. Ethology 83:215-228.

Salmon, M., J. Wyneken, E. Fritz, and M. Lucus. 1992. Seafinding by hatchling sea turtles: role of brightness, silhouette and beach slope as orientation cues. Behavior 122:56-77.

Scarpaci, C., D. Nugegoda and P.J Corkeron. 2001. Behavioural studies of dolphins and dolphin watchers in Port Phillip Bay, Australia. Abstract presented at the Fourteenth Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 2001, Vancouver, Canada. 189 p.

Scarpaci, C., S.W. Bigger, P.J. Corkeron and D. Nugegoda. 2000. Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of 'swim-with-dolphin' tour operations. J. Cetacean Res. Manage. 2(3):183-185.

Scheidat, M., C. Castro, J.Gonzalez, and R. Williams. 2004. Behavioural responses of humpback whales (*Megaptera novaeangliae*) to whalewatching boats near Isla de la Plata, Machalilla National Park, Ecuador. J. Cetacean Res. Manage. 6: 63-68.

Schlegel, K. and M. Füllekrug. 2002. 50 years of Schumann Resonance. Physik in unserer Zeit 33(6):256-269. [Transl. C. Geoghan 2007]

Schmidt, D.E., and H.E. Esch. 1993. Magnetic orientation of honeybees. Naturwissenschaften 80:41-43.

Schmidt-Koenig, K. 1961. Die Sonne als Kompaß im Heim-Orientierungssystem der Brieftauben. Z. Tierpsychol. 18:221-244.

Schmidt-Koenig, K. 1990. The sun compass. Experientia 46:336-342.

Schorr, G.S., Falcone, E.A., Moretti, D.J., Baird, R.W., Webster, D.L., Hanson, M.B., and Andrews, R.D. 2011. Satellite telemetry reaches new depths: A case study of the application of a new depth-linked satellite tag to Cuvier's beaked whales. Poster presentation at the Fourth International Science Symposium on Bio-logging, Hobart, Tasmania, March 2011. Available at: http://www.cascadiaresearch.org/reports/Schorr_et_al_2011_bio-loggingposter.pdf.

Schreer, J.F., and K.M. Kovacs. 1997. Allometry of diving capacity in air-breathing vertebrates. Canadian Journal of Zoology 75:339-358.

Schulten, K. 1982. Magnetic field effects in chemistry and biology. Pages 61-83 *in* J. Treusch, editor. Advances in Solid State Physics, Volume 22. Viewig, Braunschweig.

Schulten, K., and A. Windemuth. 1986. Model for physiological magnetic compass. Pages 99-106 *in* G. Maret, editor. Biophysical Effects of Steady Magnetic Fields. Springer-Verlag, Berlin.

Sears, C.J., B.W. Bowen, R.W. Chapman, S.B. Galloway, S.R. Hopkins-Murphy, and C.M. Woodley. 1995. Demographic composition of the feeding population of juvenile loggerhead sea turtles (*Caretta caretta*) off Charleston, South Carolina: evidence from mitochondrial DNA markers. Marine Biology 123:869.

Semm, P., and R.C. Beason. 1990. Responses to small magnetic variations by the trigeminal systm of the bobolink. Brain Research Bulletin 25:735-740.

Sergeant, D.E. 1991. Harp Seals, man and ice. Canadian Special Publications of Fisheries and Aquatic Sciences 114: 153 p.

Shaffer, S.A., Tremblay, Y., Weimerskirch, H., Scott, D., Thompson, D.R., Sagar, P.M., Moller, H., Taylor, G.A., Foley, D.G., Block, B.A., and Costa, D.P. 2006. Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. Proceedings of the National Academy of Sciences of the United States of America, 103(34): 12799-12802. *In* Ronconi, R.A., Koopman, H.N., McKinstry, C.A.E., Wong, S.N.P, and Westgate, A.J. 2010b. Inter-annual variability in diet of non-breeding pelagic seabirds *Puffinus* spp. at migratory staging areas: evidence from stable isotopes and fatty acids. Marine Ecology Progress Series, 419: 267-282.

Shantsev, D.V., F. Roth, C. Twarz, A. Frisvoll, and A.K. Nguyen. 2010. Shallow water CSEM using a surface-towed source. 72nd EAGE Conference & Exhibition incorporating SPE EUROPEC 2010, Barcelona, Spain, 14 - 17 June 2010.

Shaver, D.J. 1998. Sea turtle strandings along the Texas coast, 1980- 94. United States Department of Commerce, NOAA Tech. Rep. NMFS 143: 57-72.

Shirihai, H. 2002. A complete guide to Antarctic wildlife: The birds and marine mammals of the Antarctic continent and the Southern Ocean. Kirwan, G.M. (ed.). ALULA Press Oy, Finland. 510p.

Shirihai, H. 2006. Princeton Field Guides: Whales, dolphins, and other marine mammals of the world. Kirwan, G.M. (ed.). Princeton University Press, Princeton, NJ. 384p.

Singh, K. H. W. Kuang, T.J. Sabaka, A.V Kuvshinov. 2009. Oceanic magnetic anomalies induced from Kuroshio currents. American Geophysical Union, Fall Meeting, 2009.

Smith, E.D. 1974. Electrophysiology of the electrical shark-repellent. T Inst Elect Engineers. August:166-181.

Smith, E.D. 1991. Electrical shock barrier: initial trials and prospects. Power Eng. July:167-176.

Smith, W.G., 1968. A neonate Atlantic loggerhead turtle, *Caretta caretta*, captured at sea. Copeia 4:880.

So, P.P.M., M.A. Stuchly, and J.A. Nyenhuis, 2004. Peripheral nerve stimulation by gradient switching fields in magnetic resonance imaging. IEEE Transactions on Biomedical Engineering 51:1907-1914.

Soma, R. 1985. Radio biotelemetry system applied to migratory study of turtle. Journal of the Faculty of Marine Science Technology Tokai University 21:47.

Sousa-Lima, R.S., M.E. Morete, R.C. Fortes, A.C. Freitas and M.H. Engel. 2002. Impact of boats on the vocal behavior of humpback whales off Brazil. Journal of the Acoustical Society of America Vol. 112(5, Pt. 2):2430.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals 33(4):411-522.

Southern, W. E. 1972. Influence of disturbances in the earth's magnetic field on Ring-billed Gull orientation. Condor 74:102-105.

Southern, W. E. 1974. The effects of superimposed magnetic fields on gull orientation. Wilson Bulletin 86:256-271.

Spraker, T.R., L.F. Lowry and K.J. Frost. 1994. Gross necropsy and histopathological lesions found in harbor seals. pp. 281-311. *In:* T.R. Loughlin (ed.). Marine mammals and the Exxon Valdez. Academic Press, San Diego. 395 p.

St. Aubin, D.J. 1990. Physiologic and toxic effects on polar bears. pp. 235-239. *In:* J.R. Geraci and D.J. St. Aubin (eds.), Sea mammals and oil: confronting the risks. Academic Press, San Diego. 282 p.

Standora, E.A., J.R. Spotila, J.A. Keinath, and C.R. Schoop. 1984. Body temperatures, diving cycles, and movement of a subadult leatherback turtle, *Dermochelys coriacea*. Herpetology 40:169-176.

Stapput, K., M. Gesson, R. Wiltschko, and W. Wiltschko. 2005. Light-dependent magnetoreception: behavior of migratory birds under monochromatic and bichromatic lights. *In*: Orientation and Navigation. RIN 05 Proceedings Reading. England: Royal Institute of Navigation.

Stapput, K., O. Güntürjün, K.-P. Hoffmann, R. Wiltschko, and W. Wiltschko. 2010. Current Biology 20:1259-1262.

Stapput, K., P. Thalau, R. Wiltschko, and W. Wiltschko. 2008. Orientation of birds in total darkness. Current Biology 18:602-606.

Stephenson, D. and K. Bryan. 1992. Large-scale electric and magnetic fields generated by the Oceans. Journal of Geophysical Research 97 (C10):15467-15480.

Stinson, M.L. 1984. Biology of sea turtles in San Diego Bay, California, and the northeastern Pacific Ocean. Master's Thesis, San Diego State University. 578 p.

Stockin, K.A., D. Lusseau, V. Binedell, N. Wiseman, and M.B. Orams. 2008. Tourism affects the behavioural budget of the common dolphin *Delphinus* sp. in the Hauraki Gulf, New Zealand. Mar. Ecol. Prog. Ser. 355:287-295.

Stryer, I. 1988. Biochemistry. W.H. Freeman, New York.

Suryan, R.M. and J.T. Harvey. 1999. Variability in reactions of Pacific harbor seals, *Phoca vitulina richardsi*, to disturbance. Fish. Bull. 97(2):332-339.

Swimmer, Y., R. Arauz, M. McCracken, L. McNaughton, J. Ballestero, M. Musyl, K. Bigelow, and R. Brill. 2006. Diving behavior and delayed mortality of olive ridley sea turtles *Lepidochelys olivacea* after their release from longline fishing gear. Marine Ecology Progress Series 323:253-261.

Taylor, P.B. 1986. Experimental evidence for geomagnetic orientation in juvenile salmon, *Oncorhynchus tschawytscha* Walbaum. Journal of Fishery Biology 28:607-623.

Taylor, P.B. 1987. Experimental evidence for juvenile Chinook salmon, *Oncorhynchus tshawytscha* Walbaum, orientation at night and in sunlight after a 7º change in latitude. Journal of Fish Biology 31:89-111.

Teas, W.G. 1994. Marine turtle stranding trends, 1986-1993. Pages 293-295 *in* K.A. Bjorndal, A.B. Bolton, D.A. Johndon, and P.J. Eliazar, compilers. Proceedings of the 14th Annual Symposium on Sea Turtle Biology and Conservation. NOAA Techinal Memorandum NMFS-SEFSC-351.

Telfer, T. C., J. L. Sincock, G. V. Byrd, and J. R. Reed. 1987. Attraction of Hawaiian seabirds to lights: conservation efforts and effects of moon phase. Wildlife Society Bulletin 15:406-413.

Terhune, J.M. and W.C. Verboom. 1999. Right whales and ship noises. Mar. Mamm. Sci. 15(1): 256-258.

Thalau, P., T. Ritz, K. Stapput, R. Wiltschko, and W. Wiltschko. 2005. Magnetic compass orientation of migratory birds in the presence of a 1.315 MHz oscillating field. Naturwissenschaften 92:86-90.

Thorup, K., and R. A. Holland. 2009. The bird GPS – long-range navigation in migrants. Journal of Experimental Biology 212:3597-3604.

Tremblay, Y., Guinard, E., and Cherel, Y. 1997. Maximum diving depths of northern rockhopper penguins (*Eudyptes chrysocome moseleyi*) at Amsterdam Island. Polar Biology, 17: 119-122.

Tricas, T.C. 2001. The neuroecology of the elasmobranch electrosensory world: why peripheral morphology shapes behavior. Environmental Biology of Fishes 60:77-92.

Tricas, T.C., and J.G. New. 1998. Sensitivity and response dynamics of elasmobranch electrosensory primary afferent neurons to near threshold fields. Journal of Comparative Physiology A 182:89-101.

Tsurutani, Bruce T. and Walter D. Gonzalez (1993), —The Causes of Geomagnetic Storms During Solar Maximum, *EOS* 79.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. Journal of Mammalogy 89(3):549-558.

Tyler, R.H. and Mysak, L.A. 1997. Electromagnetic fields generated by a three dimensional global ocean circulation. *Journal of Geophysical Research*, 102(C3):5531-5551.

Ugolini, A., and A. Pezzani. 1992. Learned solar orientation in *Idotea baltica*. Mesogee 52:77

University of California. 1996. MacroWorlds: Exploring the Structure of Material. Berkley Laboratory, University of California, CA. http://www.lbl.gov.MacroWorlds/ ALSTool/ EMSpec?EMSpec2.html

USFWS (U.S. Fish and Wildlife Service). 2011a. Hawksbill sea turtle fact sheet. http://www.fws.gov/northflorida/SeaTurtles/Turtle%20Factsheets/hawksbill-sea-turtle.htm

USFWS. 2011b. Olive ridely sea turtle fact sheet. http://www.fws.gov/northflorida/SeaTurtles/Turtle%20Factsheets/oliveridley-sea-turtle.htm

Uttley, J., Monaghan, P., and White, S. 1989. Differential effects of reduced sandeel availability on two sympatrically breeding species of tern. Ornis Scandinavica, 20: 273-277.

van Rhijn, F.J., and J.C. van Gorkom. 1983. Optic orientation in hatchlings of the sea turtle, Chelonia mydas/ III. Sea-finding behavior: the role of photic and visual orientations in animals walking on the spot under laboratory conditions. Marine Behavior and Physiology 9:211-?

Vanderlaan, A.S.M. and C.T. Taggart. 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Marine Mammal Science 23(1):144-156.

Vanselow, K.H., and K. Ricklefs. 2005. Are solar activity and sperm whale *Physeter macrocephalus* strandings around the North Sea related? Journal of Sea Research 53:319-327.

Vanselow, K.H., K. Ricklefs, and F. Colijn. 2009. Solar driven geomagnetic anomalies and sperm whale (*Physeter macrocephalus*) strandings around the North Sea: An analysis of long term datasets. The Open Marine Biology Journal. 3:89-94.

Viguier, C. 1882. Le sens deL'orientation et ses organes chez les animaux et chez l'homme. Rev Phil France Estranger 14:1-36.

Vitale, L. 1995. Electromagnetic Field Fundamentals. Presented to the New York Interagency Engineering Council, May 17, 1995. VitaTech Engineering, Inc. http://www.mnsinc.com/ emf/pub7.html.

von Arx. 1962. A Introduction to Physical Oceanography. Addison-Wesley, London.

von der Emde, G. 1998. Electroreception. Pages 313-343 *in* D.H. Evans, editor. The Physiology of Fishes. CRC Press, Boca Raton.

von Middendorff, A. 1859. Die Isepiptesen Rufslands. Mem Acad Sci St Petersbourg VI Ser Tome 8:1-143.

Walcott, C. 1996. Pigeon homing: Observations, experiments and confusions. Journal of Experimental Biology 199:21-27.

Walcott, C. 2005. Multi-modal orientation cues in homing pigeons. Integrative Comparative Biology 45:574-581.

Walcott, C., J.L. Gould, and J.L. Kirschvink. 1979. Pigeons have magnets. Science 205:1027-1029.

Walker, M.C., C.E Diebel, J.L. Kirschvink. 2003. Detection and use of the Earth's magnetic field by aquatic vertebrates. Chapter 3. Pages 53-74 *in* S.P. Collins and N.J. Marshall, editors. Sensory Processing in Aquatic Environments. Springer.

Walker, M.M. 1984. Learned magnetic field discrimination in yellowfin tuna, *Thunnus albacares*. Journal of Comparative Physiology A 155:673-679.

Walker, M.M. 1997. Structure and function of the vertebrate magnetic sense. Nature 390:371-376.

Walker, M.M., and M.E. Bitterman. 1989. Honeybees can be trained to respond to very small changes in geomagnetic field intensity. Journal of Experimental Biology 145:489-494.

Walker, M.M., J.L. Kirschvink, G. Ahmed, and A.E. Diction. 1992. Evidence that fin whales respond to the geomagnetic field during migration. Journal of Experimental Biology 171:67-78.

Walker, M.M., T.P. Quinn, J.L. Kirschvink, and C. Groot. 1988. Production of single-domain magnetite throughout life by sockeye salmon, *Oncorhynchus nerka*. Journal of Experimental Biology 140:51-63.

Wallraff, H.D. 1991. Conceptual approaches to avian navigation systems. Pages 128-165 *in* P. Berthold, editor. Orientation in Birds. Basel, Switzerland:Birkhäuser.

Wang, J.H., J.K. Jackson and K.J. Lohmann. 1998. Perception of wave surge motion by hatchling sea turtles. Journal of Experimental Marine Biology and Ecology 229:177-1986.

Wanless, S., Barton, T.R., and Harris, M.P. 1997a. Blood hematocrit measurements of 4 species of North Atlantic seabirds in relation to levels of infestation by the tick *Ixodes uriae*. Colonial Waterbirds, 20(3): 540-544.

Wanless, S., Harris, M.P., Buger, A.E., and Buckland, S.T. 1997b. Use of time-at-depth recorders for estimating depth and diving performance of European shags. Journal of Field Ornithology, 68(4): 547-561.

Warkentin, I. and Newton, S. 2009. Birds of Newfoundland: Field guide. Boulder Publications. Portugal Cove-St. Philip’s, NL. 237p.

Watanuki, Y. 1986. Moonlight avoidance behavior in Leach's Storm-Petrels as a defense against slaty-backed gulls. Auk 103:14-22.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammals Science 2(4):251-262.

Weimerskirch, H. and Y. Cherel, Y. 1998. Feeding ecology of short-tailed shearwaters: breeding in Tasmania and foraging in the Antarctic? Marine Ecology Progress Series 167: 261–274.

Wershoven, R.W., and J.L. Wershoven. 1991. Stomach content analysis of stranded juvenile and adult green turtles in Broward and Palm Beach Counties, Florida. Pages 124-126 *in Proceedings of the 11th Annual Workshop on Sea Turtle Biology and Conservation*. NOAA Technical Memorandum NMFS-SEFSC-302. U.S. Department of Commerce.

Whitehead, D. 2002. Electric field measurements in Cook Strait (New Zealand) and Bass Strait (northern Tasmanian Coast) in relation to elasmobranch distribution. In: Final Environmental Impact Statement and Supplement to the Draft Integrated Impact Assessment Statement, June 2002, Basslink Pty.Ltd.

Williams, R., D.E. Bain, J.C. Smith and D. Lusseau. 2009. Effects of vessels on behaviour patterns of individual southern resident killer whales *Orcinus orca*. Endangered Species Research 6:199-209.

Williams, T.D., Briggs, D.R., Croxall, J.P., Naito, Y., and Kato, A. 1992. Diving pattern and performance in relation to foraging ecology in the gentoo penguin, *Pygoscelis papua*. Journal of the Zoological Society of London, 227: 211-230.

Williams, U., and J. Chardine. n.d. The Leach's Storm-Petrel: General information and handling instruction. Petro-Canada, St. John's, NL. 3 p.

Wilson, R.P., Bost, C.A., Pütz, K., Charrassin, J.-B., Culik, B.M., and Adelung, D. 1997. Southern rockhopper penguin *Eudyptes chrysocome chrysocome* foraging at Posession Island. Polar Biology, 17: 323-329.

Wilson, R.P., Culik, B.M., Coria, N.R., Adelung, D., and Spairani, H.J. 1989. Foraging rhythms in Adelie penguins (*Pygoscelis adeliae*) at Hope Bay, Antarctica; determination and control. Polar Biology, 10: 161-165. *In* Wanless, S., Barton, T.R., and Harris, M.P. 1997. Blood hematocrit measurements of 4 species of North Atlantic seabirds in relation to levels of infestation by the tick *Ixodes uriae*. Colonial Waterbirds, 20(3): 540-544.

Winklhofer, M and J.L. Kirschvink. 2010. A quantitative assessment of torque-transducer models for magnetoreception. Journal of the Royal Society Interface 7: 273-289.

Wiltschko, R., and W. Wiltschko. 1981. The development of sun compass orientation in young homing pigeons. Behaviour in Ecological Sociobiology 9:135-141.

Wiltschko, R., and W. Wiltschko. 1998. Pigeon homing: effect of various wavelengths of light during displacement. Naturwissenschaften 85:164-167.

Wiltschko, R., D Gehring, S. Denzau, O. Güntürkün. 2010. Interaction of magnetite based receptors in the beak with the visual system underling ‘fixed direct’ responses in birds. Frontiers in Zoology 7:24-29.

Wiltschko, R., C. Haugh, M. Walker, and W. Wiltschko. 1998. Pigeon homing: sun compass use in the southern hemisphere. Behavioral Ecology and Sociobiology 43:297-300.

Wiltschko, R., K. Stapput, T. Ritz, P. Thalau, and W. Wiltschko. 2007. Magnetoreception in birds: different physical processes for two types of directional responses. HFSP Journal 1:41-47.

Wiltschko, R., R. Kumpfmüller, R., R. Muth, and W. Wiltschko. 1994. Pigeon homing: the effect of a clock-shift is often smaller than predicted. Behaviour in Ecological Sociobiology 35:63-73.

Wiltschko, W. 1968. Über den Eisenfluß statischer Magnetfelder auf die Zugorientierung der Rotkenhlchen. *Erithacus rubecula*. Z. Tierpsychol 25:537-558.

Wiltschko, W., and F.W. Merkel. 1966. Orientierung zugunruhiger Rotkenlchen im statischen magnetfield. Verh Dtsch Zool Ges 59:362-367.

Wiltschko, R., T. Ritz, K. Stapput, P. Thalau, and W. Wiltschko. 2005. Two different types of light-dependent responses to magnetic fields in birds. Current Biology 15:1518-1523.

Wiltschko, W., and R. Wiltschko. 1972. Magnetic compass of European robins. Science 176:62-64.

Wiltschko, W., and R. Wiltschko. 1975. The interaction of stars and magnetic field in the orientation system of night migrating birds. I. Autumn experiments with European warblers (Gen. Gylvia). Z tierpsychol 37:337-355.

Wiltschko, W., and R. Wiltschko. 1995a. Magnetic Orientation in Animals. Springer-Verlag, Berlin.

Wiltschko, W., and R. Wiltschko. 1995b. Migratory orientation of European robins is affected by the wavelength of light as well as by a magnetic pulse. J. Comp. Physiol. A 177:363-369.

Wiltschko, W., and R. Wiltschko. 1996. Magnetic orientation in birds. The Journal of Experimental Biology 199:29-38.

Wiltschko, W., and R. Wiltschko. 1999. The effect of yellow and blue light on the magnetic compass orientation in European robins, Erithacus rubecula. Journal of Comparative Physiology A 184:295-299.

Wiltschko, R., and W. Wiltschko. 2009. Avian Navigation. Auk 126:717-743.

Wiltschko, W., P. Daum, A. Fergenbauer-Kimmel, and R. Wiltschko. 1987. The development of the star compass in Garden Warblers, *Sylvia borin*. Ethology 74:285-292.

Wiltschko, W., R. Wiltschko, W.T. Keeton, and R. Madden. 1983. Growing up in an altered magnetic field affects the initial orientation of young homing pigeons. Behaviour in Ecological Sociobiology 12:135-1542.

Wiltschko, W., U. Munro, H. Ford, and R. Wiltschko. 1993. Red light disrupts magnetic orientation of migratory birds. Nature 364:525-527.

Wilzeck, C., W. Wiltschlko, O. Güntürkün, J. Buschmann, R. Wiltschlko, and H. Prior. 2010. Learning magnetic compass directions in pigeons. Animal Cognition 13:443-451.

Witherington, B.E. 1995. Observations of hatchling loggerhead turtles during the first few days of the lost year(s). Pages 154-157 *in* Proceedings of the Twelfth Annual Sea Turtle Workshop on Sea Turtle Biology and Conservation (compilers J.I. Richardson and T.H. Richardson). NOAA Technical Memorandum NMFS-SEFSC-361.

Witherington, B.E., 1994. Some "lost year" turtles found. *In* Proceeding of the Thirteenth Annual Symposium. Sea Turtle Biology and Conservation, Schroeder, B.A., and Witherington, H.E., Compilers. NOAA Technical Memorandum NMFS-SEFSC-341.

Witzell, W.N. 1987. Selective predation on large cheloniid sea turtles by tiger sharks *Galeocerdo cuvier*. Japanese Journal of Herpetology 12:22-29.

Witzell, W.N., and J.R. Schmid. 2004. Immature sea turtles in Gullivan Bay, Ten Thousand Islands, southwest Florida. Gulf of Mexico Science 22: 54-61.

World Health Organization. 2005. Electromagnetic Fields. WHO Information Fact Sheet 205. Revised 1998. http://www.who.int/inf-fs/rn/fact205.html.

Würsig, B., S.K. Lynn, T.A. Jefferson and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. Aquat. Mamm. 24: 41-50.

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. Aquat. Mamm. 24(1):41-50.

Wyneken, J., M. Salmon, and K.J. Lohmann. 1990. Orientation by hatchling loggerhead sea turtles *Caretta caretta* L. in a wave tank. Journal of Experimental Marine Biology and Ecology 139:43-50.

Wyneken, J.. 1997. Diving physiology. Pages 165-198 *in* P.L. Lutz and J.A. Musick, editors. The Biology of Sea Turtles. CRC Press, Boca Raton.

Yang, H. and V.P. Pasko. 2006. Three-dimensional finite difference time domain modeling of the diurnal and seasonal variations in Schumann resonance parameters. Radio Science 41:1-10.

Yano, A., M. Ogura, A. Sato, Y. Sakaki, Y. Shimizu, N. Baba, and K. Nagasawa. 1997. Effect of modified magnetic field on the ocean migration of maturing chum salmon, *Oncorhynchus keta*. Marine Biology 129:523-530.

Yeagley, H.L. 1947. A preliminary study of a physical basis of bird navigation. Part I. Journal of Applied Physics 18:1035-1063.

Yorke, E.D. 1979. Possible magnetic transducer in birds. Journal of Theoretical Biology 77:101-105.

Zimmerman, M.A., and J.D. McCleave. 1975. Orientation of elvers of American eels, *Anguilla rostrata*, in weal magnetic and electric fields. Helgol Wiss Meeresunters 27:175-189.

APPENDIX A - DIVING DEPTHS OF MARINE ANIMALS

Diving Depths of Seabirds Worldwide

Species	Species (Latin Name)	Distribution	Max Diving Depth (m)	Reference
Procellariidae				
Balearic Shearwater	*Puffinus mauretanicus*	Mediterranean	- Usually around 5 - Max recorded 26	Aguilar et al. 2003
Black-vented Shearwater	*Puffinus opisthomelas*	Pacific coast of North America	50	Keitt et al. 2000a Keitt et al. 2000b
Buller's Shearwater	*Puffinus bulleri*	Pacific Ocean (vagrant to west Atlantic Ocean)	Shallow	Shirihai 2002
Flesh-footed Shearwater	*Puffinus carneipes*	South Indian Ocean to North Pacific	Shallow	Shirihai 2002
Fluttering Shearwater	*Puffinus gavia*	South Australia to East New Zealand	Shallow	Shirihai 2002
Greater Shearwater	*Puffinus gravis*	North and South Atlantic	- Usually < 2 - Max recorded 18.9	Proctor and Lynch 2005 Ronconi et al. 2010a
Hutton's Shearwater	*Puffinus huttoni*	Coastal Australia to New Zealand	Shallow	Shirihai 2002
Little Shearwater	*Puffinus assimilis*	South Pacific, Atlantic, and Indian Oceans	Shallow	Shirihai 2002
Manx Shearwater	*Puffinus puffinus*	Northwestern, Northeastern, and Southwestern Atlantic	Shallow	Guilford et al. 2008 Warkentin and Newton 2009
Sooty Shearwater	*Puffinus griseus*	Atlantic, Pacific, and south Indian Oceans	- Usually < 10 - Max recorded > 60	Brown et al. 1978 Shirihai 2002 Shaffer et al. 2006 Ronconi et al. 2010b
Wedge-tailed Shearwater	*Puffinus pacificus*	Tropics	- Usually to 5 - Max recorded 11.72	Peck et al. 2004 Peck and Congdon 2006
Northern Fulmar	*Fulmarus glacialis*	North Atlantic and North Pacific	3	Hobson and Welch 1992 Proctor and Lynch 2005 Warkentin and Newton 2009
Southern Fulmar	*Fulmarus glacialoides*	Sub-Antarctic and coastal and insular Antarctica	Shallow	Shirihai 2002
Antarctic Petrel	*Thalassoica antarctica*	Coastal Antarctica, Southern Ocean	Shallow	Shirihai 2002
Atlantic Petrel	*Pterodroma incerta*	South Atlantic	Shallow	Shirihai 2002
Black Petrel	*Procellaria parkinsoni*	South Pacific	Shallow	Shirihai 2002
Black-winged Petrel	*Pterodroma nigripennis*	South Pacific Ocean	Shallow	Shirihai 2002
Blue Petrel	*Halobaena caerulea*	Circumpolar in Southern Ocean	Shallow	Shirihai 2002
Cape Petrel	*Daption capense*	Southern Ocean and southern hemisphere	Shallow	Shirihai 2002
Chatham Petrel	*Pterodroma axillaris*	East New Zealand	Shallow	Shirihai 2002

Species	**Species (Latin Name)**	**Distribution**	**Max Diving Depth (m)**	**Reference**
Cook's Petrel	*Pterodroma cookii*	South Pacific, around New Zealand (migrates as far as North Pacific)	Shallow	Shirihai 2002
De Filippi's Petrel	*Pterodroma defilippiana*	Southeast Pacific Ocean off southwest South America	Likely Shallow	Shirihai 2002
Gould's (White-winged) Petrel	*Pterodroma leucoptera*	Southwest Pacific Ocean off eastern Australia	Likely Shallow	Shirihai 2002
Gray Petrel	*Procellaria cinerea*	Circumpolar in sub-Antarctic	Shallow	Shirihai 2002
Greater Snow Petrel	*Pagodroma* [*nivea*] *confusa*	Coastal and inland Antarctica	Shallow	Shirihai 2002
Juan Fernández Petrel	*Pterodroma externa*	Southeast Pacific	Likely Shallow	Shirihai 2002
Kerguelen Petrel	*Pterodroma* (*Aphrodroma* or *Lugensa) brevirostris*	South Atlantic and South Indian Oceans	Shallow	Shirihai 2002
Lesser Snow Petrel	*Pagodroma* [*nivea*] *nivea*	Coastal and inland Antarctica	Shallow	Shirihai 2002
Magenta Petrel	*Pterodroma magentae*	East New Zealand	Presumed Shallow	Shirihai 2002
Mottled Petrel	*Pterodroma inexpectata*	Islands off New Zealand (migration: North Pacific and Gulf of Alaska in winter, to Indo-Pacific Antarctic ice in late summer)	Shallow	Shirihai 2002
Northern Giant Petrel	*Macronectes halli*	Southern Ocean	Shallow	Shirihai 2002
Pycroft's Petrel	*Pterodroma pycrofti*	North New Zealand	Presumed Shallow	Shirihai 2002
Soft-plumaged Petrel	*Pterodroma mollis*	South Atlantic and South Indian Oceans	Shallow	Shirihai 2002
Southern Giant Petrel	*Macronectes giganteus*	Southern Ocean	Shallow	Shirihai 2002
Spectacled Petrel	*Procellaria* [*aequinoctialis*] *conspicillata*	Southern Ocean (from eastern South America to western Australia)	Presumed 13	Shirihai 2002
Stejneger's Petrel	*Pterodroma longirostris*	North to Southeast Pacific Ocean	Likely Shallow	Shirihai 2002
Westland Petrel	*Procellaria westlandica*	Southwestern Australia to South America	Shallow	Shirihai 2002
White-chinned Petrel	*Procellaria aequinoctiali*	Southern Ocean	13	Shirihai 2002
White-headed Petrel	*Pterodroma lessonii*	Southern Ocean	Shallow	Shirihai 2002
Antarctic Prion	*Pachyptila desolata*	Antarctic waters (widespread)	Shallow	Shirihai 2002
Broad-billed Prion	*Pachyptila vittata*	South Atlantic (Southwest Africa) and New Zealand	Shallow	Shirihai 2002
Fairy Prion	*Pachyptila turtur*	South Atlantic (southeast South America), South Indian, and southeast Australia to New Zealand	Shallow	Shirihai 2002
Fulmar Prion	*Pachyptila crassirostris*	Mid-south Indian Ocean, and New Zealand	Shallow	Shirihai 2002
Saint Paul Prion	*Pachyptila* [*vittata/salvini*] *macgillivrayi*	Southern Ocean (St. Paul)	-	Shirihai 2002
Salvin's Prion	*Pachyptila salvini*	South Indian Ocean (southwest Africa to New Zealand)	Shallow	Shirihai 2002
Slender-billed Prion	*Pachyptila belcheri*	Southern Ocean	Shallow	Shirihai 2002
Hydrobatidae				
Black-bellied Storm-petrel	*Fregetta tropica*	Circumpolar in Antarctic	Near Surface	Shirihai 2002

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Gray-backed Storm-petrel	*Oceanites nereis*	Southern Ocean	Shallow	Shirihai 2002
Leach's Storm-petrel	*Oceanodroma leucorhoa*	Mid- to North- Atlantic and Pacific	Near Surface	Linton 1978 Elliott et al. 1992 Warkentin and Newton 2009
White-bellied Storm-petrel	*Fregatta grallaria*	South Pacific, Atlantic, and Indian Oceans	Shallow	Shirihai 2002
White-faced Storm-petrel	*Pelagodroma marina*	South Atlantic, Indian, and Pacific Oceans	Near Surface	Shirihai 2002
Wilson's Storm-petrel	*Oceanites oceanicus*	Pacific, Indian, and Atlantic Oceans	Near Surface	Croxall and Prince 1980 Warkentin and Newton 2009
Pelecanoididae				
Common Diving-petrel	*Pelecanoides urinatrix*	South Atlantic (mid, and southeast South Africa), and mid-south Indian Oceans, and southeast Australia to New Zealand	Shallow	Shirihai 2002
Magellanic Diving-petrel	*Pelecanoides magellani*	Southern South America	Shallow	Shirihai 2002
South Georgian Diving-petrel	*Pelecanoides georgicus*	Mid-south Atlantic and Indian Oceans, and south New Zealand	Shallow	Shirihai 2002
Sulidae				
Australasian Gannet	*Morus serrator*	South and southeast Australia to Indian Ocean	20	Shirihai 2002
Cape Gannet	*Morus capensis*	South Africa to Indian Ocean	Presumed 20	Shirihai 2002
Northern Gannet	*Morus bassanus*	Northwest and Northeast Atlantic	10	Lewis et al. 2002 Warkentin and Newton 2009
Phalaropodinae				
Red Phalarope	*Phalaropus fulicarius*	Circumpolar	0	Ainley and Sanger 1979 Briggs et al. 1984 Warkentin and Newton 2009
Red-necked Phalarope	*Phalaropus lobatus*	Circumpolar	0	Ainley and Sanger 1979 Warkentin and Newton 2009
Laridae				
Antarctic Tern	*Sterna vittata*	South Atlantic and Indian Oceans, and south New Zealand	Shallow	Shirihai 2002
Arctic Tern	*Sterna paradisaea*	Circumpolar	Near Surface	Uttley et al. 1989 Warkentin and Newton 2009
Common Tern	*Sterna hirundo*	Northern hemisphere	Near Surface	Uttley et al. 1989 Warkentin and Newton 2009

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Kerguelen Tern	*Sterna virgata*	Prince Edward, Marion, Crozet, and Kerguelen Islands in south Indian Ocean	Shallow	Shirihai 2002
White-fronted Tern	*Sterna striata*	Southeastern Australia and New Zealand	Shallow	Shirihai 2002
Black-legged Kittiwake	*Rissa tridactyla*	Circumpolar	Near Surface	Wanless et al. 1997a Warkentin and Newton 2009
South American Tern	*Sterna hirundinacea*	Coasts of mid- to southern South America	Shallow	Shirihai 2002
Black-billed Gull	*Larus bulleri*	New Zealand	Shallow	Shirihai 2002
Brown-hooded Gull	*Larus maculipennis*	Coasts of mid- to southern South America	Shallow	Shirihai 2002
Dolphin Gull	*Larus scoresbii*	Coastal south Chile and Argentina to islands of Cape Horn and Falklands	0	Shirihai 2002
Glaucous Gull	*Larus hyperboreus*	Circumpolar	Near Surface	Erikstad 1990 Warkentin and Newton 2009
Great Black-backed Gull	*Larus marinus*	Circumpolar	Near Surface	Camphuysen and Webb 1999 Warkentin and Newton 2009
Herring Gull	*Larus argentatus*	Around North America	Near Surface	Camphuysen and Webb 1999 Warkentin and Newton 2009
Iceland Gull	*Larus glaucoides*	Northwest Atlantic	Near Surface (Coastal)	de Graaf et al. 1985 Warkentin and Newton 2009
Ivory Gull	*Pagophila eburnea*	Arctic	Near Surface	Divoky 1976 Warkentin and Newton 2009
Kelp Gull	*Larus dominicanus*	South America, Africa, and Australia, New Zealand, South Atlantic and Indian Oceans, and coastal Antarctica	Shallow	Shirihai 2002
Red-billed Gull	*Larus scopulinus*	Coasts and islands of New Zealand	Shallow	Shirihai 2002
Silver Gull	*Larus novaehollandiae*	Coasts and islands of Australia	Shallow	Shirihai 2002
Chilean Skua	*Catharacta* [*skua*] *chilensis*	Coasts and islands of south-central Chile and south Argentina to Cape Horn	Near Surface	Shirihai 2002
Falkland Skua	*Catharacta* [*skua*] *antarctica*, subspecies *antarctica*	Falklands and South Argentina	0	Shirihai 2002
Great Skua	*Stercorarius skua*	North and South Atlantic	Near Surface	Evans 1982 Warkentin and Newton 2009
South Polar Skua	*Catharacta maccormicki*	Antarctic (North Atlantic during summer)	Near Surface	Proctor and Lynch 2005 Hahn et al. 2008

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Subantarctic Skua	*Catharacta* [*skua*] *antarctica*, subspecies *lonnbergi*	Southern Ocean to the Lesser Antilles (Atlantic Ocean)	0	Shirihai 2002
Tristan Skua	*Catharacta* [*skua*] *antarctica*, subspecies *hamiltoni*	Gough, Inaccessible, and Tristan Islands	0	Shirihai 2002
Long-tailed Jaeger	*Stercorarius longicaudus*	Circumpolar	0	Hoffman et al. 1981 Warkentin and Newton 2009
Parasitic (Arctic) Jaeger (Arctic Skua)	*Stercorarius parasiticus*	Circumpolar	0	Hoffman et al. 1981 Warkentin and Newton 2009
Pomarine Jaeger (Pomarine Skua)	*Stercorarius pomarinus*	Circumpolar	Near Surface	Burger 2003 Warkentin and Newton 2009
Alcidae				
Atlantic Puffin	*Fratercula arctica*	North Atlantic	- Usually < 50 - Max 180	Piatt and Nettleship 1985 Elliott et al. 1992 Warkentin and Newton 2009
Black Guillemot	*Cepphus grylle*	Circumpolar	- Usually < 30 - Max 50	Piatt and Nettleship 1985 Warkentin and Newton 2009
Common Murre	*Uria aalge*	Northwest Atlantic	- Usually to 60 - Max 180	Piatt and Nettleship 1985 Wanless et al. 1997a Warkentin and Newton 2009
Thick-billed Murre	*Uria lomvia*	Northwest Atlantic	- Usually < 100 - Max 210	Croll et al. 1992 Wanless et al. 1997a Warkentin and Newton 2009
Dovekie	*Alle alle*	Northwest Atlantic	- Usually around 30 - Max 35	Falk et al. 2000 Warkentin and Newton 2009
Razorbill	*Alca torda*	North Atlantic	120	Piatt and Nettleship 1985 Wanless et al. 1997a Warkentin and Newton 2009
Spheniscidae				
Adélie Penguin	*Pygoscelis adeliae*	Antarctic	- Usually 20 to 40 - Max 175	Wilson et al. 1989 Wanless et al. 1997a Shirihai 2002
African Penguin	*Spheniscus demersus*	Coastal South Africa	- Usually 30 - Max 130	Shirihai 2002
Blue Penguin	*Eudyptula minor*	Australia and New Zealand	30	Montague 1985 Braidwood 2009
Chinstrap Penguin	*Pygoscelis antarctica*	Sub-Antarctic	102	Bengston et al. 1993 Wanless et al. 1997a Shirihai 2002

Species	Species (Latin Name)	Distribution	Max Diving Depth (m)	Reference
Emperor Penguin	*Aptenodytes forsteri*	Coastal Antarctica	- Usually 50 - Max 500	Ancel et al. 1992 Wanless et al. 1997a Shirihai 2002
Erect Crested Penguin	*Eudyptes sclateri*	South New Zealand	-	Shirihai 2002
Fiordland Penguin	*Eudyptes pachyrhynchus*	South Australia and New Zealand	-	Shirihai 2002
Gentoo Penguin	*Pygoscelis papua*	Circumpolar (sub-Antarctic)	156	Williams et al. 1992
King Penguin	*Aptenodytes patagonicus*	High sub-Antarctic and low-latitude Antarctic zones	- Usually 25 - Max 322	Shirihai 2002
Little Penguin	*Eudytula minor*	South Australia and New Zealand	67	Montague 1985 Wanless et al. 1997a Shirihai 2002
Macaroni Penguin	*Eudyptes chrysolophus*	Sub-Antarctic (mid-western to mid-eastern hemispheres)	- Usually to 20 - Max 115	Shirihai 2002
Magellanic Penguin	*Spheniscus magellanicus*	Coastal South America (vagrant in south Australian region)	Likely Relatively Shallow	Shirihai 2002
Northern Rockhopper Penguin	*Eudyptes* [*chrysocome*] *moseleyi*	High sub-Antarctic	168	Tremblay et al. 1997 Shirihai 2002
Rockhopper Penguin	*Eudyptes chrysocome*	Circumpolar (sub-Antarctic)	66	Wilson et al. 1997 Shirihai 2002
Royal Penguin	*Eudyptes schlegeli*	Southwest New Zeland	135	Hull 2000 Shirihai 2002
Snares Penguin	*Eudyptes robustus*	South New Zealand	Relatively Shallow	Shirihai 2002
White-flippered Penguin	*Eudyptula* [*minor*] *albosignata*	South New Zealand	Likely Relatively Shallow	Shirihai 2002
Yellow-eyed Penguin	*Megadyptes antipodes*	South New Zealand	Approx. 44	Shirihai 2002 Mattern et al. 2007
Phalacrocoracidae				
Great Cormorant	*Phalacrocorax carbo carbo*	Nearly Cosmopolitan	30	Grémillet et al. 1998 Shirihai 2002
Little Pied Cormorant	*Phalacrocorax melanoleucos*	Indonesia, New Guinea, and New Caledonia, south to Australia and New Zealand	Shallow	Shirihai 2002
Pied Cormorant	*Phalacrocorax varius*	Australia and New Zealand	Presumed Relatively Shallow	Shirihai 2002
Antarctic Shag	*Phalacrocorax* [*atriceps*] *bransfieldensis*	Antarctic Peninsula region	Presumed Relatively Shallow	Shirihai 2002
Aukland Shag	*Phalacrocorax* [*campbelli*] *colensoi*	South New Zealand Islands	Shallow	Shirihai 2002
Bounty Shag	*Phalacrocorax* [*campbelli*] *ranfurlyi*	South New Zealand Islands	Shallow	Shirihai 2002
Campbell Shag	*Phalacrocorax* [*campbelli*] *campbelli*	South New Zealand Islands	Shallow	Shirihai 2002
Chatham Shag	*Phalacrocorax* [*carunculatus*] *onslowi*	New Zealand Islands (Chatham)	-	Shirihai 2002
Crozet Shag	*Phalacrocorax* [*atriceps*] *melanogenis*	Prince Edward, Marion, and Crozet Islands	Presumed Relatively Shallow	Shirihai 2002
European Shag	*Phalacrocorax aristotelis*	North Atlantic and Pacific Oceans	61	Wanless et al. 1997b Bird Forum 2009

Species	Species (Latin Name)	Distribution	Max Diving Depth (m)	Reference
Heard Shag	*Phalacrocorax* [*atriceps*] *nivalis*	Heard Island	Shallow	Shirihai 2002
Imperial Shag	*Phalacrocorax* [*atriceps*] *atriceps*	Southern South America	Presumed Relatively Shallow	Shirihai 2002
Kerguelen Shag	*Phalacrocorax* [*atriceps*] *verrucosus*	Kerguelen group	Presumed Relatively Shallow	Shirihai 2002
Macquarie Shag	*Phalacrocorax* [*atriceps*] *purpurascens*	Macquarie, Bishop, and Clerk Islands	Presumed Relatively Shallow	Shirihai 2002
Pitt Shag	*Phalacrocorax featherstoni*	New Zealand Islands (Chatham)	Relatively Shallow	Shirihai 2002
Rock Shag	*Phalacrocorax magellanicus*	Southern South America	Shallow	Shirihai 2002
South Georgian Shag	*Phalacrocorax* [*atriceps*] *georgianus*	South Georgia, Orkney, and Sandwich Islands	Presumed Relatively Shallow	Shirihai 2002
Diomedeidae				
Amsterdam Albatross	*Diomedea* [*exulans*] *amsterdamensis*	South Indian Ocean	Likely 1	Shirihai 2002
Antipodean Albatross	*Diomedea* [*exulans*] *antipodensis*	Antipodes to Chile and to Tasman Sea	1	Shirihai 2002
Atlantic Yellow-nosed Albatross	*Thalassarche* [*chlororhynchos*] *chlororhynchos*	South Atlantic, Southern Ocean, South America, West South Africa, and rarely North Atlantic and Indian Ocean	Shallow	Shirihai 2002
Black-browed Albatross	*Thalassarche* [*melanophrys*] *melanophrys*	Southern Ocean (vagrant to North Atlantic)	Shallow	Shirihai 2002
Buller's Albatross	*Thalassarche* [*bulleri*] *bulleri*	Southern Ocean (South New Zealand, Australia, Africa [rare], and America, and Southwest Atlantic)	Shallow	Shirihai 2002
Campbell Albatross	*Thalassarche* [*melanophrys*] *impavida*	Sub-Antarctic (South New Zealand)	Shallow	Shirihai 2002
Chatham Albatross	*Thalassarche* [*cauta*] *eremita*	Sub-Antarctic	Shallow	Shirihai 2002
Gibson's Albatross	*Diomedea* [*exulans*] *gibsoni*	Tasman Sea to mid-Pacific Ocean	1	Shirihai 2002
Gray-headed Albatross	*Thalassarche chrysostoma*	Southern Ocean	Shallow	Shirihai 2002
Indian Yellow-nosed Albatross	*Thalassarche* [*chlororhynchos*] *carteri*	Southern Ocean	Shallow	Shirihai 2002
Light-mantled Sooty Albatross	*Phoebetria palpebrata*	Circumpolar in Southern Ocean (mostly Antarctic and sub-Antarctic)	Shallow	Shirihai 2002
Northern Royal Albatross	*Diomedea* [*epomophora*] sanfordi	Chatham and South New Zealand (circumpolar range at sea)	Shallow	Shirihai 2002
Pacific Albatross	*Thalassarche* [*buller*] sp.	Southern Ocean	Shallow	Shirihai 2002
Salvin's Albatross	*Thalassarche* [*cauta*] *salvini*	Sub-Antarctic, Southern Ocean, Southwest Indian Ocean, West South America, and rarely South Atlantic	Shallow	Shirihai 2002
Shy Albatross	*Thalassarche* [*cauta*] *cauta*	Southern Ocean	Shallow	Shirihai 2002
Sooty Albatross	*Phoebetria fusca*	South Atlantic and Indian Oceans, and Southern Ocean	Shallow	Shirihai 2002

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Southern Royal Albatross	*Diomedea* [*epomophora*] *epomophora*	South Atlantic and Indian Oceans, and Australian waters	Shallow	Shirihai 2002
Tristan Albatross	*Diomedea* [*exulans*] *dabbenena*	South Atlantic Ocean and Southwest Indian Ocean	1	Shirihai 2002
Wandering (Snowy) Albatross	*Diomedea* [*exulans*] *exulans*	Southern Ocean	1	Shirihai 2002
White-capped Albatross	*Thalassarche* [*cauta*] *steadi*	Southern Ocean, South Indian Ocean, South Atlantic	Shallow	Shirihai 2002
Diomedeidae				
Silvery Grebe	*Podiceps occipitalis*	Mid- to south South America	Shallow	Shirihai 2002
White-tufted Grebe	*Rollandia rolland*	South America	Shallow	Shirihai 2002

Diving Depths of Marine Mammals Worldwide

Species (Common Name)	Species (Latin Name)	Distribution	Max Diving Depth (m)	Reference
Mysticetes				
Antarctic Minke Whale	*Balaenoptera bonaerensis*	Southern hemisphere	Presumed similar to Northern Minke Whale	Shirihai 2006
Dwarf Minke Whale	*Balaenoptera acutorostrata* (subspecies)	Southern ocean	Presumed similar to Northern Minke Whale	Shirihai 2006
Northern Minke Whale	*Balaenoptera acutorostrata*	Northern hemisphere	Approximately 60	Blix and Folkow 1995 Shirihai 2006
Blue Whale	*Balaenoptera musculus*	Cosmopolitan	- Usually 150 to 200 - Max 500	Shirihai 2006
Bowhead Whale	*Balaena mysticetus*	High Arctic	200	Shirihai 2006
Bryde’s Whale	*Balaenoptera edeni (or brydei)*	Cosmopolitan	292	Shirihai 2006 Alves et al. 2010
Fin Whale	*Balaenoptera physalus*	Cosmopolitan	- Usually 100 to 230 - Max 474	Shirihai 2006
Sei Whale	*Balaenoptera borealis*	Cosmopolitan	Relatively shallow	Shirihai 2006
Gray Whale	*Eschrichtius robustus*	North Pacific	- Usually 50 to 60 - Max 170	Shirihai 2006
Humpback Whale	*Megaptera novaeangliae*	Cosmopolitan	Approximately 150	Shirihai 2006
North Atlantic Right Whale	*Eubalaena glacialis*	North Atlantic	Approximately 200	Nowacek et al. 2004 Shirihai 2006
North Pacific Right Whale	*Eubalaena japonica*	North Pacific	Presumed 184	Shirihai 2006
Pygmy Right Whale	*Caperea marginata*	Southern hemisphere	Relatively shallow	Shirihai 2006
Southern Right Whale	*Eubalaena australis*	Southern Ocean	184	Shirihai 2006

Species (Common Name)	**Species (Latin Name)**	**Distribution**	**Max Diving Depth (m)**	**Reference**
Odontocetes				
Atlantic Humpback Dolphin	*Sousa teuszii*	Coastal west Africa	Shallow	Shirihai 2006
Atlantic Spotted Dolphin	*Stenella frontalis*	Warm, tropical waters of Atlantic	- Usually 10 - Max 60	Shirihai 2006
Atlantic White-sided Dolphin	*Lagenorhynchus acutus*	North Atlantic temperate or sub-polar waters	Mesopelagic	Shirihai 2006
Pacific White-sided Dolphin	*Lagenorhynchus obliquidens*	Temperate or sub-polar waters of North Pacific	Shallow and Mesopelagic	Shirihai 2006
Australian Snubfin Dolphin	*Orcaella heinsohni*	North Australia to Papua New Guinea	Shallow	Shirihai 2006
Bottlenose Dolphin	*Tursiops truncatus*	Cosmopolitan tropical to temperate waters	535	Shirihai 2006
Chilean (Black) Dolphin	*Cephalorhynchus eutropia*	Chilean coastal waters	-	Shirihai 2002 Shirihai 2006
Clymene Dolphin	*Stenella clymene*	Tropical and subtropical Atlantic	Mesopelagic	Shirihai 2006
Commerson's Dolphin	*Cephalorhynchus commersonii*	Off East Argentina, Falklands and South Indian Ocean	Deep	Shirihai 2006
Common Dolphin (Long-beaked)	*Delphinus capensis*	Warm or tropical near-shore waters	280	Shirihai 2006
Common Dolphin (Short-beaked)	*Delphinus delphis*	Tropical to temperate Atlantic and Pacific	- Usually to 90 - Max 260	Shirihai 2006
Dusky Dolphin	*Lagenorhynchus obscurus*	Southern hemisphere	At least 150	Shirihai 2006
Indo-Pacific Bottlenose Dolphin	*Tursiops aduncus*	Costal Indian and southwest and northwest Pacific oceans	Presumed 535	Shirihai 2006
Indo-Pacific Humpback Dolphin	*Sousa chinensis*	- Pacific Humpback Dolphin (*S. c. chinensis*): Southwest Pacific, China to Australia -Indian Humpback Dolphin (*S. c. plumbea*): South Africa to Sri Lanka	Shallow	Shirihai 2006
Irrwaddy Dolphin	*Orcaella brevirostris*	Coasts and rivers of tropical Indo-Pacific	3	Shirihai 2006
Franciscana (Dolphin)	*Pontoporia blainvillei*	East coast of South America	Shallow	Shirihai 2006
Fraser's Dolphin	*Lagenodelphis hosei*	Cosmopolitan warm and tropical waters	600	Shirihai 2006
Haviside's Dolphin	*Cephalorhynchus heavisidii*	Coastal Southwest Africa	Deep	Shirihai 2006
Hector's Dolphin	*Cephalorhynchus hectori*	Coastal waters of New Zealand	Shallow	Shirihai 2006
Hourglass Dolphin	*Lagenorhynchus cruciger*	Southern Ocean	Relatively Shallow	Shirihai 2006
Northern Right Whale Dolphin	*Lissodelphis borealis*	North Pacific	Shallow	Shirihai 2006

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Southern Right Whale Dolphin	*Lissodelphis peronii*	Southern Ocean	-	Shirihai 2006
Peale's Dolphin	*Lagenorhynchus australis*	Coastal South America	Shallow	Shirihai 2006
Risso's Dolphin	*Grampus griseus*	Tropical and temperate waters	300	Shirihai 2006
Pantropical Spotted Dolphin	*Stenella attenuata*	Cosmopolitan tropical or warm waters	At least 170	Perrin et al. 2002 Shirihai 2006
Rough-toothed Dolphin	*Steno bredanensis*	Cosmopolitan tropical to subtropical waters	70	Shirihai 2006
Spinner Dolphin	*Stenella longirostris*	Cosmopolitan in warm waters	600	Shirihai 2006
Striped Dolphin	*Stenella coeruleoalba*	Cosmopolitan tropical and temperate waters	700	Shirihai 2006
Tucuxi (Dolphin)	*Sotalia fluviatilis*	Coastal waters and estuaries of Eastern South America	Shallow	Shirihai 2006
White-beaked Dolphin	*Lagenorhynchus albirostris*	North Atlantic temperate to sub-polar waters	Deep	Shirihai 2006
Bermeister's Porpoise	*Phocoena spinipinnis*	Coastal waters of South America	At least 60	Shirihai 2006
Dall's Porpoise	*Phocoenoides dalli*	North Pacific	500	Shirihai 2006
Finless Porpoise	*Neophocaena phocaenoides*	Warm, coastal Indo-Pacific	Relatively Shallow	Shirihai 2006
Gulf of California Porpoise (Vaquita)	*Phocoena sinus*	Gulf of California	Relatively Shallow	Shirihai 2006
Harbour Porpoise	*Phocoena phocoena*	North Atlantic and North Pacific	220	Shirihai 2006
Spectacled Porpoise	*Phocoena dioptrica*	Southern hemisphere, offshore islands	-	Shirihai 2006
Andrew's Beaked Whale	*Mesoplodon bowdoini*	Southern hemisphere	Deep	Shirihai 2006
Arnoux's Beaked Whale	*Berardius arnuxii*	Southern hemisphere	Deep	Shirihai 2006
Baird's Beaked Whale	*Berardius bairdii*	North Pacific	- Usually to 1,000 - Presumed to 3,000	Shirihai 2006
Blainville's Beaked (Dense-beaked) Whale	*Mesoplodon densirostris*	Cosmopolitan	1,408	Baird et al. 2006 Shirihai 2006
Cuvier's Beaked Whale	*Ziphius cavirostris*	Cosmopolitan	3,120	Shirihai 2006 Schorr et al. 2011
Gervais' Beaked Whale	*Mesoplodon europaeus*	Central and north Atlantic	-	Shirihai 2006
Ginko-toothed Beaked Whale	*Mesoplodon ginkgodens*	Temperate and tropical Pacific, and Indian Ocean	Deep	Shirihai 2006
Gray's Beaked Whale	*Mesoplodon grayi*	Southern hemisphere	120	Carwardine 1995 Shirihai 2006

Species (Common Name)	**Species (Latin Name)**	**Distribution**	**Max Diving Depth (m)**	**Reference**
Hector's Beaked Whale	*Mesoplodon hectori*	Southern hemisphere	Deep	Shirihai 2006
Hubb's Beaked Whale	*Mesoplodon carlhubbsi*	North Pacific	Mesopelagic	Shirihai 2006
Longman's Beaked Whale	*Indopacetus pacificus*	Indian Ocean and tropical Pacific	-	Shirihai 2006
Perrin's Beaked Whale	*Mesoplodon perrini*	California and Northeast Pacific	Deep	Shirihai 2006
Pygmy Beaked Whale	*Mesoplodon peruvianus*	East tropical and south Pacific, and off California	Deep	Shirihai 2006
Shepherd's Beaked Whale	*Tasmacetus shepherdi*	Southern hemisphere	-	Shirihai 2006
Sowerby's Beaked Whale	*Mesoplodon bidens*	North Atlantic	1,500	Shirihai 2006
Spade-toothed Beaked Whale	*Mesoplodon traversii*	Southern hemisphere	-	Shirihai 2006
Stejneger's Beaked Whale	*Mesoplodon stejnegeri*	North Pacific	1,500	Shirihai 2006
True's Beaked Whale	*Mesoplodon mirus*	Central and north Atlantic, South Africa and Australia	Deep	Shirihai 2006
Strap-toothed Whale	*Mesoplodon layardii*	Southern hemisphere	Deep	Shirihai 2006
Melon-headed Whale	*Peponocephala electra*	Tropical waters	Possibly deep (pelagic)	Shirihai 2006
Northern Bottlenose Whale	*Hyperoodon ampullatus*	North Atlantic	1,500	Shirihai 2006
Southern Bottlenose Whale	*Hyperoodon planifrons*	Southern hemisphere	Presumed 1,500	Shirihai 2006
Long-finned Pilot Whale	*Globicephala melas*	Temperate to sub-polar waters	- Usually 30 to 60 - Max 600	Shirihai 2006
Short-finned Pilot Whale	*Globicephala macrorhynchus*	Temperate to tropical waters	900	Shirihai 2006
Killer Whale	*Orcinus orca*	Cosmopolitan	260	Shirihai 2006
False Killer Whale	*Pseudorca crassidens*	Tropical waters	500	Shirihai 2006
Pygmy Killer Whale	*Feresa attenuata*	Tropical and subtropical waters	-	Shirihai 2006
Sperm Whale	*Physeter macrocephalus*	Cosmopolitan	3,000	Shirihai 2006
Dwarf Sperm Whale	*Kogia sima*	Temperate to tropical waters	300	Shirihai 2006
Pygmy Sperm Whale	*Kogia breviceps*	Temperate to tropical waters	Deep	Shirihai 2006
Beluga	*Delphinapterus leucas*	Arctic and subarctic waters	1,000	Shirihai 2006
Narwhal	*Monodon monoceros*	High Arctic	1,160	Shirihai 2006
Dugong	*Dugong dugon*	Tropical Indo-Pacific coasts	20	Perrin et al. 2002 Shirihai 2006
Steller's Sea Cow	*Hydrodamalis gigas*	Commander Islands, Northwest Pacific	Shallow	Shirihai 2006

Species (Common Name)	**Species (Latin Name)**	**Distribution**	**Max Diving Depth (m)**	**Reference**
West African Manatee	*Trichechus senegalensis*	West Africa	Shallow (At least 30)	Perrin et al. 2002 Shirihai 2006
West Indian Manatee	*Trichechus manatus*	East coast of the Americas	Relatively Shallow (At least 30)	Perrin et al. 2002 Shirihai 2006
Pinnipeds				
Antarctic Fur Seal	*Arctocephalus gazella*	Antarctic waters	181	Shirihai 2006
Australian Fur Seal	*Arctocephalus pusillus*	Southeast Australian coast	204	Reeves et al. 2002; Shirihai 2006
Galápagos Fur Seal	*Arctocephalus galapagoensis*	Galápagos archipelago	169	Shirihai 2006
Guadalupe Fur Seal	*Arctocephalus townsendi*	Guadalupe Island, Mexico	Shallow	Shirihai 2006
Juan Fernández Fur Seal	*Arctocephalus philippii*	Juan Fernández archipelago and San Felix	90	Shirihai 2006
New Zealand Fur Seal	*Arctocephalus forsteri*	Australia and New Zealand	274	Shirihai 2006
Northern Fur Seal	*Callorhinus ursinus*	North Pacific	400	Shirihai 2006
South African Fur Seal	*Arctocephalus pusillus*	South and southwest African coast	204	Reeves et al. 2002; Shirihai 2006
South American Fur Seal	*Arctocephalus australis*	South American coasts	170	Shirihai 2006
Subantarctic Fur Seal	*Arctocephalus tropicalis*	Sub-Antarctic waters	208	Shirihai 2006
Australian Sea Lion	*Neophoca cinerea*	South Australian coast	150	Shirihai 2006
California Sea Lion	*Zalophus californianus*	Northeast and Central-east Pacific	536	Shirihai 2006
Galápagos Sea Lion	*Zalophus californianus*	Northeast and Central-east Pacific	536	Shirihai 2006
New Zealand Sea Lion	*Phocarctos hookeri*	South New Zealand and sub-Antarctic islands	500	Shirihai 2006
Northern Sea Lion (Steller Sea Lion)	*Eumetopias jubatus*	North Pacific	277	Shirihai 2006
Southern Sea Lion	*Otaria flavescens*	South America	250	Perrin et al. 2002
South American Sea Lion	*Otaria byronia*	South American coasts	175	Shirihai 2006
Bearded Seal	*Erignathus barbatus*	Arctic and subarctic	288	Shirihai 2006
Caspian Seal	*Pusa caspica*	Caspian Sea	200	Shirihai 2006
Crabeater Seal	*Lobodon carcinophaga*	Antarctic	- Usually 20 to 30 - Max 530	Shirihai 2006
Gray Seal	*Halichoerus grypus*	North Atlantic, temperate to subarctic	Occasionally >300	Shirihai 2006
Harbour Seal (Common Seal)	*Phoca vitulina*	Northern hemisphere	- Usually to 150 - Max 450 recorded	Shirihai 2006

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Harp Seal	*Pagophilus groenlandicus*	High arctic	- Usually to 90 - Occasionally to 250	Shirihai 2006
Hawaiian Monk Seal	*Monachus schauinslandi*	Hawaiian Islands	- Usually ≤60 - Max 550	Perrin et al. 2002 Shirihai 2006
Hooded Seal	*Cystophora cristata*	Arctic waters	1,000	Shirihai 2006
Largha Seal (Spotted Seal)	*Phoca largha*	Extreme North Pacific	300	Shirihai 2006
Leopard Seal	*Hydrurga leptonyx*	Antarctic and sub-Antarctic	Presumed near surface	Shirihai 2006
Mediterranean Monk Seal	*Monachus monachus*	Mediterranean and Northwest Africa	Approximately 70	Shirihai 2006
Northern Elephant Seal	*Mirounga angustirostris*	Northeast Pacific	1,567	Shirihai 2006
Southern Elephant Seal	*Mirounga leonina*	Southern hemisphere	- Usually 400 to 600 - Max 2,388	Shirihai 2006 Costa et al. 2010
Ribbon Seal	*Histriophoca fasciata*	North Pacific	600	Shirihai 2006
Ringed Seal	*Pusa hispida*	Circumpolar Arctic	- Usually to 45 - Max 145	Shirihai 2006
Ross Seal	*Ommatophoca rossii*	Antarctica	212	Shirihai 2006
Weddell Seal	*Leptonychotes weddellii*	Coastal Antarctica	- Usually 50 to 500 - Max 750	Shirihai 2006
West Indian Monk Seal	*Monachus tropicalis*	Caribbean Sea	Unknown	Shirihai 2006
Walrus	*Odobenus romarus*	Arctic coasts	133	Perrin et al. 2002 Shirihai 2006