**Literature Review of Magnetoreception in Elasmobranch Fishes**

It has long been known that many species of elasmobranch fishes undertake long-distance migrations for feeding, breeding and other reasons. One theory proposed on how they manage to orient themselves during these migrations is that they use the magnetic field to navigate. Using the magnetic field would have several advantages, it would provide a long-distance cue that would not depend on being able to see the bottom or the surface.

**Evidence for Magnetoreception in Elasmobranches**

It has been shown that several species of elasmobranch can detect and respond to magnetic fields (Kalmijn:1982, Klimley:1993, Paulin: 1995). There is considerable debate within the field as to the mechanism by which elasmobranches detect magnetic fields. Some have proposed that elasmobranches use magnetite (or some other ferri-magnetic material) crystals located somewhere in the animal and use these to detect the Earth’s magnetic field in the same way that homing pigeons or trout do (Johnsen:2008, Johnsen:2005). Another theory is that the elasmobranches use their highly-developed electric sense to detect the induced voltage that is created when they move through the Earth’s magnetic field and navigate in this way (Paulin:1995). This could theoretically allow the elasmobranch to navigate in the ocean and even correct for the drift of ocean currents which the magnetite crystal model of navigation would not be able to. There is another popular theory on magneto-reception in animals and is based on the idea of optically pumped radical pairs. This class of chemicals has been shown to be unusually responsive to magnetic fields and could be used to navigate (Johnsen:2008). However to the author’s knowledge the optically pumped hypothesis has not been proposed for elasmobranches as their navigation at night is unhindered (Klimley:1993).

**Magnetite Crystals**

Locating the magnetic organ is a notoriously difficult challenge in biology for a number of reasons. For one most biological tissue is invisible to magnetic fields and so the magnetic receptor need to be at the surface of the animal as is the case for other senses (vision, hearing, smell etc). The receptors for the sense may be distributed across a considerable area of the animal with no centralised organ. Also in the case of magnetite crystals the receptors may be incredibly small ~ 50nm (Johnsen:2005). Of the three main theories of magnetoreception in animals magnetite crystals is perhaps the most common and widely accepted. Magnetite crystal chains have been found in bacteria, homing pigeons and rainbow trout (Johnsen:2005). Hodson:2000 did an instructive experiment with rays where the rays were initially trained to respond to a magnetic field and then bar magnets were placed in the nasal cavities of some rays and bars of brass of the same size and weight but with no magnetic fields were placed in the nasal cavities of others. In the experiment the rays with the magnets placed in their nasal cavities no longer responded to the external magnetic fields as they had been trained to whilst the rays fitted with the brass weights maintained their ability to detect and respond to the externally created magnetic fields. This has been taken as direct evidence for magnetite-based magnetoreception in elasmobranches while also being used as evidence against induction-based magnetoreception in elasmobranches as a magnetic field that moves with a detector would not induce an electric field in the detector. However Moltenon:2009 showed that as a ray’s body is flexible unless the relative movement between the magnet and the electric detectors in the ray (the ampullae of Lorenzini) then the induced voltage would be enough to interfere with the ray’s ability to detect magnetic fields via induction.

**Induction-based Magnetoreception**