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Dispatches

Animal Navigation: The Eel's Magnetic Guide to the Gulf Stream

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The geographic distribution of migratory species can span thousands of kilometers. Yet, traits that enable large-scale migrations are poorly understood. A recent study demonstrates that juvenile eels use the Earth's magnetism for their dispersal, with possible implications for their evolution.

The marine environment is rife with species that perform incredible migrations to accomplish their life cycle: whether to spawn, to seek for nursery areas, or simply to forage. Migratory movements tend to be extremely accurate towards particular geographic locations. For many species, migration routes are not learned but are innate, which requires organisms to possess internal orientation mechanisms. Magneto-sensing — the capacity to perceive the Earth's magnetic field — is pervasive across kingdoms [1–7]: from magneto-tactic bacteria, to nematodes (*Caenorhabditis elegans*), crustaceans (spiny lobster), fishes (salmon), birds (pigeon), mammals (mole-rat) and reptiles (sea turtle; Figure 1). Like small magnets, the entire Earth is polarized with magnetic fields converging near the poles, a phenomenon driven by the motion of the Earth's liquid core [8]. While the geomagnetic fields are rather regular, anomalies exist because of movement of the upper crust (e.g. volcanism), and can be altered, for instance, by electromagnetic radiation from the Sun. Those changes, however, are small compared to the regular magnetic field. Therefore, the Earth's magnetic field is a reliable source of navigational information, especially if we consider the large open ocean. In a recent paper, Naisbett-Jones *et al.* [9] suggest that dispersal of juvenile eels from the spawning area into the Gulf Stream is unlikely to be entirely due to passive drift. Instead, dispersal seems to also rely on the capacity to derive positional information from the geomagnetic field: juvenile eels recognize and orientate their swimming using magnetic cues similar to those present in the Sargasso Sea and North West Atlantic area (where the Gulf Stream trifurcates). However, the authors also found that glass eels, the early life stage of this species, do not rely on the geomagnetic signal of the Eastern Atlantic and coastal locations to identify freshwater systems.

The European eel (*Anguilla anguilla*) is one of 16 species of eels. All eels perform two trans-oceanic migrations to complete their life cycle, from and to the spawning grounds [10]. Their life cycle is characterized by the development of highly specialized traits through major ontogenic shifts: neonates develop into leptocephali, an early life stage with a gelatinous, leaf-like body that facilitates passive drift. Arriving at the continental shelf, leptocephali metamorphose into glass eels (Figure 2) through compression of the body [11]. Upon entering, feeding and remaining in freshwater systems, glass eels change into yellow eels, the adult form. These animals may live up to 20 years until the final metamorphosis takes place, which is accompanied by the maturation of sexual organs and triggers the spawning migration [11].

European eels spawn in the Sargasso Sea, 5000 kilometers away from the European freshwater system, where it grows and matures. The Sargasso Sea is a large region in the Northwest Atlantic Ocean that supports high primary production and higher levels of biodiversity than the surrounding oceanic environments [12]. It is delimited in the North by the Gulf Stream, in the East by the Azores current, South by the Equatorial current and on the West side by the Caribbean currents [12]. The Gulf Stream plays a key role in the European eel's life cycle, as it connects the spawning and the foraging area of the species. Entering the Gulf Stream immediately after hatching increases the dispersal success of early life stages and hence recruitment [13].

Naisbett-Jones *et al.* [9] found that juvenile eels sense both the field intensity and the magnetic inclination of the Earth. These results provide evidence that glass eels possess a magnetic map based on the inclination and intensity of the magnetic field, a bi-coordinate orientation system, perhaps similar to that previously reported in sea turtles [7]. However, one could argue that leptocephali, the life-stage present in the Sargasso Sea, may not possess that same magnetic-sensing ability as the glass eels used in the experiment. This is because the metamorphosis from one life stage to another involves a substantial body re-arrangement and related physiological changes [11]. Certainly, more studies are needed to clarify whether magneto-sensing is present in all life stages. It is known though that adult eels are magneto-sensitive [14]. Therefore, a contribution of the study by Naisbett-Jones *et al.* [9] is that magnetic cues are used at different stages of the species' life cycle.

If species have evolved adaptations to cryptic selective pressures within the oceanic environment as the eels did, this is because Oceans are not homogenous water masses. Decrypting the eel's movement ecology gets us closer to elucidate their population structure and evolution. The ability to sense and follow the Earth's magnetic field could very well be the speculative mechanism that mediates the spawning migration, i.e. the return to the Sargasso Sea. Therefore,

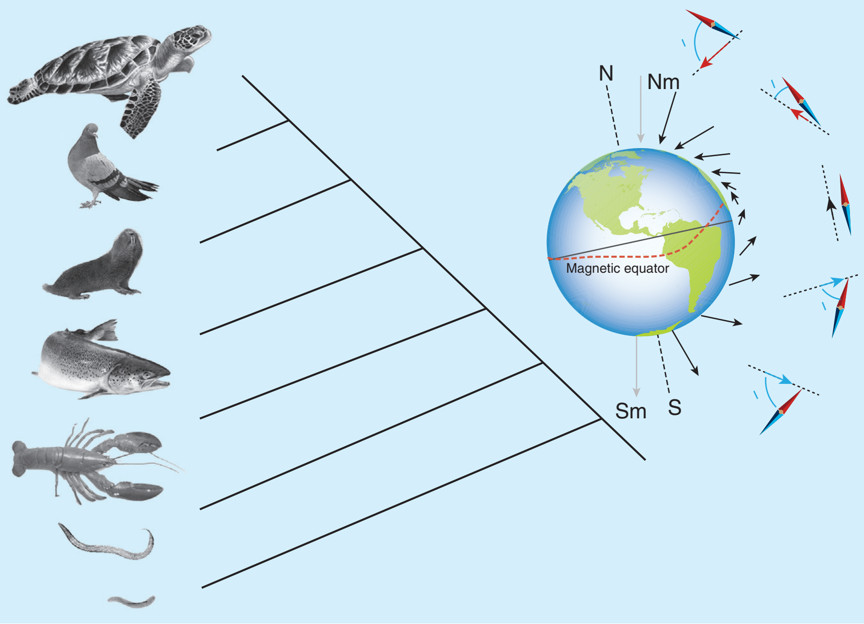

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Figure 1. Magnetic orientation in animals.
Schematic phylogeny of species known to use the Earth's magnetic fields for movements and/or orientations. The direction of magnetic vectors (right arrows) and their intensity (proportional to the length of the right arrows) is represented. The magnetic field lines leave the surface of the Earth at the Southern magnetic pole (pointing upwards), run around the globe parallel to the magnetic equator, and re-enter at the Northern magnetic pole (pointing downward). The geographic poles (North N and South S) as well as the magnetic poles (Nm and Sm) are depicted.

an implication of the results by Naisbett-Jones and co-workers [9] relates to the paradigmatic view that eels use a panmictic, i.e. random, mode of reproduction [15,16]. The few alternative hypotheses to panmixia suggest a temporal displacement of genetically distinct cohorts of progenitors [17] or a spatial segregation within the Sargasso Sea of genetically distinct spawning groups, with highly philopatric adult females and male-mediated gene flow among groups [13].

Magneto-sensing in the eel offers possible evolutionary scenarios for the existence of sub-populations in the Sargasso Sea. In order to identify how they need to orientate their swimming, eels need to know where they are. Hence it is conceivable that they might imprint on their natal area, similar to sea turtles [18]. Given the large extent of the Sargasso Sea, eels may imprint on specific locations (using their bi-coordinate system), and achieve an accuracy as high as turtles, down to a few tens of kilometers [19] upon their spawning migration. Consequently, the Sargasso Sea would be perceived as a heterogeneous spawning ground with several reproductive units.

Figure 2. Glass eel catch from anestuarine area.
Photo kindly provided by Dr. Derek Evans, AFBI, UK.

When the population size is high, the genetic cohesiveness among spawning sites would be maintained: the unsynchronized spawning migration of mature eels due to the productivity of the freshwater system, latitude or sex would ensure a continuous supply of breeders to all spawning areas. From a population genetic perspective, this gene flow would be equivalent to panmixia. On the other hand, if the population undergoes a drastic reduction in size, the lack of spawners would effectively fragment the Sargasso Sea, reducing connectivity among the putative spawning areas. Under these conditions, low gene flow increases genetic differentiation, and especially so if population size remains low for several generations. European eels experienced a major collapse in recruitment that occurred during the early 1980s and the population failed to recover its population size to the pre-decline levels [20]. Together with their newly discovered geomagnetic-sensing ability, scenarios of population structure at the Sargasso sea driven by habitat fragmentation become plausible.

The study of Naisbett-Jones *et al.* [9] offers fresh perspectives on eel biology. If correct, it would be interesting to know whether magnetic sensing abilities vary between sexes and how accurate it is. This would be relevant to further dismiss or accept the proposed hypothesis of eel female philopatry and further reveal the likelihood of a structured Sargasso Sea. Further studies may also investigate the molecular mechanism of such sensing and its universality across a broad range of taxa.

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Centrosome Assembly: Reconstructing the Core Cartwheel Structure *In Vitro*

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Centrioles are microtubule-based cylinders essential for the formation of centrosomes and cilia. A recent study provides a new cell-free assay that reconstitutes the initial structure formed during centriole assembly — the cartwheel — and proposes a new model for its formation and growth.

As Richard Feynman said, "What I cannot create, I do not understand". This quote is particularly pertinent to scientists studying the assembly of cellular organelles. While much work has been carried out in whole cells with the aim of understanding the molecular mechanisms governing the formation of whole organelles, their *in vitro* reconstruction has lagged behind. This is particularly true for a one billion-year-old tiny cellular structure, the centriole, which is essential for the generation of two organelles, cilia and centrosomes. Cilia and centrosomes are involved in many critical cellular processes, such as cell motility and cell division. Abnormalities in their structure and in their number cause multiple diseases, including cancer, microcephaly and ciliopathies. In a recent study in