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ELECTROMAGNETIC SENSES. Many lower organisms are known to orient themselves in artificial electric fields, but the biological significance and the sensory basis of this behaviour is obscure. A number of fish species, however, make use of their electrical sensitivity in the course of their normal life for the purpose of ORIENTATION and COMMUNICATION, and a considerable amount is known about the sensory system that gives them this ability. Two types of electrosensitive fish have to be distinguished: those that detect distortions of the earth's electrical fields, and those that detect distortions of weak electrical fields that are generated by the fish themselves, or by other members of their species by means of special electrical organs. These appear to be modified muscles, and sometimes modified nervous structures. Apart from these so-called weakly electric fish there are also some so-called strongly electric fish, examples being the electric ray (*Torpedo*), and the electric eel (*Electrophorus electricus*). These animals produce shocks capable of stunning prey or even predators. However, they do not seem to possess a specialized electric sense.

An example of electrosensitive fish that are not electric themselves is the dogfish *Scyliorhinus*, which is capable of detecting its prey fish, even when they are buried in the sand, by the local distortion of the geophysical electrical field that they cause. The SENSE ORGANS that are used for this are called the *ampullae Lorenzini*, named after the anatomist who discovered them. Interestingly these organs, which occur widely distributed over the body surface, but especially on the head of sharks (Selachii), were variously suspected of being thermoreceptors, osmoreceptors, or mechanoreceptors until it was established that their function was electroreceptive. They consist of clusters of several sensory cells recessed under the skin and are connected to the outside by a canal filled with modified cells having a low electrical resistance. They are thought to be evolutionary derivatives from lateral line organs (see MECHANICAL SENSES).

The other type of electrosensitive fish, the weakly electric fish, belong to the families Gymnarchidae (with one species, *Gymnarchus niloticus*), Mormyridae, and Gymnotidae (gymnotid eels). They generate their own electric fields, either in the form of continuously and regularly oscillating fields, or of variably spaced electric pulses. There are two types of electrosensitive receptors in these fish: ampulla receptors, rather similar to the ampullae Lorenzini, and tuberous receptors, of a slightly different structure. These receptors differ mainly in that the former respond to static or slowly changing electric fields, while the latter only respond to rapidly changing fields. Some species possess either one or the other type of receptor, others both. Behaviourally the receptors are used to detect, locate, and even discriminate objects in the water on the basis of the distortions that they impose on the electric fields generated by the electric organs. It is, for example, possible to train *Gymnarchus niloticus* to approach an electrically non-conductive stimulus object to obtain a food reward, and to avoid a conductive but otherwise identical stimulus object, the approach to which is punished with a mild electric shock. But these electric fish also respond to electrical discharges of other members of their own species, in the sense that they modify their own discharge rate to be different from that of neighbouring fish. Thus they avoid interference with their electrolocation, and, to some extent, communicate with each other by this means. *Gymnotus*, for example, signals aggressive intentions towards neighbours with bursts of some 250 pulses a second.

Sensitivity to magnetic fields has been demonstrated in a number of animals. Certain bacteria, placed in a drop of water under the microscope, tend to accumulate at its northern edge. If a magnet is brought near to the droplet, they orient according to the magnetic 'north' of its field. Electron-microscopic examination reveals that they contain two chain-like iron-rich structures (similar structures have been found in the abdomen of honey-bees, *Apis mellifera*, and in the retina of pigeons, *Columba livia*) which terminate in two bundles of *flagellae* or hairs, with which they propel themselves. The function of this magnetic orientation behaviour is not understood. It is possible that it helps them to reach the oxygen-poor, deep water in which they thrive: in northern latitudes, where these bacteria are found, the 'north' of the earth's magnetic field not only points northwards, but also downwards. Similar kinds of magnetically oriented behaviour has also been described in lower animals, such as turbellarian flatworms (Turbellaria) and snails (Gastropoda). The sensory organs involved, and the biological function of this behaviour, are unknown.

The earth's magnetic field is also known to cause a slight error in the orientation of the waggle dance of the foraging bee, the dance that it uses to communicate the direction of a food source to hive companions, and which is otherwise determined by the position of the sun and the pull of gravity. It may be that the earth's magnetic field is used in some aspect of NAVIGATION in bees.

The situation is different in birds. HOMING pigeons, with either magnets or electromagnetic coils attached to them, are disoriented when flying back to their home loft when the sky is overcast, so that they are unable to use the sun as an alternative cue for direction. Similarly, experiments with European robins (*Erithacus rubecula*) held in a circular cage revealed that, in the absence of other cues, they correctly orient their escape attempts for MIGRATION, guided only by the earth's magnetic field. If the earth's magnetic field is modified by superimposing an artificial magnetic field with electromagnetic coils, then the animal directs its escape efforts in a manner consonant with the resulting field. Interestingly, robins do not seem to be able to distinguish the 'north' and 'south' of a magnetic field. However they apparently can detect the downward inclination of the earth's magnetic field, which is northward in northern latitudes, and southward in southern latitudes. The sensory structures responsible for this magnetic orientation of birds are not known. J.D.

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