too strong they lose direction. Birds also try to avoid rain, fog or heavy cloud. Migration weather requirements vary between species (see also about the effect of wind on migration at Falsterbo, below).

Orientation

Another fascinating aspect of migration is how birds are able to plot the right course on their travels across land, sea, desert and mountain ranges. We know that migrating birds draw on a range of resources to help them find their way, for instance the sun, stars and the Earth's magnetic field.

A bird's sun compass enables it to plot its course with the help of the sun's position in the sky and the bird's internal biological clock. This clock allows birds to determine the sun's position relative to the points of the compass at different times of the day. That birds possess such a clock has been proven by experiments in which birds have been kept indoors for at least four days in an artificial cycle of light and darkness (Fig. 2).

Many birds that migrant at night set off on their journeys at twilight. The sun sets exactly in the west at the spring and autumn equinoxes and between the south-west and north-west at other times of the year.

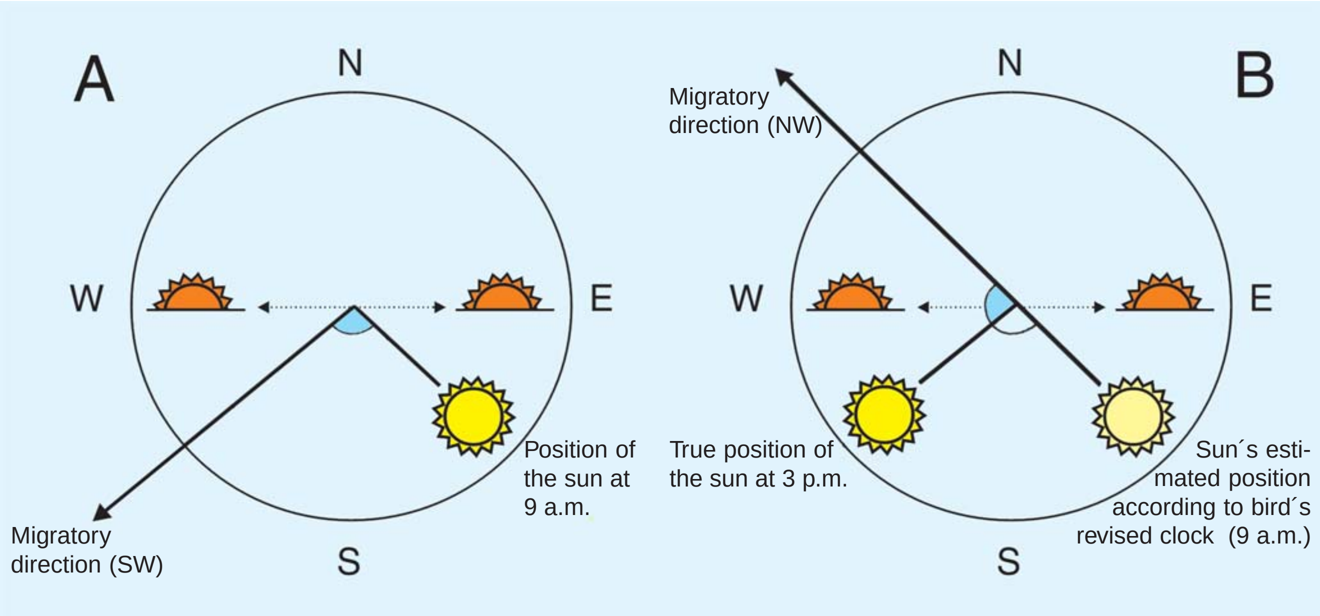


Fig. 2. The sun compass.
A. A bird heading towards south-west at 9 am. Having learnt that the position of the sun at that time of day is in the south-east, the bird must, in order to find south-west, add 90° to the position of the sun.
B. The same situation but this time for a bird whose inner clock has been altered to run six hours late after being kept for at least four days in a room without natural daylight. Artificial light was turned on/off six hours later than the actual time of sunrise/sunset. When released, the bird proceeds in the same manner as in A, i.e. adding 90° to the position of the sun, since the inner clock says 9 a.m. and by rights the sun should be in the south-east. As the correct time is in fact 3 p.m., the sun is in the south-west, and the bird will set off towards the north-west instead. Diagram: Rachel Muheim.

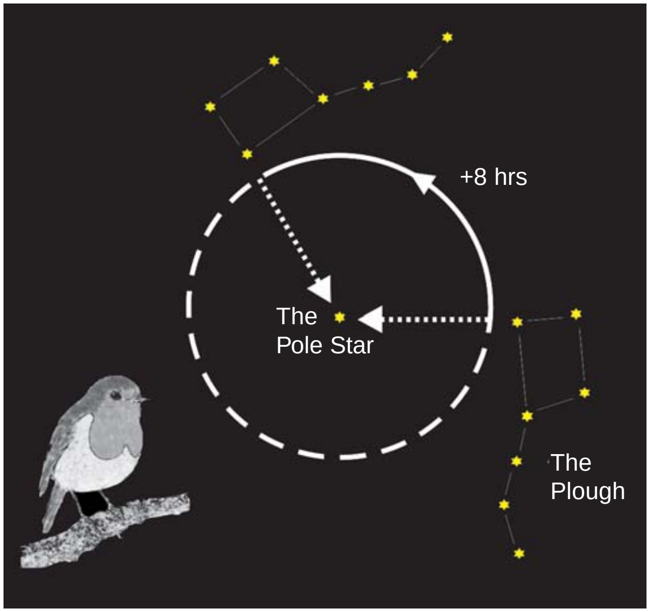


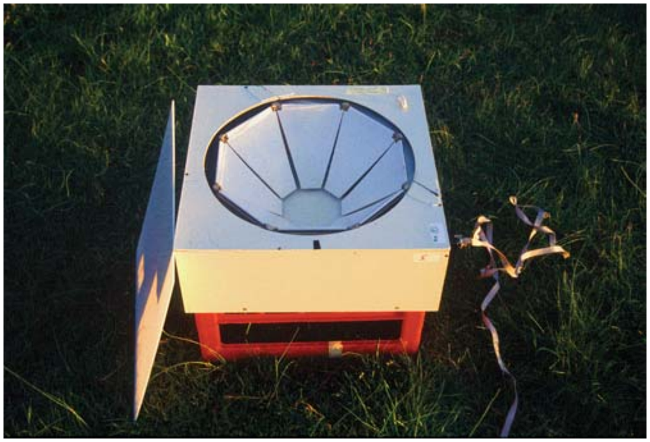
Fig. 3. The star compass
An example of how migratory birds use their star compass. The relative positions of the stars are the same, independent of season or time of night. Birds use these patterns for orientation.

If a line is drawn through the two stars at the end of the Plough, the projection of this line will hit the Pole Star head on (= north). In spite of the changing position of the Plough during the night this straight line will always indicate the position of the Pole Star. In the southern hemisphere, where the Pole Star can´t be seen, other constellations may be used in a similar way. Diagram & drawing: Rachel Muheim.

This direction indicator could well act as an important link between birds' daytime and night-time compasses. Similarly, birds also draw on their ability to gauge polarised light in order to orientate themselves. When the sun or the light from the setting sun is not directly visible birds only need a gap in the clouds to assess the polarization of the light in the sky.

Birds that migrate at night can use neither the sun nor the last rays of light just before dusk. On clear nights they instead navigate using the stars. The birds

Orientation cages set up for experiments at Falsterbo. Below: Inside an orientation cage. When a bird moves inside the cage, every "jump" in each sector is registered on a computer. The sector with the largest number of "jumps" indicates the direction of orientation. Photos: Rachel Muheim.



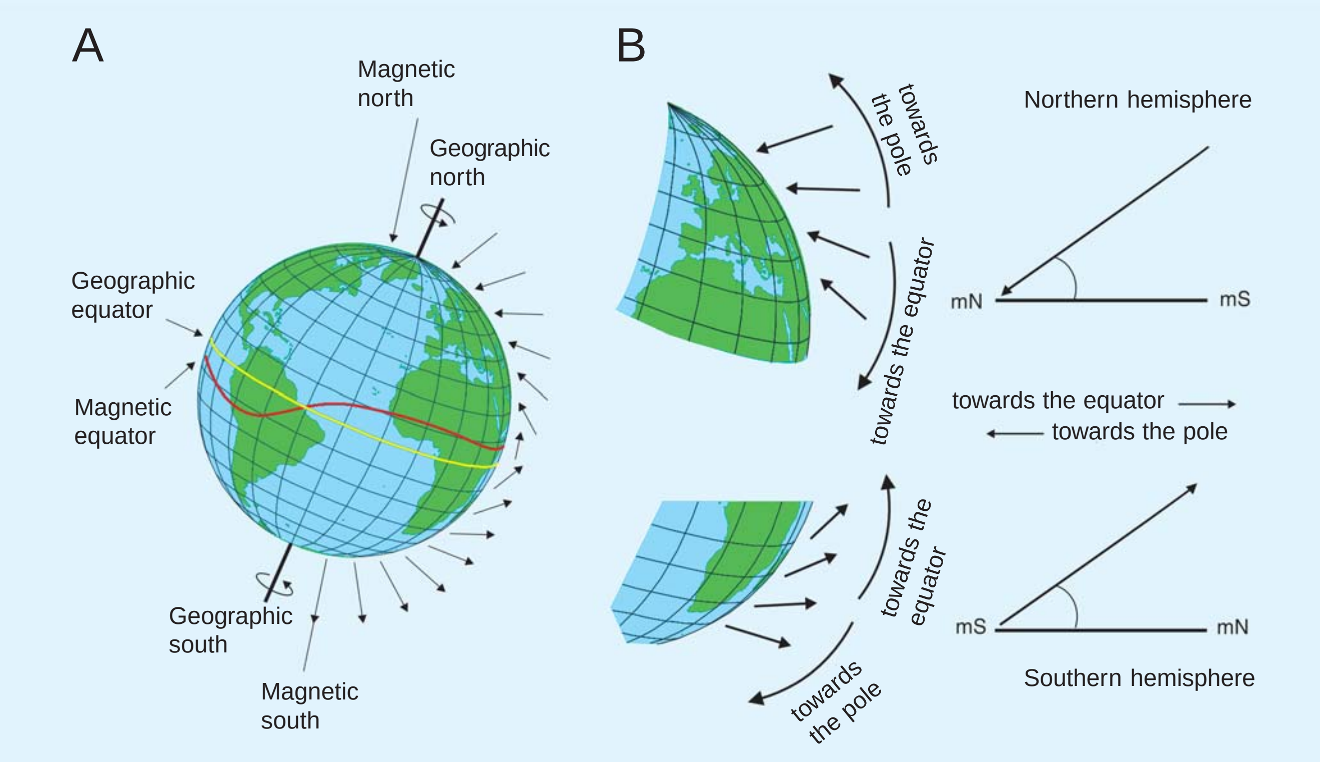


Fig. 4. The magnetic compass.
A. The Earth's magnetic field. The arrows show the course of the magnetic field lines. Their length is drawn relative to the magnetic field intensity at different latitudes. The magnetic field intensity is strongest at the magnetic poles (about 68 µT) and weakest at the magnetic equator (about 23 µT). The steepness of the magnetic field lines relative to the surface of the Earth shows the angle of inclination, which is maximal at the magnetic poles (±90º) and minimal (0º) at the magnetic equator.
B. The avian inclination compass provides the animals with information on the axial alignment of the magnetic field (direction along the magnetic north-south axis) and the direction towards the magnetic pole (intersection of magnetic field line and horizon) that lies closest and the magnetic equator (direction where magnetic field lines and horizon diverge). The steepness of the inclination angle provides the birds with information on magnetic latitude. An inclination compass does not perceive the polarity (direction) of the magnetic field lines, as used by our technical compasses (always pointing towards magnetic North). Diagram: Rachel Muheim. µT= microTesla (unit for magnetic field intensity).

use the rotation of the stars around the Pole Star, which they learn to regard as geographic north, and the constellations that are closest to the Pole Star (Fig. 3). In the Southern hemisphere, from where the Pole Star cannot be seen, birds must navigate using the patterns formed between other constellations.

When neither the sun nor the stars are visible, birds can use the Earth's magnetic field as a compass. Birds' own internal magnetic compasses follow the inclination of the magnetic field and do not differentiate between north and south but rather between the poles and the equator (Fig. 4).

A pair of Pied Flycatchers have found their way “back home” after spending the winter in tropical Africa. In addition to their well-developed orientation senses, birds are also supposed to have navigational or mapping abilities. Reading road signs is, however, an ability yet to be proven... Photo: P-G Bentz.

We know that birds’ magnetic sense is affected by magnetic anomalies, that is areas with abnormal magnetic fields. Migrating birds appear to find it difficult to remain oriented when they cross such areas. And birds that hatch in such areas may have magnetic compasses that are completely awry.

One might then ask if birds’ navigational ability is affected by the proliferation of electromagnetic fields emitted by mobile phone base stations and other antennae. It is unlikely that overall migration patterns are altered, but there is no definitive evidence either way. Reports of increased navigational error among homing pigeons have been ascribed to increased sunspot activity rather than man-made antennae.

Despite their highly developed navigational sense, birds probably also possess a “map sense” – an ability to navigate to a set target such as the nest-boxes where they bred the previous year. The functioning of this sense remains a mystery, but it is likely that birds can combine information from a variety of factors (sun, stars, magnetic fields and topography such as coastlines and rivers) to determine their position.