Where the wild things go

Every year in the spring and autumn billions of migrating animals travel thousands of miles between continents. The arctic tern (*Sterna paradisaea*) makes a round trip of 35,000km, effectively circumnavigating the globe, to travel between its wintering and breeding areas. But how much do we know about animal migration?

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Title image: Arctic Tern (*Sterna paradisea*) adult pair, Iceland. Photo: Mark Sisson/FLPA

Since the time of Aristotle 2000 years ago, migratory movements have fascinated mankind. Over the last 100 years, immense effort has been put into understanding the nature of the migratory movements that animals, especially birds, make. Yet for many of these species we are only a little further in understanding where they go or how they get there than Aristotle was (Wikelski et al, 2007). How does a bird that travels thousands of miles accurately relocate its wintering and breeding grounds year after year, while facing constant challenges of displacement by weather and the variability of environmental conditions along the route? Indeed, what challenges does it in fact face along the route and how do these affect its ability to reach its endpoint? How do migrating butterflies such as the Monarch (*Danus plexippus*) reach the Gulf of Mexico from the northeastern United States? Why do some bats hibernate while others from the same region apparently migrate 2,000km south to do the same?

In the case of the bat we say ‘apparently’ because to date nobody has been able to track a migrating insectivorous bat. Evidence for migration in bats comes from the seasonal distribution of the animals and anecdotal observations, not from the ability to observe the migratory route.

This highlights the problem of studying small animals and reveals an amazing lack of knowledge about many species that are important for agriculture and for disease transmission. This is not to mention conservation and climate change issues. Much of the previous research on migration and orientation in smaller animals has been focused on birds and thus we will largely take examples from them.

Why don't we know more?

In 1984 a book was published entitled *Bird navigation: the solution of a mystery?* (Baker, 1984). However, 20 years later the answer remains 'not yet'. So difficult has been the task of studying migrating animals in the wild that much of what we know about their orientation mechanisms and physiology during migration has been derived from either laboratory-based studies or from following only parts of their paths.

Laboratory studies have discovered that birds use a magnetic compass and a star compass, they have studied the physiological changes that prepare a bird for a migratory journey of thousands of kilometres, and they have shown that turtles and newts may use the earth's magnetic field to locate their position, i.e. as on a map.

In the case of migratory birds, laboratory studies take the form of an Emlen funnel. A bird hops around in a funnel, lined usually with typewriter correction paper, and the scratches it makes are analysed for direction. It turns out that during the migratory season, the scratches are often concentrated in the same direction along which free-flying conspecifics migrate. This has allowed researchers to study the environmental cues that these animals use to take up a migratory direction.

However, for an animal travelling thousands of kilometres, it is hard to reconcile this behaviour with hops of a few inches in a funnel. This becomes more of an issue with the discovery that even non-migratory birds show migratory restlessness. On a migratory journey, environmental conditions change vastly but this is not reproducible in the lab.

The problem, in the case of wide-ranging animals such as birds, bats and insects, is that the ability to follow the path an animal makes during migration over hundreds or thousands of miles is one of the greatest challenges in biology. So far researchers are largely unable to study the orientation and navigation of small animals in the wild over large distances.

How have researchers tried to overcome this and take the study of animal movement into the wild? For field-based study of avian navigation, researchers have for many years relied on a 'model' species, the homing pigeon, *Columba livia,* which will often reliably return to a home loft, and will usually be oriented in the direction of that loft soon after being released from a distant site, all other things being equal.

It turns out that the homing pigeon uses many of the same cues for orientation as have been shown to be used by migratory birds, such as a sun compass and a magnetic compass. However, in one aspect homing pigeons may differ. They appear to use their sense of smell to tell them where they are and which direction they need to go to return home. This method of homing appears to have only a short range however, (at most 700km) and does not explain the ability of migrating birds to relocate their wintering ground after displacements of thousands of kilometres. We still do not know what migratory birds use, although several experiments in the laboratory hint at the magnetic field playing a role (Wiltschko and Wiltschko, 2006).

Thus research on orientation and navigation in birds is caught between studying the behaviour of animals that move thousands of kilometres by either observing them hop in one place, or by studying a 'model' species that may not be a fully accurate representation of the animals it aims to represent.

In insects, laboratory studies are possible but no suitable model species exists and so field studies are relatively rare (Wikelski et al, 2007). In bats, the situation is worst of all: a lack of either suitable laboratory behaviour or of a model species for field study makes our knowledge of migration, orientation and navigation in these animals surprisingly poor.

Why do we need to know more?

It would be unfair to just dismiss the wealth of data from orientation cage experiments and from homing pigeon research, yet there are several examples which demonstrate why small scale experiments alone do not give a complete picture. For instance, a laboratory-based study showed that an intact trigeminal nerve was necessary for magnetoreception in pigeons (Mora et al, 2004). However, when a homing study was performed it was discovered that an intact trigeminal nerve was not necessary to allow pigeons to home: rather, an intact olfactory nerve was needed.

This confirmed that olfactory cues are a necessary component to allow pigeons to home, but that the magnetic field appears to play no role (Gagliardo et al, 2006). This result indicated that the conclusions of the former paper (i.e. that magnetoreception was necessary for pigeon homing) were unwarranted.

Laboratory studies of the compass system in migrating birds indicate that the magnetic compass is a reference system upon which all other compasses are calibrated (Wiltschko and Wiltschko, 1995). However, a recent field based study on migrating thrushes, demonstrated that the sunset was the primary calibration reference (Cochran et al. 2004) in Catharus thrushes.

Clearly then, research based only on laboratory studies is incomplete; we need to be able to track the behaviour of migrating birds, bats and insects in the wild to test and confirm hypotheses created from laboratory studies.

How do we find out more?

Ringing recoveries

To accurately study the behaviour of wide ranging animals in the field (that are cryptic, shy and often faster than the researchers studying them) they must be tracked. Ringing data in migratory birds was the first attempt to accurately document the migratory paths of birds but it requires immense effort and coordination in order to accurately sight the animal. In most species, many thousands of ringed birds are required to obtain just tens to hundreds of data points. Ringing recoveries have indicated much about the start and end points of migration in many species of birds, but not much in between.

Figure 1. (a) Satellite transmitters can be fitted to large birds such as this Marsh Harrier and then (b) their global movement patterns can be tracked. (Track data from Fuller et al. [1998], Hake et al. [2001, 2003] and Kjellén et al. [2001])

Satellite tracking

In the 1980s a breakthrough was made in animal tracking technology with the emergence of satellite tracking systems such as ARGOS. In this a receiver is attached to the animal's back and sends a signal to the satellite which calculates the animal's position. A wandering albatross (*Diomedia exultans*) was tracked through the entirety of its foraging path (Jouventin and Weimerskirch, 1991), a journey of some 3,000km. With the advent of this system, large birds (over 300g weight) could be tracked on their migratory journeys and the data remotely downloaded via the satellite (Figure 1). The receivers have not yet reduced in size sufficiently for birds or other animals less than 300g to be tracked – the smallest radios are now about 9 grams and they are not expected to become much smaller.

Most larger birds are social migrants (i.e. they migrate in groups). Their migration mechanisms have been influenced by this and may not be the same as in the smaller passerine birds that make up the bulk of migrating species.

GPS

At the same time as satellite tracking was becoming a reality, the US military installed a satellite system which could pinpoint one's location to an accuracy of just a few metres. GPS has since come into everyday use, with SatNav systems in cars and even in mobile phones. This has led some to speculate that there will soon be no such thing as being lost. The arrival of GPS was greeted with great excitement by wildlife biologists. Potentially, here was a means to track animals with a precision of less than a metre. GPS would revolutionise the field.

Unfortunately we are still waiting for this to become reality. Several research groups have developed GPS tags small enough to fit on a pigeon, circa 15-20g, but only one research group has used it to perform an experimental study of navigation behaviour.

The other problem with current smaller GPS devices is that they require the animal to be recovered. This is fine for a homing pigeon which returns to its loft, or seabirds which return to a nest after foraging (although the occasional non-appearance of an animal at the end of an experiment may explain a certain reluctance to use these expensive devices), but it is not fine for a small migrating bird which would have to be re-caught at the end of its journey. It is possible to remotely download GPS data via satellite or GSM technology, but this increases both the weight and cost of the device.

The fact is that GPS, like satellite tracking technology, is still too large to track small birds, bats and insects. Advances in GPS have been commercially and military driven and wildlife biology is apparently not a productive enough avenue. The need for a device weighing less than 2g (including power pack) has so far not arisen outside of wildlife biology (although if the recent film of *The Da Vinci Code* is to be believed, the French police have a 'tracking dot' that would do just nicely. If it exists in reality, it is not readily available). GPS may very well one day revolutionise the field of small animal tracking but we have stopped holding our breath.

Radio tracking

Radio tracking is not a new technique. It was successfully used in the 1960s to track animals (Lord et al, 1962). Compared to satellite tracking it is relatively labour-intensive because the animal has to be actively followed by the researcher, who carries the receiver. As such it is a relatively underused technique for tracking animals.

As it is less accurate than either satellite or GPS, radio tracking is generally considered the poor relation of tracking technology. However, it has one advantage over the other systems: the transmitter that is attached to the animal can be as little as 0.3g and is the only one with a weight less than 1.5g that is necessary to track small passerine birds, bats and insects (Figure 2).

Radio tracking has recently been used to test theories of how the magnetic compass is used in thrushes (Cochran et al, 2004), to demonstrate the presence of a magnetic compass in homing bats (Holland et al, 2006) and even to track migrating dragonflies (Wikelski et al, 2006). In these experiments, animals were captured and fitted with radio transmitters. Upon release they were tracked with a combination of ground and aerial tracking in order to follow their paths. With small highly mobile animals, an ability to track from the air is often essential as terrain greatly reduces the ability to follow them for long periods (Figure 3). Radio tracking currently thus presents the only way to test hypotheses of navigation in the field in small wide-ranging animals.

Intriguingly, it is possible to pick up the radio signal emitted by these receivers from space, and a low earth orbit satellite would make radio tracking a far less labour-intensive process, while allowing the possibility of finally obtaining the full path of small migrating animals during their migratory journey (Wikelski et al, 2007).

Where do we go from here?

If we are to really solve the 'mystery' of bird navigation, we need to be able to study the behaviour of wild birds. To fully achieve this we need to be able to follow their path over their entire migration route. This

Figure 2. Radio tagged bats (a), birds (b) and insects (c), can be tracked from a plane and these transmitters are also detectable from low earth orbit.
Figure 2 © Christian Ziegler

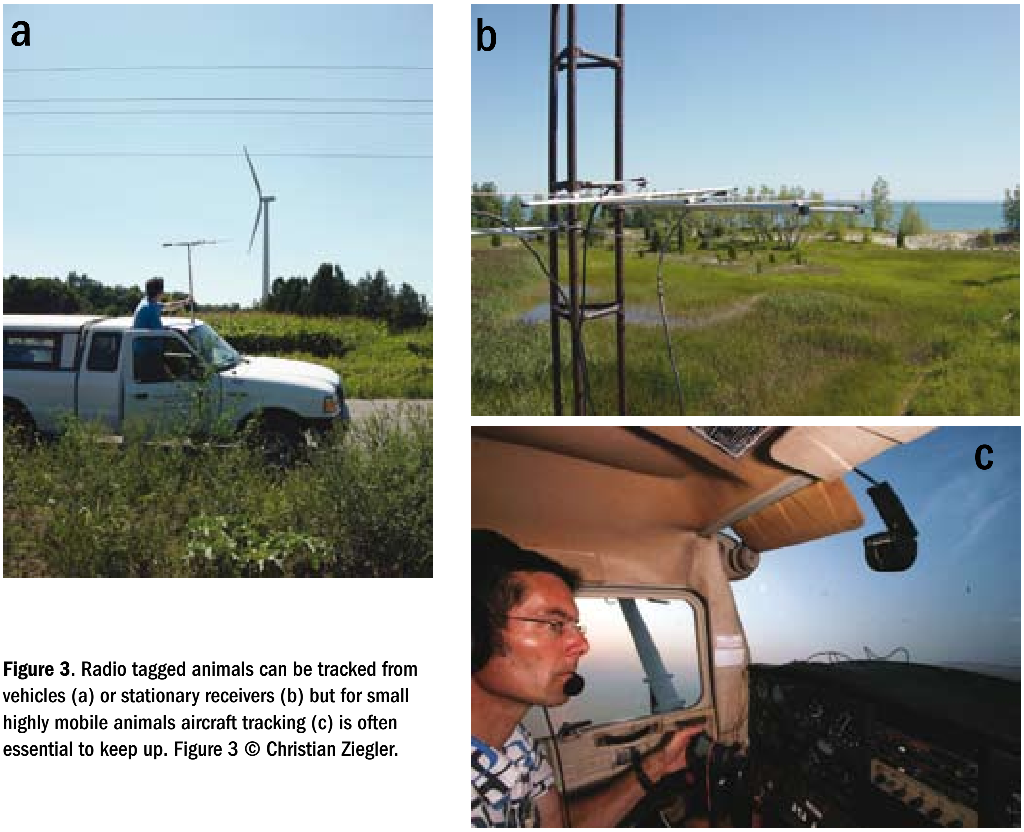

Figure 3. Radio tagged animals can be tracked from vehicles (a) or stationary receivers (b) but for small highly mobile animals aircraft tracking (c) is often essential to keep up. Figure 3 © Christian Ziegler.

requires either a satellite designed to receive the low-power radio signals from the smallest transmitters or the development of a small (<2g) GPS device whose data can be remotely downloaded.

Several recent initiatives are aimed at providing such a service to researchers. The ICARUS initiative (International Cooperation of Animal Research Using Space) is perhaps the most ambitious. ICARUS is working towards establishing a remote sensing platform that can track radio transmitters as small as 0.3g. Within ICARUS the technical (satellite) solution is currently being designed, with the development of a prototype satellite design by the Princeton University aerospace engineering design class in spring 2006. This will be followed soon by tests of various satellite design options. Progress of the ICARUS initiative can be tracked via the homepage www.IcarusInitiative.org. Other projects include the DTUsat (www.dtusat.dtu.dk), which is constructing a satellite to receive accurate GPS positions from 5g transmitters.

Being able to track small animals over large spatial scales is vital not just for investigating the problem of navigation but also for assessing the impact of animal movement on such commercially important issues as agriculture and disease transmission (Wikelski et al, 2007).

Finally, at a time when over a million species are under threat from climate change (Thomas et al, 2004), unless we can work out where they go and how they get there, there is no hope of assessing the full impact of human activity on the billions of animals that move thousands of miles every year. We need to know where the wild things go.

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James Crabbe is Executive Dean of the Faculty of Creative Arts, Technologies and Science and Professor of Biochemistry at the University of Bedfordshire. He is also Supernumerary Fellow of Wolfson College, Oxford University, and Visiting Professor at the University of Reading, and at Beijing Normal University at Zhuhai in China. Before becoming Executive Dean, he was Head of the School of Animal and Microbial Sciences and Professor of Protein Biochemistry at the University of Reading, and before that a Lecturer and Fellow at the University of Oxford. In 2006 he won the 6th Aviva/Earthwatch Award for Climate Change Research. He has over 125 publications in refereed International journals, several books and book chapters, and prize-winning commercial software in molecular modelling. His research specialties include computational biology; coral reefs; proteins and enzymes in health & disease. He is also a PADI Assistant Instructor and Master SCUBA Diver, having made over 430 logged research dives since 2000. He has made several classical recordings, one of which won an award, and has worked with BBC TV and Radio, and on the Science and Art programme of the Wellcome Trust.

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