T. ALERSTAM; M. ROSÉN

Flight of the navigators

The Arctic is a unique testing ground for studying how birds navigate long distances. **Jane Qiu** catches up with an expedition to unravel the signals that help birds on their migrations.

The captain of an ice-breaker has few problems navigating during the polar summer. The 24-hour sunlight provides constant illumination of the surroundings. When storms whip up, the captain can turn to a suite of global-positioning devices, which pinpoint the ship's location to a matter of metres. Yet all this electronic sophistication is put to shame by the migratory birds wheeling overhead, which navigate thousands of kilometres using nothing more than what is in their heads.

This summer, the ice-breaker *Oden* tracked migrating birds as they left the Arctic through the Bering Strait, the narrow waterway between Alaska and Siberia. More than 50 polar scientists had gathered as part of a wide-ranging project called Beringia 2005. Among them were Thomas Alerstam of Lund University in Sweden and his research team. They were there to shed light on one of ornithology's greatest mysteries: how do birds navigate during their annual migration?

Thousands of birds gather from all over the world to breed and rear their young in the summer Arctic, where the landscape is temporarily rich with thousands of plants and insect species. Birds such as the Arctic tern (*Sterna paradisaea*) fly 18,000 kilometres across featureless oceans to get there, and navigational skills are crucial. Drifting off course could cause the birds to miss the land and succumb to exhaustion. When summer wanes, they must once again find their way back, heading as far as South America, New Zealand or even the Antarctic.

The precise nature of their navigational gift has fascinated scientists for hundreds of years[1]. In the early nineteenth century, studies in basic magnetism, along with expeditions to the North and South Poles, inspired scientists to propose that birds are guided by an inner magnetic sense, like a compass needle. Nearly two centuries later, this seemingly bizarre idea was supported by the discovery of magnetite, or iron oxide, in the brains of some bird species. The magnetite is thought to act as a tiny compass[2].

Clued up

But birds use a number of different navigational cues. As well as Earth's magnetic field, these include the landscape, and the positions of the Sun and the stars. In controlled laboratory experiments, scientists have demonstrated that a number of bird species can use these cues and others, separately or in combination. However, no one knows how the birds put them together to find their way. "It is a different matter in the wild," says Alerstam. "Which cues do they use then? Are some cues more important than others? We have no answer to these questions yet."

To navigate, birds need to know in which direction they are heading. A magnetic compass sense can tell them; so can the position of the Sun, as long as they know the time of day. But direction alone cannot keep a bird on course, says Sönke Johnsen, a biologist at Duke University in Durham, North Carolina. "A compass sense is often not enough to guide an animal to a specific destination or to steer reliably along a long and complex migratory route," he says. Birds must also be able to determine their position relative to a destination and continuously recalculate their heading.

Just three parameters of Earth's magnetic field may be enough to guide the birds on their journeys, researchers think. The first, the strength of the magnetic field, varies with latitude. The second, dip angle, is the angle between the magnetic field line at a given location and Earth's surface; this angle is 0° at the equator and 90° at the north and south magnetic poles. The third parameter, magnetic variation, marks the difference between directions towards the geographic and magnetic poles, and varies depending on location on Earth's surface.

Exactly how birds derive their direction and position from this information isn't entirely clear. The problem is further complicated at high latitudes, where Earth's magnetic field lines converge. "As the dip angle approaches 90°, the magnetic field lines go almost straight into the Earth, leaving very little of the horizontal information that is necessary for orientation," says Alerstam. As birds get closer to the north magnetic pole, which lies 1,400 km from its geographic counterpart, magnetic variation increases. And magnetic minerals in the Arctic Ocean or the tundra can give rise to

T. ALERSTAM

Ocean cruisers: flocks of birds are tracked by the ice-breaker *Oden* (left) and its radar (right) as they migrate to the richness of the Arctic tundra (above).

anomalies in the magnetic field in the region. Daily variations in the magnetic field are also more erratic, because of the way that solar radiation affects the magnetic poles.

The 24-hour daylight of the polar summer means that the birds cannot even use the stars or daily rhythms of the Sun as a pointer. But the very complexity of the Arctic makes it an attractive location for testing birds' navigational strategies. "The only way to find out how birds cope in such complicated geomagnetic regions is to go out there and take a look," says Alerstam.

Bearing up

Two months into this summer's expedition, Alerstam wasn't certain that his team would find any answers. At 4:00 a.m. on 14 August, *Oden* was steering slowly through thick ice towards Wrangel Island off Siberia. The ship swayed heavily from side to side and the ice was so dense that it had to reverse slightly to gain enough momentum to advance another 50 metres. "We can only hope that the equipment will survive such harsh treatment," Alerstam wrote in his notes.

After a few hours, the ice thinned and *Oden* started to sail smoothly. In the ship's operation room, Alerstam was absorbed in watching hundreds of echoes appearing on the radar screens. Conditions were perfect after several days of rain, and *Oden*'s radar equipment had picked up echoes of large flocks of migratory birds heading out of the Arctic. Most of them were travelling east and south at high altitudes, 2,000 to 3,000 metres up. One echo even came from an altitude of 4,800 metres — a record height for the trip.

Radar tracking allows scientists to follow individual birds or flocks for up to 15 kilometres. By the end of the trip, Alerstam and his team had recorded nearly 600 such tracks. Based on these echo recordings, they calculated flock densities as well as the speed, direction and altitude of the migration. The motion of helium-filled balloons released from *Oden* was also tracked, and this information on wind patterns allowed the team to calculate the headings and trajectories of the birds themselves.

The different cues that birds might use for navigation generate very different trajectories, particularly at high latitudes. So researchers can calculate specific paths for each cue and compare them with where the flocks actually go, revealing which cues are most important to the birds. Alerstam calculated several possible routes for the species they wanted to track.

> "Expeditions such as Alerstam's are pushing bird-navigation studies from a steady state to a new level."
> — Martin Wikelski

He predicted that, if the birds navigate mainly using a magnetic compass, they would fly northeast from the expedition site towards high Arctic Canada.

Predicting paths for birds that are using a Sun compass is more complicated because the directional information depends on the bird's sense of time. At high latitudes, the distances between longitudes are so small that migratory birds may fly across three or four lines of longitude in a single day. Either the birds' internal clocks adjust to the local time as they go, or they remain constantly jet-lagged. Alerstam calculated that birds following the Sun and not adjusting to local time would curve to the southeast, passing through the Bering Strait and western and northern Alaska. Birds that fly using a Sun compass and correct it for the shifting time zones might be expected to fly a route somewhere between the Bering Strait and the magnetic route.

In 1994, Alerstam went on an expedition to the Russian Arctic and discovered that most birds in western Siberia flew towards the east at the end of the breeding season, a puzzling observation as the birds' destination was south. It turned out that their migratory paths were most consistent with a Sun-compass route without time correction, and Alerstam inferred that the birds were using the Sun to navigate while experiencing constant jet lag[3]. So on the *Oden* trip, says Alerstam, "we expected to see massive migrant flow — mostly on southeast courses — over the Bering Strait, western and northern Alaska, and northwesternmost Canada." That is exactly what his team found (see map, overleaf).

Coarse corrections

One curious feature of the strategy that uses the Sun without time correction is that it gives trajectories that approximate a 'great circle' route. A great circle is the shortest arc connecting two points on the globe. Following a great circle route is quicker, but requires the traveller to change compass course continuously; navigating with a constant magnetic compass course is easier, but results in much longer routes. Pilots and sailors regularly follow great circle routes with the help of complex geometric computing. And it seems that birds have found a way to do this too.

"It makes sense as this saves energy, which is important given that they have to fly

SOURCE: J. BÄCKMAN & T. ALERSTAM; J. BÄCKMAN

Spotting birds through telescopes helps to identify flocks picked up by radar.

thousands of miles," says Alerstam.

How have birds learned this navigational trick? For most animals that travel in east–west directions, changes in the time of sunset or sunrise reset their internal clock — but this process takes a few days. If it also takes days in Arctic birds, then as they migrate long distances towards the east or west they will be constantly out of phase with the local time, and misread the Sun as a result. Not knowing that they are out of sync, they will end up flying along the energy-saving great circle routes. "Maybe it is a lucky coincidence," says Alerstam.

Another possibility is that the birds can correct for the changing time zones, but actively suppress this adjustment. According to the late Eberhard Gwinner of the Max Planck Institute for Ornithology in Andechs, Germany, migratory birds in the Arctic should be able to adjust their internal clock very swiftly[4]. In the Arctic summer, some birds have low levels of melatonin, a hormone that is usually controlled by the daily cycle between light and dark. Lower melatonin levels suggest that the birds have a weaker clock in the polar summer, which may allow them to adapt quickly to changing environmental conditions, but could also be readily suppressed.

Of course birds must have some sense of time to find their direction, even if it is then slightly offset by jet lag. "There are other natural cues the birds rely on, such as the colour and polarization patterns of light," says Michaela Hau of Princeton University in New Jersey.

Once the birds find their way to lower latitudes, points out Alerstam, the conditions for navigation become much less extreme. He suggests that they may then use different strategies to find their way.

Are we nearly there yet?

One thing is clear from the past 30 years of research: birds use a delicate combination of cues to create a sophisticated backup system. If one cue is taken away from them, they will use the next down the line. And the cues that birds use and the way they navigate depends crucially on geographic location and weather conditions.

"At the end of the day, both fieldwork and laboratory experiments are necessary for understanding bird orientation. And they should always go hand in hand," says Martin Wikelski of Princeton University. "Expeditions such as Alerstam's represent one of those points where we are pushing things from a steady state to the next level," he says.

In another such push, Wikelski is working on an international initiative to study small-animal migration around the world. This project will use unmanned aerial vehicles or even a specialized radio receiver in low Earth orbit. Either approach would allow researchers to map the global migratory patterns of birds and insects carrying embedded miniature radio transmitters.

"To track individual birds around the globe will completely revolutionize avian research," says Alerstam. Such studies will not only shed light on bird navigation, but also have implications for preventing or containing animal-based epidemics such as avian influenza. The study of migrating birds may thus have a bearing on much wider questions than just how and why they fly. ■

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