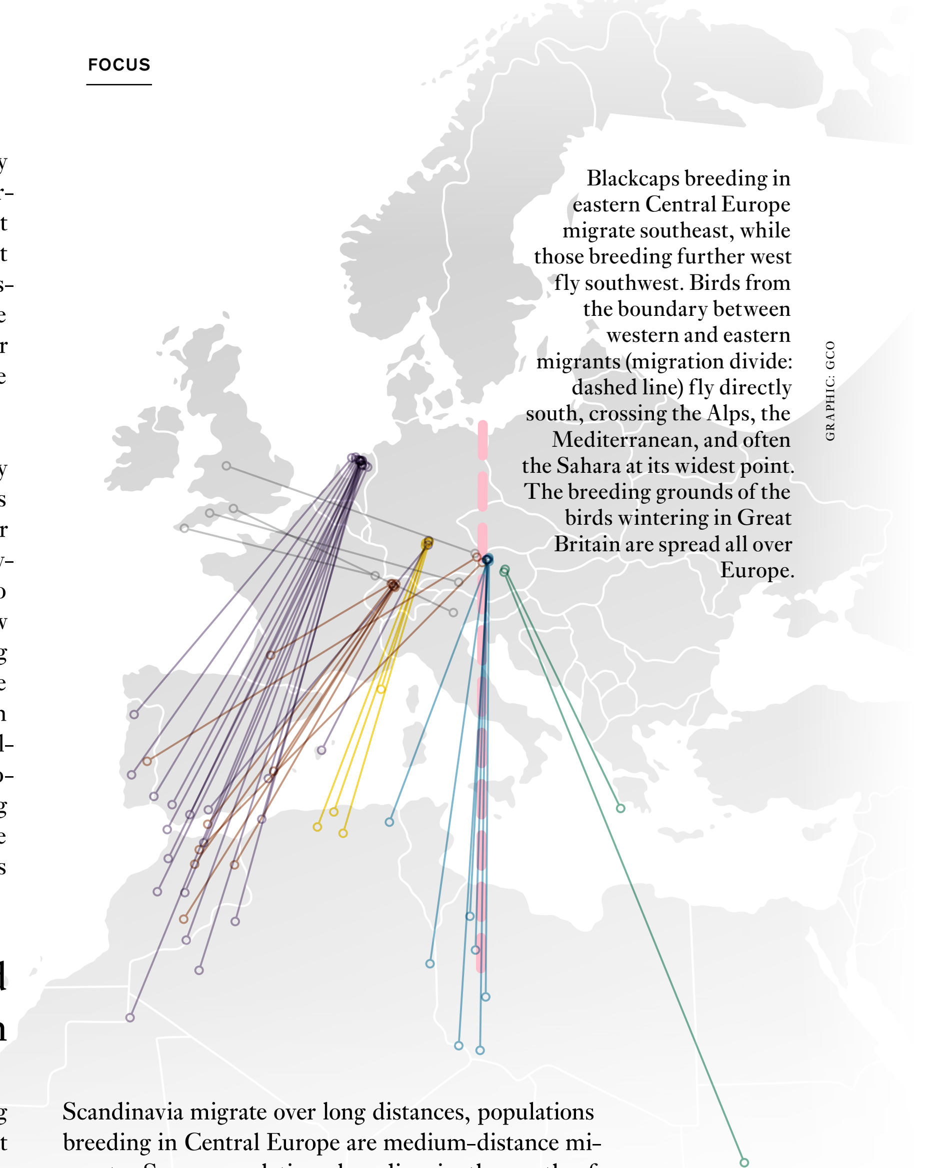
Male and female blackcaps are easy to distinguish based on phenotype: where the males have a black cap reminiscent of the headdress of monks, the crown of the females is colored brown.

ILLUSTRATION: CORINNA LANGEBRAKE

HOMESICKNESS IS IN THE GENES

TEXT: CATARINA PIETSCHMANN

This fall, millions of birds in the northern hemisphere once again heading south towards their non-breeding grounds. Miriam Liedvogel will be keeping her fingers crossed that some of them in particular will return safely next spring. The scientist at the Max Planck Institute for Evolutionary Biology in Plön has provided them with a bit of extra luggage to carry: specialized sensors known as light-level geolocators. Upon safe return next spring, these tiny light-sensors should reveal the birds whereabouts throughout the winter.



Blackcaps breeding in eastern Central Europe migrate southeast, while those breeding further west fly southwest. Birds from the boundary between western and eastern migrants (migration divide: dashed line) fly directly south, crossing the Alps, the Mediterranean, and often the Sahara at its widest point. The breeding grounds of the birds wintering in Great Britain are spread all over Europe.

GRAPHIC: GCO

Through the open window comes a symphony of many voices. Loud and confident, as if the singers understood perfectly that they are the focus of the work that is done here. The trees and bushes of the grove that surrounds the Institute of Ornithology in Wilhelmshaven host songbirds of all kinds, with a few male blackcaps, easily recognizable by their black feather caps, also chirping along. The females, meanwhile, are still busy raising their young.

It is mid-July, and the young birds have no idea that they will soon be setting off on a great journey: southwards to North Africa, where it's pleasantly warm in winter and there are plenty of insects to eat. They will be traveling at night and alone; their parents often fly off two weeks earlier. Nevertheless, the young ones will know exactly where they are going and where their wintering grounds will be. Miriam Liedvogel is Director at the Institute of Avian Research, a non-university research facility with its renowned field office "Vogelwarte Helgoland." Here and at the Max Planck Institute for Evolutionary Biology in Plön, where part of her working group conducts research, the 44-year-old studies the genetic basis of the orientation and navigation abilities of migratory birds.

Scholarships for bird migration research

Liedvogel's interest in bird migration manifested during her voluntary ecological year that she spent at the coast of East Frisia after graduating from high school. She then went on to study biology and earned her PhD at the University of Oldenburg. Initially, as a Marie Curie scholarship holder, she researched genes that control the timing of breeding in birds, and this was how she came to study the genetics of bird migration as a grantee of the Alexander von Humboldt Foundation in Lund, Sweden. This foundation eventually brought her back to Germany with a returnee fellowship, and since 2014, Liedvogel has been leading her own research group at the Max Planck Institute for Evolutionary Biology in Plön.

The desire to move – whether over land, through water, or through the air – is widespread in the animal kingdom. Birds possess this urge, but similarly, so do bats, butterflies, fish, sea turtles, whales and, of course, large mammals such as bison, buffalo, wildebeest, and reindeer. They all follow a genetic program that is passed from one generation to the next: "migratory genes" that have probably evolved, been lost, and re-emerged independently in these animals – necessitated, for example, by changing climatic conditions such as ice ages. Miriam Liedvogel wants to find out which genes control bird migration. The migratory behavior of blackcaps is the case study, since the birds exhibit the whole range of different behaviors; populations that breed in Scandinavia migrate over long distances, populations breeding in Central Europe are medium-distance migrants. Some populations breeding in the south of Spain only migrate a short distance, while other populations in southern Spain stay put. And even within a population, not all individuals exhibit the same behavior. Whether a bird from a partial migratory population decides individually from year to year if it will fly away or winter locally remains an unanswered question. Miriam Liedvogel therefore wants to find out whether one individual within a partial migrant population that migrates in one year does so regularly, and she's hoping to gain further insights from robins. These birds, too, are partial migrants in northern Germany: part of the population flies south in winter, while the other individuals winter locally. Conspecifics from Scandinavia, meanwhile, spend the winter with us.

Blackcaps present an especially good model for bird migration because their migration strategy varies not only in the propensity to migrate and migratory distance, but also in their direction of migration: populations breeding in eastern Europe migrate southeast in the fall and fly around the Mediterranean to the southeast, while blackcap populations breeding in western Europe circle past the Mediterranean to the southwest. This creates what is known as a "migration divide" – not a clearly recognizable border, but a narrow strip in which western and eastern migrants presumably mix.

The strip runs north-south across Central Europe between Berlin and Prague, and Liedvogel's team has found that breeding birds along the migration divide choose a "middle path." They fly directly south, crossing the Alps, the Mediterranean, and often the Sahara – the latter at a much wider point than if they were to fly around the Alps and the Mediterranean to the east or west. The last few decades have also seen the development of an entirely new flight route to Great Britain. But more on that later. The fact that songbirds inherit both the urge to migrate and the chosen route from their parents has been known for some time: Peter Berthold, Director at the Max Planck Institute in Radolfzell on Lake Constance until 2004, discovered this in the 1990s with elaborate breeding and crossbreeding experiments. His team mated parent birds from populations to the west and east of the migration divide and raised the young birds by hand. As soon as the parents left freely for their wintering grounds, the birds in the cage became restless. Without knowing the orientation preferences of their parents, the young birds tried to imitate them, fluttering excitedly in the same direction in which their parents took off. If birds from both populations were crossed with each other and the genes responsible for the flight direction were mixed, the offspring chose the middle path, i.e., the direct path to the south.

Liedvogel's research builds on Berthold's work. The main difference is that she no longer studies the animals under controlled conditions in a cage, opting instead to study them in the wild. But how does she know which migration direction a free-ranging blackcap has chosen in the fall and where it spent the winter? "The smallest GPS tracking transmitters still weigh three grams and are consequently too heavy for songbirds, which weigh about 20 grams, so we attach geolocators to the birds' backs," the researcher explains. These tiny archival "trip recorders" are 0.5-gram photocells with a memory card; they record the light intensity and thus

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PHOTO: MELINA MÖRSDORF FOR MPG

Miriam Liedvogel with a female blackcap. The researcher aims to find out which genes control the bird's migratory behavior. Birds at the institute are kept in large aviaries so that their behavior can be studied under controlled conditions.

the length of the day and night as well as the exact time. Using this data stored on the geolocator, the researchers can later determine, with an accuracy of roughly 50 kilometers, the particular location of the birds at any point on their migration, and thus reconstruct the route. "When the migration started, where the bird was flying, where and how long it rested, where its wintering grounds were, and when it flew back again – all this we won't know until we have recaptured the birds next spring and analyzed the data stored on the chip," Liedvogel explains. The researchers therefore have to hope that their birds will return to the same territory at their breeding grounds – which many of them do. Following this, they must retrieve the data, because it's still stored on the geolocator. It can take quite a bit of effort before a bird is netted. The researchers then remove the geolocator, download the data, and in addition to the migratory route, they also analyze the bird's genetic makeup using a blood sample.

GRAPHIC: GCO AFTER MOURITSEN, H. LONG-DISTANCE NAVIGATION AND MAGNETORECEPTION IN MIGRATORY ANIMALS. NATURE 558, 50–59 (2018).

This way, the researchers recover between 20 and 25 percent of the geolocators. So far, they have only tracked the routes of adults that had already successfully flown south once and returned. "We'd like to know how young birds fly to their wintering grounds the very first time, what they learn along the way, and how this newly acquired knowledge, combined with their inherited information, affects their subsequent routes," Liedvogel says. "Unfortunately, mortality in the first year is just too high for this technology to be working out." A migratory bird leaving its wintering grounds year after year has a lot of preparation to do each time: first, it molts in time to make sure all its feathers are fresh and unused for the long flight. At the same time, it builds up fat reserves. Blackcaps, for example, switch from insects to fruit as their food source in the fall and stock up on energy for the long journey. Many songbird species also change their chronotype from diurnal to nocturnal. In the cool of the night, they use less energy to cool their bodies, and therefore less fluid; in addition, they are better protected from birds of prey.

It is possible that just a few genes control all these processes, but these then act all the more strongly. "I suspect that a few master switches coordinate a complex network of further processes," says Miriam Liedvogel. One gene for a modulator of neuropeptide Y could be a candidate for such a switch, as a messenger substance that controls appetite and feed intake. "If this is produced in small quantities, the bird stays slim. If larger quantities are produced, appetite increases, and a lot of fat can be stored."

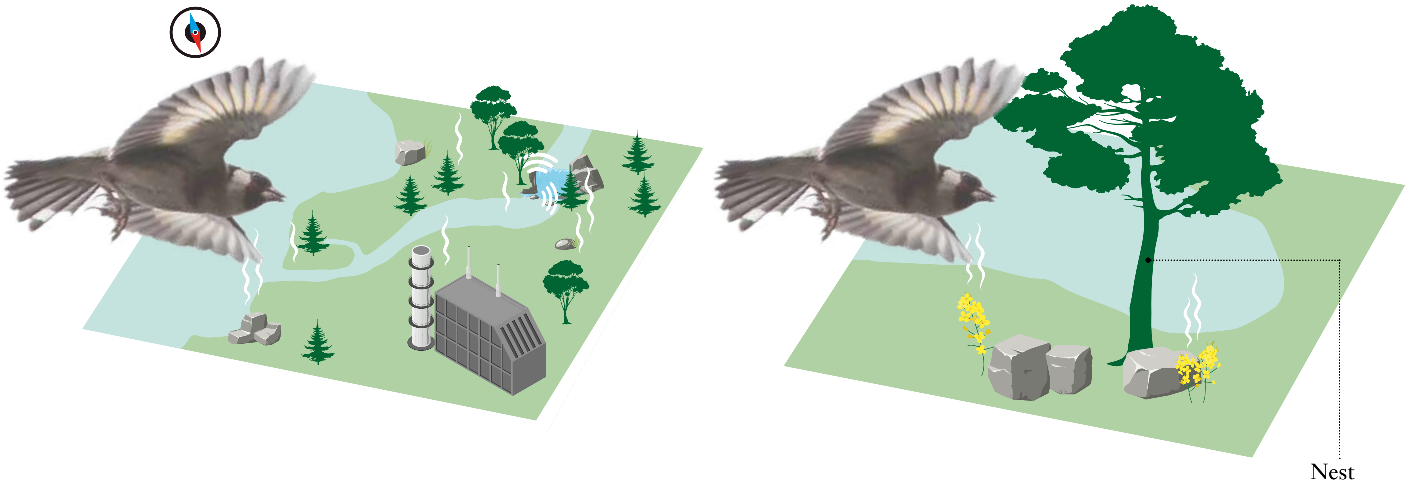
A build-up of fat reserves could be the domino that triggers the whole cascade. If the impulse fails, then the signal to leave also remains absent. Some populations breeding in Spain do not migrate at all and remain in the breeding area throughout the year. They do not accumulate fat reserves comparable to those of their migrating conspecifics, even during the migration period.

When a blackcap sets off for migration, it instinctively knows the direction, as Peter Berthold's experiments have shown. Since it flies at night, it can use the stars for navigation, and it also has a magnetic compass to keep its bearings. Other species that mostly migrate during the day follow conspicuous landscape features such as rivers, railroad tracks, or coastlines. They remember good resting places and include them as stopovers in their flight planning. But how does the small bird find its way when flying alone in the night sky? It orients itself according to the rotation pattern of the stars and the Earth's magnetic field – even when the sky is cloudy. According to the researchers' findings, there is a specific area in the bird's forebrain for night vision. "Since birds apparently perceive the Earth's magnetic field through their eyes, this area is probably also involved in magnetic field orientation," Miriam Liedvogel explains. This magnetic sense seems to be the most important aid to orientation, and it is possible that the birds inherit a kind of magnetic memory from their parents: "This is the right place, this is where I need to land." And on their return: "This is where I come from." Their sense of smell may also play a role. And what about when landmarks disappear, such as the River Po in northern Italy, which dried up this year? This is not a problem, because the migratory birds' "navigation system" has a back-up. "If

SUMMARY

Whether and where a bird migrates in fall is something it inherits from its parents, but the genes that control migration behavior are still to be identified.

To prepare for migration, birds change their behavior and metabolism. These adaptations are controlled by complex networks, which may, in turn, be regulated by a few controlling genes.



Birds can use various navigation aids on a long-distance flight: first, they orient themselves by the position of the sun and the starry sky as well as the earth's magnetic field (left). As soon as they reach their destination, smells, conspicuous landscape features, background noise, and the magnetic compass provide important clues (center). To orient themselves within their breeding area and find their nest, for example, birds rely on prominent landscape features such as trees or bodies of water as well as their sense of smell (right).

one navigation system fails, the bird can fall back on other strategies, such as the magnetic map and the star compass."

Unfortunately, in many areas of the world these days, the night is no longer dark. Landmarks that birds previously used to orient themselves are now outshone by light pollution, which can easily cause migratory birds to veer off course. "We know of several cases especially in the US, where thousands of dead birds are regularly found at the foot of illuminated skyscrapers during migration periods," Miriam Liedvogel recounts.

The global decline in insects and the climate crisis are likewise causing populations of many migratory bird species around the globe to plummet. "The hardest hit are the long-distance migrants, because their migration program is the most firmly fixed at the genetic level. If they leave too late in the fall, it may already be too cold, and they will freeze to death on migration." Short- and medium-distance migrants like blackcaps cope better with such changes. Due to the mild winters, blackcaps are now returning to northern Germany from the south three weeks earlier. "This is good for them because the oaks are sprouting earlier these days. This in turn means that the moth caterpillars, which feed on the leaves, become available earlier in the year as a source of food for rearing the young," explains Liedvogel.

The speed at which birds can adapt to new conditions is shown by even more profound behavioral changes through which the animals react to the warming climate. Since the 1960s, ornithologists have observed that an increasing number of blackcaps are turning northwest to overwinter in the British Isles instead of flying south. The birds are lured to the parks and gardens of Great Britain thanks to the mild winters resulting from the Gulf Stream. Extra food is an additional incentive: the British are known to be bird lovers, stocking countless feeders year after year and even baking special bird cakes. Added to this is the much shorter flight distance. "A study, in which many enthusiastic volunteers participated, has shown that birds wintering in Great Britain are able to replenish their fat reserves much faster and leave for their breeding grounds ten days earlier than their conspecifics wintering in the south. This would also allow them to choose the best territories for breeding," Liedvogel surmises.

Wintering in gardens can even affect the birds' body type: garden-dwelling blackcaps have longer bills and rounder wing tips. Likely an adaptation to their change in winter ecology: eating different food, living in gardens where better maneuverability is beneficial, and flying shorter migratory distances overall. It would appear that the blackcap is rapidly adapting its behavior, physiology, and morphology to changing conditions, which is apparently benefiting it at present: unlike many other bird species, such as the pied flycatcher, blackcap populations in Germany are stable and even increasing slightly. Flexibility and adaptability could also guarantee its survival in uncertain times in the future.

www.mpg.de/podcasts/gehen-oder-bleiben (in German)