Elusive. Migrating bats have proven tough to study.

ECOLOGY

Deadly Flights

Massive wind turbines seem to be killing more and more migratory bats, prompting research into these neglected creatures and efforts to minimize the toll

On a warm, late-April night, Volker Kelm drives his battered station wagon across a bleak expanse of scrubby fields a few kilometers from the German border with Poland. The site is a brown coal strip mine owned by the German energy giant Vattenfall; the only other vehicles on the access roads are massive earthmovers. The Berlin-based environmental consultant parks on a dirt access road and pulls out what looks a bit like an old-fashioned tape recorder but is actually a monitor capable of picking up ultrasonic calls from bats ranging up to 120 kilohertz.

Tuning the detector to the 32-kilohertz range favored by *Nyctalus noctula*, one of Europe's most common bat species, Kelm starts scanning the sky. At 20:59, just as the day's last light dwindles away, the bat detector begins to chirp. Kelm watches as a trio of *Nyctalus* bats—known as the common noctule all across Europe—makes their way across the field in the direction of a long line of blinking red lights on the horizon: dozens of wind energy turbines, a night's flight away.

With 40-meter blades whose tips move at up 360 kilometers per hour, wind turbines are what bring Kelm out tonight to spy on bats. Vattenfall wants to build a new wind farm on a tapped-out part of the mining site, but the turbines have a reputation for killing bats and European regulations compel the company to hire someone to conduct an environmental assessment. At a glance, the mine-scarred ground seems an unlikely home to bats. "For bats, the countryside here is not that interesting," Kelm says. "There are no meadows, no rivers—it's really a desert here."

But scientists have learned that even if there are no bat roosts nearby, wind turbines can pose a threat. Like many birds, some bat species are migratory, moving long distances on a seasonal basis, usually from summer feeding grounds to winter hibernation sites. The common noctule, for example, lives in forests during the warm summer and fall months, but may travel hundreds of kilometers to caves to hibernate. Fortunately for Vattenfall, the three *Nyctalus* bats spotted by Kelm are the only migratory species he will see all night, despite also using night-vision goggles.

Kelm's surveys won't always bring such good news. With wind power booming around the world—in Germany alone, nearly 20,000 wind-energy installations have been built since 1990—researchers are seeing a marked increase in dead bats. The turbines simply rotate their blades too quickly for the winged mammals to avoid. "There's nothing that fast in nature," Kelm says. "They're using sonar to look for butterflies and insects, not windmill blades."

The deaths have led to a flurry of research on migratory bats and their behavior. "The problem with bats and wind energy has pushed a lot of work that wouldn't have occurred otherwise," says Edward Arnett of the Austin, Texas–based nonprofit Bat Conservation International. Indeed, at a January conference in Berlin on migratory bats, wind farms were a dominant theme. Scientists are racing to figure out what brings the bats in contact with wind turbines, and what can be done to save them.

There are no easy answers, in part because little is known about migratory bats. "There are huge questions: 'How big are the populations? Where do they migrate? Are they really being killed by wind farms?' Sometimes it looks like that, but we don't know," says Martin Wikelski, an expert on bat migration at the Max Planck Institute for Ornithology in Radolfzell, Germany. And without concrete data, persuading government regulators and energy companies to relocate proposed wind farms, let alone change the operations of existing turbines or shut them down, is difficult.

Bat signals

The first hints of a problem were reported in Europe almost a decade ago, when ornithologists and environmental consultants looking for evidence of bird collisions at wind-energy sites began noticing dead bats on the ground. The bat fatalities became particularly apparent in Germany, which has the most wind-energy facilities in the world and is a central location in Europe that makes it a crossroads for migratory birds and bats.

Still, getting definitive death counts wasn't easy. Bats are small, light, and hard to spot without experience and training. "They look like little rocks on the ground. They sort of blend in because of their size and color," says Boston University bat biologist Thomas Kunz. By the time the sun comes up on a field full of bat casualties, scavengers such as foxes and coyotes may have made off with many of the carcasses, skewing the true number of bat kills even further.

In the fall of 2003, consultants looking for bird kills at Mountaineer, a wind-energy facility located atop a wooded, West Virginia mountain ridge, found large numbers of eastern red bats and hoary bats dead near the turbine blades. "There were a few hundred bat fatalities, unlike anything in the literature," says Paul Cryan, a U.S. Geological Survey research biologist based in Fort Collins, Colorado. Adjusting for the limitations of ground surveys, researchers estimated that the Mountaineer windmills alone were killing between 1400 and 4000 bats a year (*Science*, 9 April 2004, p. 203). Suddenly, the problem was no longer just a European one.

As dead bats were tallied on both sides of the Atlantic, one thing rapidly became clear: Wind-energy plants aren't equal-opportunity killers. "Migratory bats are the ones that die in wind parks, not the locals," Kelm says. Indeed, in Germany, 90% of bat fatalities at wind farms are from just five species, all migratory. North American researchers found similar patterns.

Unfortunately, migratory bats are notoriously uncooperative research subjects: They're nocturnal, solitary, and too small to be tracked with current GPS or radio transmitter tags, which at a minimum of 16 grams weigh almost as much as the average 20-gram bat. The traditional method to study these bats has

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been banding—attaching lightweight metal tags to a bat's forearm—but that relies on someone finding and reporting the tag, either by catching the bat somewhere along its migration route or finding a dead one. Still, thanks to banding programs that date back almost a century, German researchers have a general idea of European bat migration. It tends to be latitudinal, as opposed to the north-south migrations of birds, for example, but the data are frustratingly vague.

U.S. bat scientists have had it even worse. Because of concerns among biologists over disturbing bats during their hibernation period, there has been a moratorium on bat banding in North America for decades. As a result, there's almost no information on where migratory bats in the United States come from. "We don't really know where they are for much of the year," says Cryan. "They're not an easy animal to follow."

Lethal blades. Hoary bats (*Lasiurus cinereus*) are among the bats most often found dead (*inset*) near wind turbines in North America.

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With no way to document the migration corridors the animals use, researchers have turned to what biologist Erin Baerwald of the University of Calgary in Canada calls "destructive sampling," examining the corpses of dead bats found below turbines for clues to their diet during migration, brain development, genetics, age, and cause of death. Dissecting these bats has yielded some surprises. A study out last summer showed that many are killed not by collisions with turbine blades, but by barotrauma, fatal bubbles or ruptures in bats' lungs and hearts caused by the low-pressure zones the massive blades create in their wake.

Biologists are also deploying a rapidly advancing array of technological tools to study how bats interact with the blades and towers, some of which now reach as high as 150 meters. Researchers can now install "batcorders" inside turbines that are capable of recording hundreds of hours of bat calls. Other techniques include thermal imaging to watch bat behavior around turbines and night-vision goggles to spot their flight paths.

The data provided by these gadgets are yielding new insights into migratory bat behavior and clues as to how to reduce the impact of wind farms. Christian Voight, a behavioral physiologist at the Leibniz Institute for Zoo and Wildlife Research in Berlin, notes that during their long-distance travels and hunting forays, migratory bats don't stick as close to the ground as locals do, and that may put them on a collision course with the blades of windmills.

There's even a possibility the turbines actively attract bats. Researchers have observed tree bats flocking around tall trees during mating season, perhaps using them as rallying points for mating and roosting. As the most prominent object on the horizon, windmills may look like particularly tall trees to migrating bats crossing unfamiliar landscapes. That has led to concerns that preconstruction surveys like Kelm's are not that useful, because bat activity could increase after a turbine is built.

Minimizing the danger

Amid all the uncertainties, scientists are gathering potentially useful data. The activity of migratory bats spikes in the late summer and early fall, when the animals have given birth to their young and are actively hunting to store up energy for winter hibernation. "During the fall migratory period, there's twice as many bats and birds out there as in the spring," Kunz says.

And bat recorders placed on and around windmills detect the highest levels of bat calls on warm, dry nights when wind speeds are below 6 meters per second—ideal conditions for insects, and for the bats that feed on them. Drawing on such data, Arnett and bat biologist Oliver Behr of the University of Erlangen-Nürnberg in Germany have set up separate experiments in the United States and Germany to see if feathering windmills—shifting the angle of the blade so that it's parallel to the wind—on nights when bats are most likely to be active reduces bat fatalities. Arnett, for example, worked with Portland, Oregon–based Iberdrola Renewables to randomly feather windmills at a Pennsylvania facility over the course of 3 months last year. The results were encouraging: Daily ground surveys during the study found between 53% and 87% fewer bat fatalities at the inactive windmills.

And because bats tend to be most active on nights with low wind speeds, Arnett says the financial impact of "operational mitigation" would be minimal. "The projected loss to the facility was 0.3% to 1% of annual production," Arnett says. "We think it's worth it to reduce the fatalities." This summer, Arnett is continuing the study and also testing acoustic devices that might drive bats away from windmills by interfering with their sonar abilities, much as marine biologists have similarly warned dolphins away from fishing nets.

For his part, Kelm will be back at the German strip mine every 10 days for the next 5 months, listening for the calls of the common noctule. Ironically, the very wind turbines that threaten these creatures of the night have helped scientists understand them better. "In the last 15 years, people have started really talking about bats, really brought them out of the darkness and into the light, so to speak," Kelm says. "Wind energy provoked research and has provided results."

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