IN BRIEF

**Automated-sensor networks** monitor much of our environment, but some data collection in the digital age still requires the efforts and close analyses of phalanxes of context-sensitive human beings who can help solve problems of scale.

**A field called citizen science,** which involves public participation in research, marshals laypeople's observations, often by way of high-tech consumer devices and machines.

**Based at the Cornell Lab** of Ornithology, in collaboration with the National Audubon Society, eBird is one of the most mature such efforts. It and its ilk have yielded academic-caliber results in astronomy, computer science and public health, while giving skilled amateurs more opportunities to contribute.

CITIZEN SCIENCE

# Data on Wings

A modest effort to enlist amateur bird-watchers in the cause of ornithology wound up producing a fire hose of data and helping rewrite the rules of science

*By Hillary Rosner*

**Hillary Rosner** has reported on science and the environment around the globe—from Borneo to Nicaragua and from Iceland to Ethiopia. She was awarded an Alicia Patterson Foundation fellowship in 2012.

IN THE 230-ACRE FOREST BEYOND STEVE KELLING'S WALL-TO-WALL OFFICE WINDOWS, 50 SPECIES OF migratory birds—warbling vireos, rose-breasted grosbeaks, cedar waxwings—have arrived overnight. On this early May afternoon their calls ring through the forest in a giant songbird mash-up. How Kelling, or anyone here at the Cornell Lab of Ornithology in Ithaca, N.Y., can concentrate on work is a mystery.

Of course, the scene beyond the window is the work. Kelling pulls up an animated map on his laptop. It is the U.S., etched in white against a black background. A bar below the map shows the passage of time, a year in total. At first, nothing happens. Suddenly, around April, a burst of orange appears in southern California. It spreads like flames to the north and east, until the entire western third of the country is ablaze, glowing and flickering in various shades of orange and white. Then it reverses, the color vanishing from north to south, until, by November, the whole map is dark again. We have just watched the annual migration of the western tanager.

More than 300 species now have their own migration maps, generated with data collected by eBird, the 10-year-old citizen science project that Kelling oversees as director of information science at the lab. In a recent month roughly 11,000 bird-watchers uploaded more than three million sightings to eBird's database, which now contains more than 110 million records. Some 90,000 people have participated overall, and the number of records is growing by about 40 percent every year.

Birders are known for their compulsive commitment to and meticulous habits in recording their observations. Yet until recently, sharing them has taken place haphazardly and largely apart from the work of scientists. That is changing. Kelling and his colleagues are pioneers in the emerging world of citizen science. Technology—Wi-Fi, smartphones, processing capability—has revolutionized what science can do with ordinary people's data, enabling a standing army of amateurs eager to participate in real research.

Ornithologists are not the only ones benefiting. Scientists from fields as diverse as ecology, anthropology and public health have begun to take advantage of the link that technology has given them to regular people willing to work for the simple joy of participating—or the payoff of results. (The data from eBird alone have spawned research on topics from climate science to artificial intelligence.) So far citizen scientists have discovered unknown galaxies, determined elusive protein structures, and gathered evidence needed by land managers to help protect forests and watersheds. The results from eBird—perhaps the best-known citizen science venture—show how valuable public involvement can be to a specific area of research.

Cumulatively, however, the spread of citizen science may amount to something much larger, signaling a shift in the way scientists and the public think about the enterprise of science. A new age of participatory science is taking shape at the exact moment when society may need it most—as we cope with complex problems such as climate change that require both copious data and an engaged citizenry. "Some of our biggest conservation, scientific and social challenges," says Abe Miller-Rushing, science coordinator at Acadia National Park in Maine, "can't be addressed without it."

## BACK TO THE ROOTS

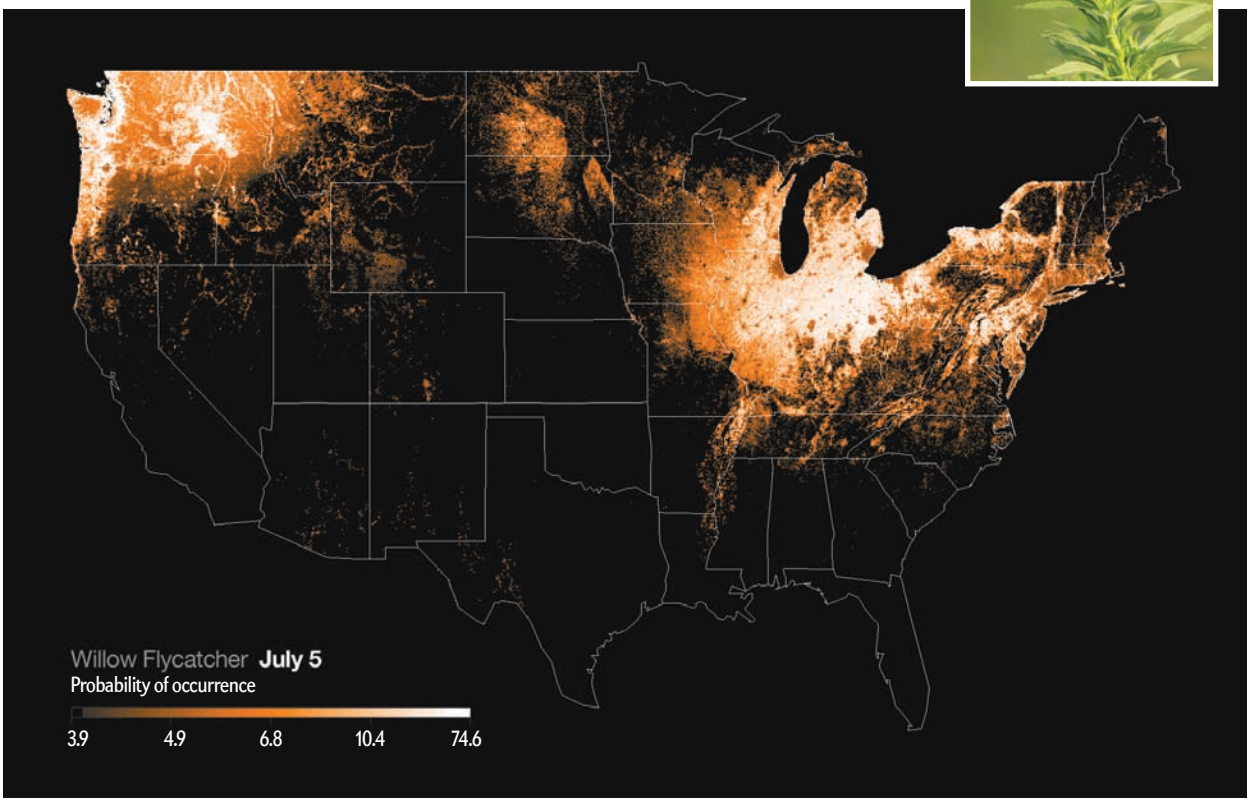
FOR STEVEN MLODINOW, an avid birder and family practice physician based in Longmont, Colo., participating in eBird makes him feel a bit like a modern-day Linnaeus, the 18th-century Swede who is considered the father of modern taxonomy. "If you go way back," Mlodinow says, "naturalists were all untrained, and science was largely driven by people who were self-trained or minimally trained at universities. So as a doctor, I feel like I've gone back to, say, 18th-century Britain."

Since the dawn of human expression, people have observed the world around them and recorded what they saw. Amateurs have always participated in science. Thomas Jefferson collected 50 years of weather data; Henry David Thoreau assiduously record-

PRECEDING PAGES: PAUL NELSON

# Powerful Public Data

**This still shot** from an animated forecast of the year-round, migratory behavior of the willow flycatcher population relies on a predictive model fed with data collected by eBird volunteers. Such animated migration maps have yielded biological insights about more than 300 U.S. species. Maps for Canada, Central America and South America are in the offing. The photograph at the right shows a flycatcher.




ed plants' flowering times in his local woods. Some of science's biggest breakthroughs were done by people with little to no formal training in their field—Nikola Tesla, Srinivasa Ramanujan, Isaac Newton, Charles Darwin.

Meteorology may be the clearest example. Back in the 1840s, the first secretary of the Smithsonian Institution envisioned a network of volunteer weather stations. The project swallowed a sizable portion of the institution's budget and at times had 600 participants. The telegraph helped volunteers share the nearly half a million observations gathered annually. Government agencies eventually stepped in, but a nationwide network of cooperative weather stations persists today. It hatched discoveries about weather patterns, annual snowfall, plant hardiness and the importance of topography. It also made possible the drought monitor maps we still depend on.

Input from volunteers constitutes "the majority of what we know about climate in the past," said Nolan Doesken, Colorado's state climatologist, during a recent presentation. "To put it in proper historical perspective, we need that baseline."

Ornithology is another natural fit for amateurs. Birders, after all, are already primed to collect data; they have been doing it for centuries. Lighthouse keepers, for one, kept detailed records of birds they saw. The National Audubon Society's Christmas Bird Count has been around for more than 110 years. When eBird first launched in 2002, its leaders had a simple, one-way notion in mind: How could birders amass data so that they would be useful to scientists? Despite the fact that researchers have built large-scale automated-sensor networks all over the world to monitor virtually every aspect of our environment (atmospheric carbon, stream flows, rainfall, nitrogen pollution), some data collection still requires humans. "There are no autonomous sensors that can identify birds—or any organism, for that matter," Kelling says. "So what you have to do is replace those autonomous sensors with a type of sensor that can make the right kind of decisions and observations." In other words, an actual person—in the eBird case, the kind who is obsessed with finding, watching, counting and bragging about birds.

The project quickly hit a wall, however. Birders were entering around 50,000 records each month, too little to be useful, and that number would not budge. "After two and a half years," Kelling recalls, "we recognized that we were failing. We needed somebody from the birding community to champion us." The

GLENN BARTLEY *Corbis (bird)*; COURTESY OF THE CORNELL LAB OF ORNITHOLOGY *(map)*

lab hired two experienced birders to oversee the project (and later added a third).

The key, the team quickly realized, was ensuring that birders got something out of the arrangement, too. The eBird scientists wanted data that could help with conservation. Yet that was not enough to motivate the bird-watchers, who had to spend extra time learning the database, changing their note-taking habits and uploading records. The new project leaders also pondered what tools bird-watchers would love.

Bird-watching is ultimately a form of list keeping. So, to attract the community, says Chris Wood, one of the project leaders, eBird would have to offer new and better things to do with those lists: organizing them, sharing them, using them as the basis for (mostly) friendly competition. Today eBird is almost like Facebook for birders, a social network they can use to track and broadcast their birding lives. The eBird database, as well as an associated smartphone app, lets birders organize everything from their life lists—all the species they have ever seen—to the number of times they have seen a particular species, to lists of what they have seen at favorite spots. Just as important, they can see everyone else's lists—then try their damnedest to outdo them. When Mlodinow saw two least flycatchers at an eastern Colorado grassland, he could quickly see that his was the earliest sighting of the bird that spring. "Yes, we got the record!" he exclaimed.

"It's hard to overestimate what a powerful motivating effect those games can have," Wood says later.

Sitting in a conference room at the Cornell Lab—more wall-to-wall windows on the chattering forest—Wood pulls up the records for a county in southwestern Kansas. "You can see who has submitted the most checklists and seen the most species," he says. Kelling, who has been sitting quietly at the far end of the table, suddenly pipes up:

"I'm the highest list in Tompkins County," he boasts.
"No, he's not!" Wood tells me, grinning. "He thinks he is."

Still, eBird is not all fun and bird games. Citizen science comes with serious challenges, perhaps the biggest of which is how to ensure that data are trustworthy. One way eBird's leaders help to maintain data quality is by relying on birders to serve as regional experts. In Colorado, Mlodinow and two other birders—science teacher Bill Schmoker and wildlife monitor Christian Nunes—spend hours every week uploading their observations and vetting others' records. They look at any data the system flags as questionable, up to 8 percent of the three million records entered each month. Their work helps to keep the records as accurate as possible. (It also trains algorithms to weight different contributors' records based on their level of expertise.)

These efforts seem to be bearing fruit. The eBird data are holding up and are beginning to have an impact on public policy. By overlaying eBird distribution data on U.S. public lands maps, researchers have determined which threatened or endangered birds occur on which federal agency's land at which time of year—knowledge the agencies use to determine budget priorities.

A new project using eBird data, known as BirdCast, issues migration forecasts—imagine a weather report that predicts flocks of Baltimore orioles instead of thunderstorms. "The cool thing about Doppler radar," Kelling says, "is it doesn't care what it bounces off of—bugs, smoke, birds." He pulls up a familiar-looking radar image of moving clouds. But he is watching something else: not the blue of the storm cells but smaller green areas—flocks of birds flying through the night. By combining eBird data with radar images, weather information and computer models, BirdCast will soon be able to generate weekly migration predictions for any area of the country. (Currently the lab issues weekly forecasts during spring and fall migration periods, as well as special reports for unusual events such as superstorm Sandy.) These reports, Kelling says, could prompt cities to turn off their downtown lights or wind farms to shut off their turbines on nights when thousands of birds are passing overhead.

Citizen science projects of all stripes are generating research with practical applications. LiMPETS, a long-term monitoring program on the California coast, relies on students and teachers to gather data that will help direct cleanups after an oil spill or other coastal contamination. The Wisconsin Department of Natural Resources draws on citizens to keep tabs on local air, water and wildlife. Across the globe in the African Sahel, the Meningitis Weather Project, run by the University Corporation for Atmospheric Research, used villagers' observations of local weather patterns to predict the onset of the rainy season, when meningitis risk drops dramatically and vaccinations become unnecessary; the project helps to extend the vaccine supply.

Beyond aiding public policy, citizen science solves a problem of scale. Scientists cannot be everywhere at once, a fact that has

BEYOND BIRDS

## How to Get Involved

If you would rather skip the Ph.D. and dive right into assisting with academic-caliber scientific research, here are a few resources to help find a citizen science project suited to your skills and interests.

**ZOONIVERSE:** Join hundreds of thousands of people who are participating in science projects on topics such as discerning signs of exoplanets in light-curve changes and describing digitized 19th-century piano scores. **www.zooniverse.org**

**SCIENTIFIC AMERICAN'S CITIZEN SCIENCE PROJECTS PAGE:** More than 100 mostly free projects are indexed and described on this mini site, which is updated weekly. Projects can be sorted by cost to participate and type of work: observation, questionnaire, fieldwork or data processing. **www.scientificamerican.com/citizen-science**

**AMERICAN GUT PROJECT:** It's not free or pretty, but you can take part at various price points, including an option that provides a stool, skin or oral sample collection kit. Simply put, participants help scientists characterize the microbial diversity of the American public and ascertain the impact of diet. **www.indiegogo.com/americangut**

**CITIZEN SCIENCE CENTRAL:** It's hardly all about birds at the Cornell Lab of Ornithology. This portfolio of more than 140 projects can be browsed by categories such as water quality, weather and astronomy. **www.birds.cornell.edu/citscitoolkit**

left us with what Arfon Smith, director of citizen science at Chicago's Adler Planetarium, calls "fogs of ignorance"—points on a map where we have almost no historical data on phenomena such as weather events or biodiversity. Expanding the number of people observing the world, whether flowers or stars or toxins, improves our capacity to understand it.

## A NEW FIELD OF SCIENCE

ON A SWELTERING AUGUST weekend in Portland, nearly 300 people packed a room at the Oregon Convention Center for the Conference on Public Participation in Scientific Research. Over two days participants showcased their projects, introduced databases and other practical tools, chronicled the historical contributions of amateurs, and made the case that public participation in science could be an engine for change. The conference concluded with a massive brainstorming session about what exactly citizen science would look like as a formalized field—with a professional organization, annual meetings and a journal.

Miller-Rushing from Acadia and two researchers from the Cornell Lab, Rick Bonney and Jennifer Shirk, hatched the conference idea over dinner one night. In 2006 the lab received National Science Foundation funds to develop best practices for citizen science. Now the lab is the field's de facto headquarters. Bonney is credited with coining the term "citizen science" in the 1990s; Shirk, curious why scientists would undertake these projects given the professional risk and potential for logistical headaches, is studying the field for her Ph.D.

One reason they are pushing to create an official discipline is to trade ideas across far-flung research areas: ecology, astronomy, computer science, epidemiology. The scientists of citizen science need a forum, Shirk says, "to get together and say, 'Here's what I'm doing, here's what we're struggling with.' " Researchers could draw from one another's success or failure with such tasks as recruiting volunteers or coping with a crushing amount of data.

For public participation in scientific research to become its own field, it will have to solve some challenges. For one, how do you knit together the vastly different goals and project types? Researchers have tried to catalogue projects, but at a fundamental level citizen science projects fall into two categories: those where the public directly serves the scientists and those where the scientists directly serve the public. (The two groups are not mutually exclusive; having better data on animal migrations or droughts or molecular structures arguably also serves the public.)

Galaxy Zoo, home to some of the world's best astronomical information, began with a group of postdoctoral researchers drowning in downloads from the Sloan Digital Sky Survey. Galaxy Zoo now includes images from the Hubble Space Telescope and has spawned a family of online citizen science projects called Zooniverse, in which volunteers help to make sense of data. Zooniverse's nearly 720,000 participants transcribe weather observations from World War I warships, identify species in photographs from the seafloor and categorize whale calls. The scientists benefit from all these projects. At the other end of the spectrum, researchers participating in University College London's new Extreme Citizen Science (ExCiteS) group are helping marginalized communities empower themselves through science. In a recent project, residents of one blighted London neighborhood collected more than 1,100 noise samples, using decibel monitors, to show that a nearby scrap yard was deafening. The university's geographic information system (GIS) experts turned the data into a neighborhood noise map, which was instrumental in convincing local officials to regulate the scrap yard's volume.

Such community-based projects turn science into a social endeavor. At the Portland conference, one participant spoke of "incorporating multiple kinds of knowledge"—information from indigenous communities, local hunters, or other people with traditional learning or a deep sense of place. That concept may be hard for some scientists to stomach.

Muki Haklay, co-director of ExCiteS, believes it is time to evolve. Researchers need to think of citizen science as simply "a different way of producing scientific knowledge," he says. When the London neighborhood measured noise levels, for instance, Haklay says that he did not present the results as the final scientific conclusion. He merely passed them on to local authorities as evidence that they needed to come take a look. "You make a claim for what it's worth and how it's relevant to people's life," he notes.

One of citizen science's most important contributions may ultimately be to spread scientific literacy by giving laypeople direct contact with the process of science. "I really like the idea," Smith says, "of increasing an understanding of the scientific method, involving people in the nitty-gritty of science. If you can see more of the actual process and get exposure to more parts of the scientific work flow, then that's going to be good."

Whether it is learning the difference between elliptical and spiral galaxies, discovering how a protein's structure determines its function, helping to count wildlife or deciphering the chemical composition of a local stream, the act of directly engaging with science can be transformative. At the Portland conference, Wallace J. Nichols, a marine biologist known for his work protecting sea turtles, produced a tangible ripple of excitement in the room when he compared citizen scientists to sea star arms that break off, float away and form new organisms. "You never know what they're going to do," Nichols said.

One sunny afternoon last spring, out for a tour of a Colorado birding hotspot with eBird's Mlodinow, Schmoker and Nunes, I asked why they devote so much time to the project. I wondered if they were just do-gooders or if they felt some kind of responsibility to eBird now that it had given them handy new tools. "For a lot of serious birders," Mlodinow replied, "the scientific part of it is of note. We're frequently trying to dissect subspecies, to figure out what the ranges of subspecies are—which isn't really known, especially during migration. I think, in the long run, this will change our understanding of where subspecies are distributed." Spoken like a true scientist. SA

### MORE TO EXPLORE


**Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy.** Rick Bonney et al. in *Bioscience*, Vol. 59, No. 11, pages 977–984; December 2009.

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**SCIENTIFIC AMERICAN ONLINE**
See maps of bird migration forecasts at
ScientificAmerican.com/feb2013/citizen-science