The Sleepless Forest Observers

Ecologists are using remote observation to advance their understanding of environments. Are they losing something in the process?

by

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B.A. Biology, Grinnell College, 2020

Submitted to the Graduate Program in Science Writing in partial fulfillment of the requirements for the degree of

Master of Science in Science Writing

at the

Massachusetts Institute of Technology

September 2023

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May 19, 2023

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Submitted to the Graduate Program in Science Writing on May 22, 2023 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Science Writing

ABSTRACT

In recent years, camera traps, acoustic recorders, genetic methods to identify organisms using DNA they shed into their environments (eDNA), tags on animals to log their behaviors, and aircraft or satellite remote sensing to identify environments and species have all become less expensive, and the quality of sensors and the methods to analyze their data have improved. As a result, ecologists are using remote observation more and more in their research. “The explosion is happening now,” says Taal Levi, an ecologist at OSU who studies quantitative wildlife ecology, conservation, and environmental genetics at the Andrews. A review article published in *Frontiers in Ecology and Evolution* found that the number of scientific publications with the keyword “eDNA” tripled from 2015 to 2018, the number with the keyword “camera traps” doubled, and the number with the keyword “bioacoustics” increased by 50%.

There are good reasons for this shift. Remote sensing can help researchers learn about ecosystems. Because sensors don’t always need someone physically present, researchers can use them to collect data at larger and finer scales and in places that are difficult to observe directly. Sensors can also detect a wider range of organisms than traditional methods. Levi says these technologies are like direct observation “but instead of just you, you’ve got 5,000 versions of you that can stay awake all night long.”

Simultaneously, researchers spend less time in the field when they use remote observation. And it is in the field where they often come up with research ideas and develop a deeper intuition for an ecosystem. Remote observation can also encourage the trend of finding patterns (that an animal lives in environments with specific characteristics, for example) without learning what causes those patterns (which of those characteristics are important to the animal and why).

The Andrews is one place of many where the explosion of remote observation is happening. It was established as a site for long-term science and management studies by the Forest Service in 1948 and designated one of the first of 28 National Science Foundation funded Long-Term Ecological Research (LTER) Network sites in 1980. LTER Network sites focus on long-term and large-scale ecological processes. As a result, the Andrews has a long history of research on forests, streams, and watersheds, which makes it an especially good place to assess the transition from traditional methods to remote observation. At the Andrews, researchers are trying to get the benefits of remote observation while avoiding the risks and to find a balance between remote observation and traditional methods. That requires being intentional within the fast-paced broader culture of scientific research. Their success determines the novelty, completeness, and

accuracy of their research, which in turn influences how society understands and manages its environments.

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The ridges sweep the sky, and the streams sweep the valleys in Oregon's western Cascade mountains. Three ridges and one stream define the 15,800-acre pork chop-shaped area that is the H.J. Andrews Experimental Forest (the Andrews). Like most of the Pacific Northwest, the Andrews is a patchwork of recently logged forests, 700-year-old ones, and everything in between. The old growth stands are dominated by cedars, hemlocks, and Douglas firs. Some Douglas firs stretch 250 feet high. Logs and stumps of dead trees surround the living ones and slowly turn to soil.

Change is constant at the Andrews. Research on and management of wood in streams exemplifies some of these changes. Before the 1970s, when a tree fell into a stream, land managers and loggers removed it, thinking it was unclean and restricted the movement of fish. In truth, fish and stream ecosystems are better off when wood is left in streams. "It's a whole ecosystem being modified if you place or remove those logs," says Ivan Arismendi, an aquatic ecologist at Oregon State University (OSU) who does research at the Andrews (The Andrews is managed by the USDA Forest Service's Pacific Northwest Research Station, OSU, and the Willamette National Forest). Researchers at the Andrews helped discover the importance of wood in streams, which helped shift management practices. Now, wood is left and even placed back into streams.

Though researchers know how wood in streams impacts aquatic organisms, they don't know how it impacts land animals. If land animals use it often, managers should focus on placing wood back into streams even more. And understanding what position of wood benefits land animals most would help managers choose where and how to place the wood.

Arismendi's lab wanted to find a way to observe how land animals use wood in streams. For a long time, the only option was direct observation — staking out by the stream and waiting for animals to come along. That approach takes a lot of time, and animals often behave differently around humans. Now, there is another option. Researchers began using camera traps to automatically take photos and videos of animals in the late twentieth century, but it was not until more recently that they have become advanced and inexpensive enough for projects such as this.

Deciding to use camera traps, Arismendi's lab strapped the small boxes to trees and pointed them towards wood in streams. When an animal walked or flew in front of the camera's sensor, the camera took a 15 second video.

If Arismendi's lab used direct observation, they would have spent most of their time collecting data. They would return to OSU with field notebooks full of descriptions of which animals they observed and what those animals were doing. Instead, they returned to OSU with SD cards and spent most of their time analyzing the data. They are dedicating several months to watching the thousands of videos they collect each year and manually identifying the animals in them and what they are doing.

The wood connects the land on either side of the stream, as well as the stream and the forest ecosystems. Land animals use wood in streams a lot — to cross, to rest, to find food, to eat. The videos have captured a bear slinking across a moss-covered log, a kingfisher holding a crayfish in its beak and banging it against the wood, two river otters in a precarious wrestling match.

Camera traps are just one of many ways that researchers can remotely observe organisms. There are also acoustic recorders, genetic methods to identify organisms using DNA they shed into their environments (eDNA), tags on animals to log their behaviors, and aircraft or satellite remote sensing to identify environments and species. In recent years, sensors have become less expensive, and the quality of sensors and the methods to analyze their data have improved. As a result, ecologists are using remote observation more and more in their research. "The explosion is happening now," says Taal Levi, an ecologist at OSU who studies quantitative wildlife ecology, conservation, and environmental genetics at the Andrews. A review article published in *Frontiers in Ecology and Evolution* found that the number of scientific publications with the keyword "eDNA" tripled from 2015 to 2018, the number with the keyword "camera traps" doubled, and the number with the keyword "bioacoustics" increased by 50%.

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A short walk from headquarters, the Discovery Trail loops through a stand of old growth forest. White tubes snake along an inconspicuous side trail, through ferns, moss, and soil. The sound of a fan grows louder. The trail ends at what everyone at the Andrews calls the Discovery Tree.

The Discovery Tree and the trees surrounding it are adorned with colorful bands. One is a wire strung with small, cylindrical blue beads that measures the tree's circumference. The circumference normally changes by 0.1 to 0.2 millimeters each day, contracting as the tree moves water up to its canopy and expanding each night as it replenishes that water. A thermos-shaped instrument with three prongs extending up from the top softly beeps and measures the wind speed and direction by how the wind distorts the sounds. One tree is full of a cluster of wires resembling power lines fallen from a pole. Sensors measure air temperature, humidity, wind, and leaf wetness every ten meters up its trunk. As an accessible place to visit for research and education, sensors are concentrated here. But they span the entire Andrews.

Researchers carry their data along the windy McKenzie River, through clearcut, burned, and undisturbed forests, through farms and urban sprawl. One-hundred miles later, they arrive at OSU. They spend most of their time here, amongst large brick buildings and six-wheeled robots that deliver food across campus.

There are people even farther away who use data collected by researchers at the Andrews. Approximately one-fifth of publications that use that data are by authors who did not collect it themselves. This is made possible by the now common practice in ecology of sharing the data used in a study after the study is published, which enables more scientists to use existing data and to combine multiple data sets and analyze broader patterns. Researchers must share data that was part of research funded by the National Science Foundation, which includes most research at the Andrews.

The shift to remote observation, however, is not uniform. Even within the Andrews, adoption varies. Some people are resistant. They are "old enough or old-school enough that they're just not going to adopt this method except through collaboration," says Mark Schulze, forest director. He identifies as part of this category. Though his research includes remote observation, he does so by collaborating with people who specialize in it. Other people are eager to adopt remote observation as their primary method of learning about the environment.

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Using remote observation, researchers can answer questions that they previously could not. "We probably always had the questions, but they were just things you'd pontificate about over a beer rather than something that you could actually try and address," says Matt Betts, an ecologist at OSU who studies animal behavior, species distributions, and ecosystem function at the Andrews. Betts, for example, wondered how forest fragmentation — forests breaking into smaller patches that are farther apart — affected animals in different areas of the world. He used remotely observed biodiversity data to study this at the global scale and found that, in regions with few historical disturbances, more animals were sensitive to forest fragmentation. So, to protect animals, it may be especially important to limit fragmentation in regions with few historical disturbances.

Remote observation also enables researchers to experience the Andrews differently. "I can think in ways that I wouldn't even have dreamed of, and I wouldn't even have acknowledged that I was limited in my dreams," says Michael Nelson, an environmental philosopher at OSU who formerly led research at the Andrews. Nelson has found this is especially true with LiDAR — a form of remote sensing that can create maps of the bare earth and each layer of vegetation using an aircraft that emits and receives laser pulses. With LiDAR data researchers learned that more complex forest structures and more diverse vegetation produce small areas with cooler climates that help some bird species persist in a warming climate.

Data collected using remote observation can also be at much larger and finer scales. In 1956, researchers began measuring high and low temperatures daily at one site in the Andrews. Now, as temperature sensors have advanced, they measure it continuously at more than 400 sites. With larger and finer scale data, researchers can study trends at almost any scale. "The processes operating at the centimeter scale or the Andrews forest scale are different than the processes operating at the global scale," says Jack Williams, a geographer at the University of Wisconsin-Madison who studies earth system science, paleoecology, and biogeography and is not affiliated with the Andrews.

One project exemplifies how remote observation expands the scale that data can be collected. For a long time, researchers had to be at the same height as a bird to accurately estimate where it was in a tree. "Our height estimations from the ground are wildly inaccurate," says Nina Ferrari, a graduate student at OSU who studies birds at the Andrews. But, she says, "It's pretty difficult to be in trees all the time." From 1996 to 1999, Dave Shaw, a biologist at Oregon State University who studies forest ecology, health, and insects, did just that. He surveyed birds from a gondola hanging from a construction crane in the Wind River Experimental Forest in Washington state. He did so for over 200 hours, but he only conducted surveys at one time of day and in one forest stand.

"What Nina has been able to do is really take this to a whole other level with acoustic monitoring," says Shaw. Ferrari can use acoustic monitoring to automatically record sounds, which enables her to survey birds for much longer and in many more places. She wanted to learn why birds are where they are in vertical space and how that is affected by climate. So, she strapped platforms with recorders, temperature loggers, and relative humidity loggers at 10-meter intervals up the length of 14 trees.

Remote observation can also collect data on a wider range of organisms and in places that are otherwise difficult to observe. Because it is easier to collect more data using remote observation, researchers are more likely to detect rare organisms. One of Arismendi's camera traps, for example, captured the powerful beak and golden head of a golden eagle outside of its home range. Some animals avoid humans, which make them difficult to observe directly. They don't, however, avoid sensors. Remote observation is not only a different way to see the world but a way to see different parts of the world. "It's hard not to react to that with a bit of wow," says Nelson.

Sequencing eDNA is especially illustrative of how remote observation can help researchers answer questions that they previously could not. Like other forms of remote observation, sequencing eDNA involves collecting data that can be analyzed to learn about organisms rather than observing them directly. Before eDNA sequencing advanced, if researchers wanted to study the biodiversity of a stream, they needed people who knew how to identify each subset of organisms. They all had different processes for doing so. The fish team worked something like this: one person stunned a fish, and another caught it. They identified it, collected whatever other information they needed about it, and released it back into the stream. Stunning can occasionally cause muscles spasm in fish and damage their vertebrae. Traditional methods take a lot of time, resources, and people with deep knowledge about each subset of organisms. Such people increasingly rare. Taken together, this means comprehensive biodiversity monitoring using traditional methods is rarely possible.

Sequencing eDNA makes it possible. As they go about their lives, every organism, including humans, sheds DNA into their environment. That DNA is eDNA, and streams are full of it. By sequencing eDNA from streams, researchers can get a sense of every organism that has "set foot or fin into a flowing body of water," says Julia Jones, a geologist at OSU who studies hydrology and geomorphology at the Andrews. Streams contain not only the DNA of the organisms that live in them but also the DNA of those who live in the land around them. That DNA is transported to the stream as water from the land flows through the soil or over its surface. In addition to monitoring biodiversity, eDNA can identify whether a specific organism is in a stream. It can compare the relative abundance of different species. It can detect organisms that are difficult to observe directly and identify species that are difficult to differentiate in the field. Sculpin, for example, are a group of about 300 fish that all look similar, like they are "wearing leather jackets with studded things off them," says Brooke Penaluna, a research fish biologist at the Forest Service Pacific Northwest Research Station who studies aquatic and riverbank habitats and fish at the Andrews. But each species has different DNA. While an expert found two different sculpin species in one stream using traditional methods, eDNA sequencing identified 14 different sequences in the same stream.

Penaluna needs eDNA sequencing data to answer her questions. She wants to learn about the relationship between forests and freshwater, specifically how the age of a forest and its fire history affects the biodiversity of streams that flow through it. Knowing how forest age and fire history impacts such a wide range of organisms and in a wide range of places will help forest managers protect the ecosystem as a whole.

It all still begins in the field. Waders on and hands gloved, her research team trudges into a stream. Standing where the stream is quickest, they fill 12 one-liter bottles with stream water. On the bank, they filter all those bottles into one small vial, and plop the vial into another bottle filled with ice cubes. Back in the lab in Corvallis, they sequence the DNA. The result is what Penaluna calls "vomits of data" in the form of DNA sequences. Then comes the tricky part: linking those DNA sequences to the species they came from. They do so using reference databases — collections that link DNA sequences to species that were identified using traditional methods. The reference databases, however, are incomplete. Not all species have assigned DNA sequences. As a result, sometimes researchers can only link a DNA sequence to a related species or to a groups of species. "It's unsatisfying," says Betts. Not only that, but only knowing a related species or a group of species is not always useful for researchers. They are working to improve reference databases. But even as they do, sequencing eDNA is providing information that researchers could not otherwise get.

As data from remote observation is often larger and finer scale, it can help inform management at those scales. A key example of how remote observation can inform management is rooted in the Andrews long history of spotted owl research. Eric Forsman began studying spotted owls in 1969 as a graduate student at OSU and found that they needed old growth forests to survive. As old growth was logged, spotted owl populations plummeted. His research eventually led the U.S. Fish and Wildlife Service listing the spotted owl as an endangered species and the adoption of the Northwest Forest Plan, which protected old growth forests, helped restore watersheds, and closed down roads. Until this year, research technicians have monitored spotted owls by blaring owl calls on a big horn. The owls are drawn to the calls, even more so because they know what happens next. When an owl arrives, the technicians throw it a mouse. The owl then flies away, and the technicians run through the forest after it to find out if it is nesting and how many offspring it has if so. This all happens in the dead of night.

This summer, researchers will begin the transition to using bioacoustics to monitor spotted owls across the Pacific Northwest. There has been some initial resistance. “So many people have been catching owls for so long and really enjoying it,” says Levi. Excitement has gathered, however, as the spotted owl monitoring community has realized how much recorders will increase the scale of monitoring, both in area and in the number of species. The recorders will also detect the hoots of the barred owl, for example. The barred owl competes with the spotted owl and is causing its populations to decline despite its protected status. Forsman’s work was essential to understanding the relationship between spotted owls and old growth forests. Now, researchers need to monitor spotted and barred owls. Bioacoustics are the best way to do that.

But researchers spend less time in the field when they use bioacoustics. And it is difficult to spend less time in the field without losing something in the process.

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As ecologists use remote observation more, the very nature of their work is shifting. “We end up spending less time in the woods and more of our research time dealing with the aftermath,” says Schulze. Most people at the Andrews agree that this comes with some risk.

Field work is the reason many ecologists went into the specialty in the first place. That was the case for Marie Tosa, a graduate student at OSU who spent the first few years of graduate school at the Andrews studying western spotted skunks. These are not your average skunks. They are fuzzy, squirrel-sized animals with long, white patches. Seeing a skunk on a camera trap simply does not compare to being at the Andrews with one, from holding one in her hands. That, Tosa says, is “pure happiness.” And happiness is one of the things that sustains ecologists’ work.

Many researchers also find inspiration for their research when they are out in the field, observing what is around them. “Some of the big ‘aha’ moments that have happened at the Andrews Forest have been just when people are sitting out there, being out there,” says Lina DiGregorio, who coordinates long term ecological research at the Andrews. Betts has had many such moments. “I have to admit that a lot of my ideas over the years have come to me while I’m out, tromping around in the forest, counting birds or measuring trees,” he says. When he was out on a hot summer day, for example, he noticed that old growth forests were much cooler than younger ones. So, his lab modelled whether forest age did in fact affect temperature. They found that it did, that old growth forests are cool refuges that could help sustain biodiversity in a warming climate. That finding means that old growth forests are even more important to conserve.

Researchers also develop a deeper intuition about an ecosystem by spending time in it. “There’s this difference between data and knowledge, where the knowledge is that deeper wisdom and understanding of underlying processes and good common sense and intuition that comes from knowing these systems,” says Williams, the geographer at the University of Wisconsin-Madison. Intuition is essential to analyzing data. There are always some inaccuracies in datasets. If researchers don’t identify them when they are analyzing datasets, their findings can reflect those inaccuracies. It is easier for researchers to identify errors when they have a deep intuition about an ecosystem. “The human brain is good at catching things that are obviously wrong in a way that computers are not, as long as the human brain has some background understanding,” says Williams.

Tosa knows what it is like to both have that intuition and to not. After spending years in the field with western spotted skunks, she has a strong intuition about them. But she does not about insects, which she has not spent as much time observing in the field. She is now studying biodiversity at the Andrews, and she sequenced eDNA to learn which insects are there. Her sequences suggested that some insects were concentrated in one area, but she did not know whether that was how the insects were distributed or if there was just a problem with the methods. “I have no gut feeling of ‘oh yeah, that looks right,’” she says. If she did not speak with people who *did* have that gut feeling, she could risk publishing inaccurate findings.

There are systems in place that are meant to ensure that researchers analyze data correctly. One is metadata, information that accompanies the data itself. This can include everything from information about how, when, and where the data was collected to how each variable in the dataset is defined. Metadata helps other people understand and use the datasets, and each dataset at the Andrews includes it. But, in general, researchers vary a lot in how detailed they write their metadata. “It takes a lot of effort,” says Marty Downs, the director of research synthesis, education, and outreach at the LTER Network. “And beyond effort, it takes a perspective about who might want to use your data and what they would need to know about it.” Researchers can forget to include important information. Even when they don’t, the researchers using the data don’t always read the metadata.

Data collected at the Andrews is published with contact information for someone at the Andrews who can explain the details of how it was collected. Ideally, researchers who access the data would use the contact information. “So they can have some sense of the biology of the situation versus just downloading a bunch of ones and zeros,” says Betts. More often than he would like, they don’t use the contact information. Sometimes, Betts doesn’t find out that another researcher used data collected at the Andrews until the research is published in an academic journal. And that is only if the article cites the Andrews or the grant that funded the data collection.

Some researchers who collect data are concerned that others will not fully understand it. Without being in the field themselves, for example, researchers may not know that “this type of sensor is prone to these kinds of glitches that might look like believable data points if you just look at them in isolation," says Schulze. They may believe those data points, which should actually be discarded or corrected for glitches, and publish inaccurate results.

For the most part, these concerns have not materialized. In an article published in *PNAS* in 2018, however, they did. The authors of the article analyzed data on invertebrate abundances from the Luquillo LTER site in Puerto Rico. They found that, from the 1970s to 2012, invertebrate biomass fell 10 to 60 times and the lizards, frogs, and birds that eat them declined as a result. They attributed this to warming temperatures. The article attracted a lot of media attention. But, as explained in a *PNAS* letter published the following year, the researchers did not understand that the data collection was more concentrated in some areas than others and that the most recent collection was shortly after a hurricane. The researchers who collected it were not happy. "Not that they used the data, they were thrilled that they used the data. But that they didn't talk to them about it," says Downs. When the sampling effort and hurricane were taken into account, the food webs that the original article said were declining as a result of warming were not. As more researchers analyze data that they did not collect, incidents such as this could become more common. It will largely be up to researchers to both prevent them from happening and correct them if they do.

Beyond how researchers analyze data, remote observation can increase the likelihood that researchers will find patterns and stop there, without learning what causes those patterns. Because remote observation produces huge quantities of data, scientists often use artificial intelligence to process it. Sometimes, artificial intelligence is so good at finding patterns that it can accurately predict what an ecosystem is like in other places or at other times without complete information. As long as it can, some researchers argue the cause of the patterns isn't as important.

But others argue that researchers can't completely understand an ecosystem without knowing the cause of patterns. "It's hard to see how you get robust knowledge about what's going on in nature doing that," says Levi. Knowing that spotted owl populations have declined as barred owl populations have increased, for example, doesn't necessarily mean that there is any relationship between the two species. It could instead mean that some change in the habitat that supports barred owls harms spotted owls. Spotted owls have in fact declined because barred owls outcompete them, but forest managers need to know that causation to effectively conserve spotted owls.

If researchers do not know the cause of a pattern and assume that it will hold true in another place, at another time, they can make inaccurate predictions. Betts published an article in *Ecological Modeling* in which he explains how a model he built predicted forest birds well in the region in which the data used to build the model was collected. That same model, however, failed to predict forest birds in another region just 250 kilometers away. If that model was used in other regions, it could misinform management. Knowing the cause of a pattern not only makes predictions for other places and other times more accurate, it also makes research more helpful for management.

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Researchers at the Andrews have largely been able to avoid the risks of remote observation, including the risks of spending less time in the field. “By acknowledging that weakness, I think we can work around it,” says Betts. If they haven’t developed intuition about part of an ecosystem, they speak with someone who has. They spend their free time in the places they are studying. And their research still involves time in the field. They need to set up, maintain, and take down sensors. They need to test the accuracy of the data collected by the sensors. And they still need to be in the field to answer many of their questions. “There’s not as much change as you might think,” says Downs.

Though Ferrari’s research uses bioacoustics, for example, she spent whole summers in the field. She needed to set up the sensors, change the recorder batteries and SD cards, download the temperature data, and take down the sensors. Doing so required climbing trees, from the thin understory to the thicker canopy. The summer is a busy season, but Ferrari says time slows when she is climbing. High up, looking out, she says, “It’s this zooming out moment.” Ferrari’s research would not be possible without this field work and the moments that come with it.

Most researchers agree that field work and remote observation both have their place at the Andrews. “We don’t want to let one thing swallow the other thing,” says Nelson. “I think the challenge is to figure out what is the balance.”

By conducting experiments, researchers at the Andrews have also largely been able to avoid the risks of using remote observation to find patterns without causes. They know that both are necessary for a deep understanding of an ecosystem. “We need big data and small data. We need machine learning, and we need rigorous experiments,” says Betts.

Remote observation helps researchers learn about ecosystems in ways that were not previously possible. In doing so, it provides better information for management. That is valuable in and of itself, but it is not always clear how much of that information will be put into practice. During her writing residency at the Andrews, scientist and writer Robin Wall Kimmerer wrote:

> What do these data bring us? A chronicle of the land, a witnessing of the world, understanding and wonder, a way to predict our impact on the land. These are good things. But do they bring us any closer to saving what we love? I want a flow of data streamed into some monitoring center that measures a change of heart. I want us to see clearly the jagged peaks of rising greed and their correlation with loss.

Though the impact of research on management is not always clear, remote observation does reveal surprises about the world, and Nelson thinks those surprises can change the hearts of whoever learns about them. “If ecology is done what I would call well, it … makes us humble. It makes us empathetic. It makes us caring,” he says.

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As time marches on and remote observation continues to advance, many of the risks it comes with will intensify. It will require even less time in the field to use. Artificial intelligence will become so accurate at predicting patterns using remotely observed data that it will be even more tempting to stop the scientific process there. More people will use data from the Andrews that they didn’t collect. All the while, researchers at the Andrews must continually weigh the benefits and risks of each advancement and find the right balance between new and traditional methods.

For now, there is a sort of harmony at the Andrews. Half an hour from headquarters, along a winding gravel Forest Service road, Lookout Creek Old Growth Trail hugs the base of Lookout Mountain. A temperature sensor squats a few miles in, bright white in an expanse of green and brown. A black cord dangles from a tree — left from a graduate student who used it to pull a climbing rope up and study how dwarf mistletoe changed the structure of hemlock branches. Far from using remote observation, he climbed the trees and measured the diameter, length, and direction of each branch, as well as where the dwarf mistletoe was on the branch. Some trees took four days to measure. “There is still stuff like that that happens,” says Schulze.

Sensor or cord, remote observation or traditional method, it is all evidence of care. “Each stake stumbled upon in the middle of the forest, each aluminum tag and magenta flag, each rope reaching up into the canopy or pipe reaching down into the creek tells the walker: Someone has measured this flow, tested this soil, weighed this log, tells the walker: Someone loves this place,” writes poet Vicki Graham during a writing residency at the Andrews.

All the while, the beauty of the Andrews holds steady. Lookout Creek roars downhill, leaving its cool breath behind. Further along the trail, the creek is out of sight but still within earshot. Further still, it is snowing. Large, wet flakes fleck the soft soil and emerald needles. Back down, the snow becomes a light rain and then fog. It glows golden in the sinking sun.

Interviews
Adam Kennedy, Oregon State University Cyberinfrastructure Architect
Angel Chen, Long Term Ecological Research Data Analyst
Brooke Penaluna, Pacific Northwest Research Station Lead Scientist
Cheryl Friesen, Willamette National Forest Science Liaison
Chunglin Kwa, University of Amsterdam Faculty
Corinna Gries, Environmental Data Initiative Co-Director
David Shaw, Oregon State University Professor
Elena Aronova, University of California Santa Barbara Associate Professor
Erika Milam, Princeton University Professor
Fred Swanson, Oregon State University Emeritus Faculty
Ivan Arismendi, Oregon State University Associate Professor
John Porter, University of Virginia Research Associate Professor
John Williams, University of Wisconsin Madison Professor
Julia Jones, Oregon State University Professor
Julien Brun, Long Term Ecological Research Scientific Programmer
Lina DiGregorio, Andrews Forest Long Term Ecological Research Coordinator
Marie Tosa, Oregon State University Graduate Student
Mark Schulze, Andrews Forest Forest Director
Marty Downs, Long Term Ecological Research Network Director
Matthew Betts, Oregon State University Professor
Matthew Weldy, Oregon State University Graduate Student
Max Geier, Western Oregon University Professor Emeritus
Michael Paul Nelson, Oregon State University Professor
Nicholas Lyon, Long Term Ecological Research Data Analyst
Nina Ferrari, Oregon State University Graduate Student
Shuli Niu, Chinese Academy of Sciences Professor
Suzanne Remillard, Andrews Forest Long Term Ecological Research Information Manager
Taal Levi, Oregon State University Associate Professor

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Andrews Experimental Forest, 1948–2000, Max Geier

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Big Data, Big Waste? A Reflection on the Environmental Sustainability of Big Data Initiatives, Federica Lucivero

Big Science and Big Data in Biology: From the International Geophysical Year through the

Climate-driven declines in arthropod abundance restructure a rainforest food web, Bradford C. Lister and Andres Garcia

Data-Intensive Ecological Research Is Catalyzed by Open Science and Team Science, Kendra Spence Cheruvelil, and Patricia A. Soranno

eDNA as a tool for identifying freshwater species in sustainable forestry: A critical review and potential future applications, Ashley A. Coble, Camille A. Flinders, Jessica A. Homyack, Brooke E. Penaluna, Richard C. Cronn, and Kevin Weitemier

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