USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Pacific Northwest Research Station | Issue 245 | January 2022

Science FINDINGS

INSIDE

"Science affects the way we think together."
Lewis Thomas

Bioacoustics and Artificial Intelligence: A New Chapter for Northern Spotted Owl Monitoring and Research

Northern spotted owl habitat in an Oregon coastal forest. Photo by David Patte, U.S. Fish and Wildlife Service.

IN SUMMARY

*Northern spotted owl (*Strix occidentalis caurina*), a species listed under the Endangered Species Act, have been monitored for nearly three decades using callback surveys and mark-and-recapture methods. Callback surveys can result in negative effects on the owl yet are widely used on federal, state, and private forest land prior to activities that range from timber sales to restoration projects. Despite conservation efforts, spotted owl populations are declining due to habitat loss and invasive barred owls (*S. varia*); and as barred owl populations increase, spotted owls are becoming harder to detect with conventional methods.*

Damon Lesmeister, a research wildlife biologist with the USDA Forest Service, Pacific Northwest Research Station, is developing an approach to monitoring spotted owl populations using passive bioacoustic technology and machine learning (a form of artificial intelligence). The method is proving to be a robust way to detect spotted owls with less impact on their declining populations. The method applies to multiple scales—from the entire range of the spotted owl to a specific patch of forest—and holds promise for studying more vocalizing species.

Lesmeister is collaborating with multiple scientists and wildlife managers to establish a science-based protocol for using bioacoustic monitoring in all forests of the Pacific Northwest. By 2023, the approach is expected to replace the conventional methods for monitoring spotted owls.

"It is the language of nature to which one has to listen."

—Vincent Van Gogh

In the early days of surveying for northern spotted owls (*Strix occidentalis caurina*) in the Pacific Northwest, many wildlife biologists and technicians started their workday after dusk and finished before dawn. Fortified with a thermos of strong coffee and recordings of owl calls, they set out in the dark to find the holy grail of monitoring: an owl's nesting tree. The information they gleaned about the presence of a nesting pair might determine whether a timber sale could proceed or yield insights about population dynamics that informed conservation plans.

The northern spotted owl is one of the most well-studied species in the Pacific Northwest. Concern for the species and its dwindling

*A northern spotted owl (*Strix occidentalis caurina*) in the Olympic National Forest, Washington. Photo by Betsy Howell, USDA Forest Service.*

Key Findings

- Passive bioacoustic surveys are an effective method for detecting northern spotted owls and barred owls, an invasive species that is contributing to the decline of northern spotted owl populations.
- Passive bioacoustics can determine pair status of spotted owls, an important indicator of the health of a population. The pitch of male and female calls differs, and sites with pairs have many more detections than sites occupied by single owls.
- Vocalizing species like owls can be identified in visual representations of sound recordings called spectrograms. Trained convolutional neural networks, a type of artificial intelligence, are highly effective for processing large sound datasets and automated species identification through spectrogram image recognition.
- Rangewide, bioacoustics can be effective for monitoring spotted owl populations with even a moderate amount of sampling.

old-growth forest habitat ultimately led to the 1994 Northwest Forest Plan that covers 24 million acres in western Washington, western Oregon, and northern California. Spotted owl populations have been monitored rangewide since the mid-1990s by using labor-intensive callback surveys, often accompanied by mark-and-recapture methods that require researchers to conduct nocturnal callback surveys and, in some cases, use mice to lure owls for capture and leg-banding. But despite extensive knowledge and well-intentioned conservation efforts, northern spotted owl populations are declining and the owls are becoming harder to detect.

A new, game-changing approach to spotted owl monitoring is emerging, made possible by technological and scientific advances. "As an ecologist, I never really saw myself thinking about artificial intelligence and partnering closely with computer scientists," says Damon Lesmeister, a research wildlife biologist with the Forest Service's Pacific Northwest (PNW) Research Station. "But that's where I am now and it's really exciting work."

Lesmeister is a next-generation wildlife biologist developing next-generation tools to monitor the owl. He is at the forefront of developing a new survey method for monitoring northern spotted owl populations based on passive bioacoustic technology and artificial intelligence. The method is proving to be a more robust means of detecting the presence of spotted owls. It is less invasive to owls than the callback surveys and mark-and-recapture methods of yore, and it holds promise for learning about many more species beyond the spotted owl.

Owl Detectives Then and Now

In 2015, Lesmeister took up the baton when his predecessor, Eric Forsman, a pioneer in the study of the northern spotted owl, retired after 35 years as a research wildlife biologist with the PNW Research Station. Forsman is credited with discovering that spotted owls prefer old-growth forest habitat and have a large home range. His research, which began in the 1970s, has long informed federal forest policy and management including the Northwest Forest Plan. Under the subsequent northern spotted owl effectiveness monitoring plan published in 1999, spotted owls have been monitored from eight study areas on federal lands throughout their range in California, Oregon, and Washington using callback and mark-and-recapture survey methods to collect demographic information.

Things have changed since the 1970s when Forsman began his research on spotted owls. For one thing, barred owls weren't around then. Today the East Coast invader is everywhere, contributing to the decline of the native northern spotted owl populations and making it harder to detect spotted owls using any survey method.

Concerned about the continuing decline of the species and dwindling sample sizes, Lesmeister began visiting monitoring sites as soon as he took the helm of the northern spotted owl research program. "In some study areas," he says, "it's getting more difficult to do the analysis because you have so few animals to be able to understand what's happening with the population, other than the fact that they're nearly extinct."

Lesmeister also worried about the potential risks that callback surveys posed to the few remaining spotted owls. Barred owls have been observed approaching broadcasted calls and reacting aggressively toward the responding spotted owl, putting them at increased risk of injury. Existing survey methods can be costly and present safety concerns for people doing fieldwork, especially at night. "I started thinking about the potential to use some passive, noninvasive methods to study aspects of northern spotted owls as an alternative for monitoring spotted owl populations," Lesmeister adds.

In 2017, he developed a pilot study in partnership with Ray Davis, the monitoring lead for older forests and spotted owls within Pacific

PNW Science Findings

Providing scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Ave., Suite 1400
Portland, OR 97204

Send new subscription and change of address information to:

SM.FS.pnw_pnwpubs@usda.gov

Rhonda Mazza, editor; rhonda.mazza@usda.gov

Jason Blake, layout; jason.p.blake@usda.gov

To find Science Findings online, visit https://www.fs.usda.gov/pnw/ and click on **Publications**.

To become a digital subscriber visit: https://www.fs.usda.gov/pnw/publications/subscriptions.shtml

USDA United States Department of Agriculture

Forest Service

Northwest Region, to see how well passive bioacoustics could detect the presence of northern spotted owls. "It turns out that it's really effective," Lesmeister says. "We sort of expected that, but we didn't know when the best time would be to do the sound recordings, how long the devices need to be out there, or what kind of recording schedule makes sense." Such information is critical for designing a protocol for bioacoustic monitoring that eventually could be used more broadly.

What started as a pilot study four years ago has grown into a fully-fledged research program to inform management. At last count, more than 2,000 autonomous recording units have been distributed across more than 700 plots. Each plot is 5 square kilometers (about 2 square miles), which corresponds with the home-range size for barred owls and northern spotted owls.

A researcher checks an autonomous recording unit placed to record owl calls. Photo by Jim Swingle, USDA Forest Service.

The scientists found that with four listening devices in one plot left to record for 6 weeks, there was a 97 percent probability of detecting spotted owls and barred owls, if they were present. What's more, because the pitch of male and female owl calls differs, the scientists could determine pair status, a gold standard indicator that the owls are breeding and producing owlets. The results showed more detections at sites with spotted owl pairs than sites occupied by single owls.

By combining advances in modeling with passive bioacoustic monitoring the scientists gained further insights. For example, they developed a way to distinguish between single, pair, and even breeding pairs by incorporating recorded owl detections from a given period into occupancy models. By using computer simulations based on occupancy modelling, the scientists demonstrated that rangewide bioacoustic monitoring can effectively detect changes in spotted owl populations. Their findings contributed to a decision by the Regional Interagency Executive Committee for the Northwest Forest Plan to fully transition by 2023 to a spotted owl monitoring program based on bioacoustics.

Listening to 25 Million Acres

The new design will cover more ground than was possible when relying on people working alone in the dark for multiple nights to survey territory historically inhabited by spotted owls.

"It's really important that we draw our sample throughout the range of the northern spotted owl," Lesmeister says, "outside of the footprint of those eight historic study areas that the current demography-based program is based on."

The relative ease and cost of setting up autonomous recording units means nearly 25 million acres of forested federal lands within the range of the northern spotted owl—from the Canadian border to San Francisco and west of the Cascades all the way to the Pacific Ocean—can be sampled. The design will collect bioacoustic data from 2 percent of the 5-square-kilometer plots across that broad swath of forested land.

"Then within our historic demographic study areas, where we've been studying spotted owls in some cases since the 1980s and know more about the northern spotted owl populations in those locations, we will increase the density of our sampling to as much as 20 percent of the plots within those historic study areas."

One goal of this design is to better understand how spotted owls use the landscape and how that translates into the recordings collected by the passive bioacoustics.

*A barred owl (*Strix varia*) along the Big Quilcene River on the Olympic Peninsula. USDA Forest Service photo.*

Of Spectrograms and Supercomputers

Advances in field equipment, computer processing and artificial intelligence, and ecosystem modeling are central components of the next-generation wildlife monitoring tools that Lesmeister is developing. "Together, these advancements afford us the ability to do things today that I don't think that scientists could fathom even just 10 or 20 years ago."

Using equipment small enough to be strapped to a tree, field crews can collect high-quality sound recordings of owls. These autonomous recording units can be set to record at key times, on a precise schedule, and easily placed and picked up weeks later.

The 2,000-plus autonomous units in place to date have collected well over 2 million hours of sound recordings, and Lesmeister expects more than a million hours to be collected every year. It would take more than 100 people listening 24 hours a day, 7 days a week to listen to 1 million hours in a year. To help with this superhuman task, Lesmeister and his research assistant Zachary Ruff, an Oakridge Institute for Science and Education fellow with the PNW Research Station, turned to computer scientist Chris Sullivan with Oregon State University's Center for Genome Research and Biocomputing.

Together they developed a method for processing the large sound datasets using a type of artificial intelligence called convolutional neural networks. The recordings are converted into visual representations of the sound, called spectrograms, recognizable to the neural networks. This type of visual recognition technology works much the same way that some photo apps can organize photos, or help users identify plants and animals. The convolutional neural networks are then "trained," in this case, to identify calls of the spotted owl.

In essence, the scientists are training artificial intelligence to monitor species biodiversity in Pacific Northwest forests based on sound. They have gone from training the neural networks to recognize the sounds of 2 owl species to more than 45 species and counting (mostly birds but some mammals as well).

"Our goal ultimately is to include all vocal wildlife species in the Pacific Northwest forests," Lesmeister says, "so that we can help the Forest Service manage for biodiversity on national forests as specified in the agency's 2012 Planning Rule."

The sound data that are collected every year become part of a permanent collection stored and processed by supercomputers at Oregon State University. Decades from now, scientists and land managers will be able to access the sound recordings to assess population trends for species that may not be on anyone's radar today.

As bandwidth capacity improves, the data will become more publicly available for other researchers to use via a cloud network. For now, smaller datasets can be processed by the neural networks using a desktop or laptop computer. It just takes longer without a supercomputer.

A New Chapter

A handful but growing number of early adopters, including several Forest Service biologists, have conducted bioacoustics surveys using autonomous recording units and are processing the data to inform their project management decisions. In addition to the Forest Service, the Bureau of Land Management (BLM) and National Park Service as well as state and private entities have begun using passive bioacoustics.

Davis, who started out as a district wildlife biologist on the Siuslaw National Forest in 1992 says he would have jumped at the chance to have this bioacoustic data to help inform local project work at the time. "It hasn't happened yet, but I would imagine that eventually the new pre-project survey protocol will be based on passive bioacoustics," Davis adds.

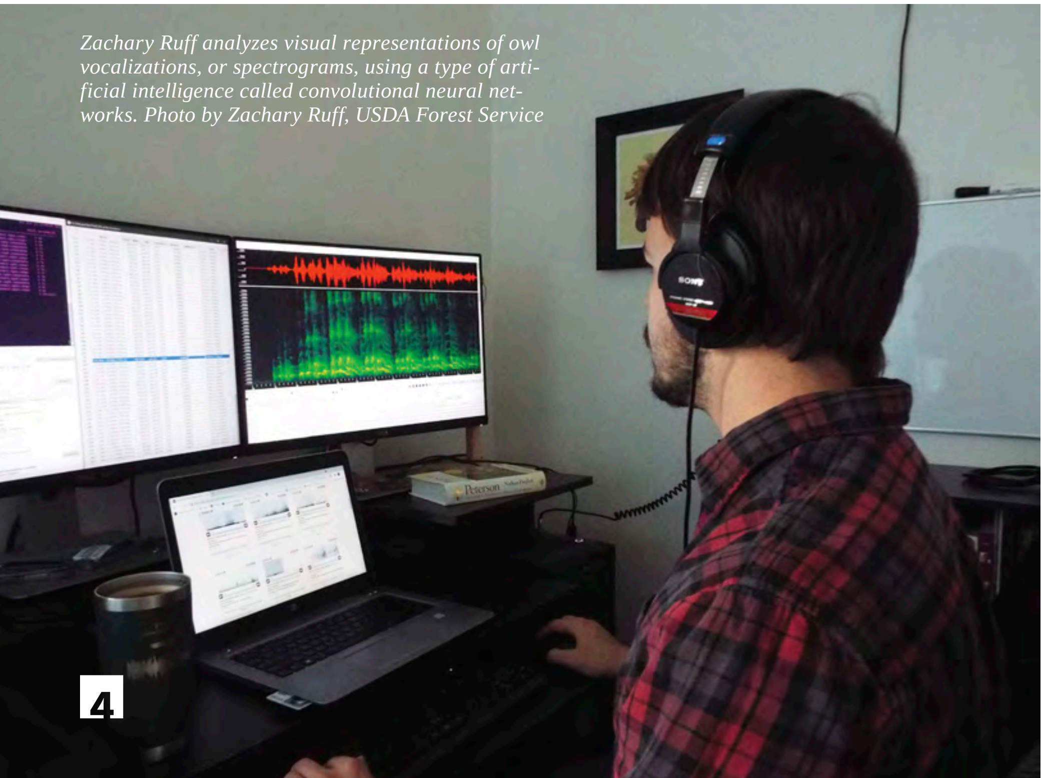
At the project level, with only broadscale bioacoustic monitoring data, a resource manager on a national forest would be able to identify the 5-square kilometer plot in the rangewide grid where their project is located and determine the likelihood that spotted owls or barred owls are using the area. At the same time, data collected at the local scale using the same bioacoustic survey method would feed into the larger grid of plots that extends throughout the range of the northern spotted owl in the United States––from northern California to the Canadian border.

"In the future, after a few years of monitoring," Davis says, "the monitoring program will be able to color each one of those plots throughout the entire range with a probability of use by northern spotted owls or the probability of use by barred owls, not to mention other species. And not just for a few [national] forest or BLM districts that have a monitoring footprint, but for every forest and every BLM district throughout the range of the spotted owl, including [national] parks."

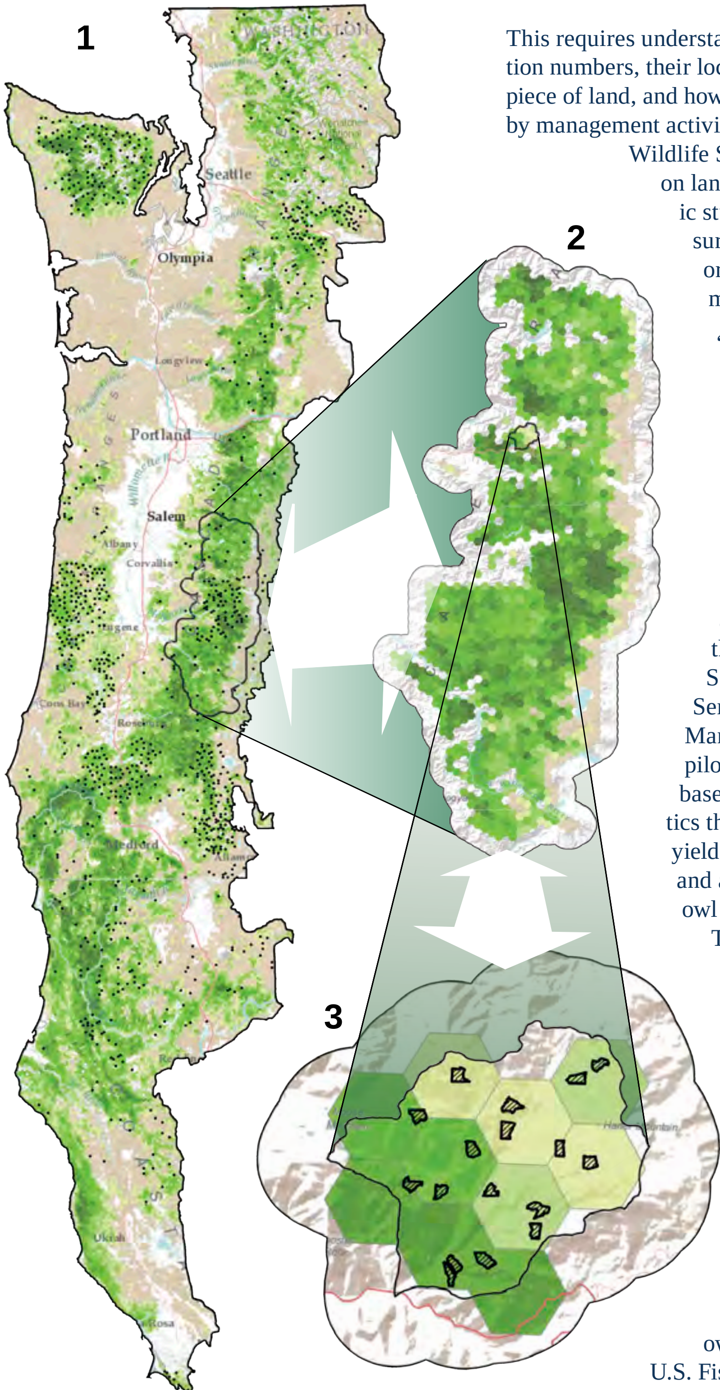
Mike Blow, a biologist with the U.S. Fish and Wildlife Service, is interested in the potential for using bioacoustics for project-level surveys and consultations. He focuses on spotted owls in northwestern Oregon and works with federal agencies like the Forest Service to help design, consult on, and implement actions ranging from timber sales to restoration projects.

LAND MANAGEMENT IMPLICATIONS

- Integrating bioacoustics and artificial intelligence can transform and improve project-level surveys and monitoring of species that require special consideration in forest management decisions.
- Passive bioacoustics is a noninvasive method to monitor northern spotted owls. Owls are not captured, and the method does not provoke a territorial response which can increase negative interactions with barred owls.
- Passive bioacoustic monitoring is more cost effective over the long term and safer for field crews. It expands the spatial coverage of the monitoring program and supports biodiversity monitoring that can inform management decisions.
- The spotted owl monitoring program under the Northwest Forest Plan is expected to fully transition to bioacoustic monitoring by 2023. As an alternative to traditional survey methods, the U.S. Fish and Wildlife Service is developing a protocol based on bioacoustic monitoring surveys designed to assess impacts that proposed management activities may have on spotted owls.



Zachary Ruff analyzes visual representations of owl vocalizations, or spectrograms, using a type of artificial intelligence called convolutional neural networks. Photo by Zachary Ruff, USDA Forest Service



Model output illustrating probable use of habitat by northern spotted owl at different scales: (1) range of northern spotted owl, (2) national forest, and (3) project. While data from the northern spotted owl monitoring program on federal land will primarily inform the rangewide model, project-scale surveys (that follow monitoring survey protocols) can provide supplemental data that can be used in either the forest-scale or rangewide models and may improve the models. Maps by Ray Davis, USDA Forest Service.

This requires understanding a species' population numbers, their location on a particular piece of land, and how they might be affected by management activities. The U.S. Fish and Wildlife Service currently relies on landscape-level demographic studies and pre-project surveys based on callback or mark-and-recapture methods.

"A lot of money is spent on surveys for endangered species," Blow says. "My hope is that we'll ultimately have a more effective method that's less cost or staff intensive."

Davis and Lesmeister are collaborating with the U.S. Fish and Wildlife Service as well as Forest Service and Bureau of Land Management biologists to pilot a new survey protocol based on passive bioacoustics that is standardized to yield consistent information and align with the spotted owl monitoring program. The U.S. Fish and Wildlife Service has begun accepting bioacoustic monitoring on a limited, trial basis as an alternative survey method to assess the potential impact of individual projects. As more becomes known about bioacoustic monitoring for spotted owls, Blow imagines the U.S. Fish and Wildlife Service might endorse greater application of the survey method.

"It's a pilot, a test, and we expect it will evolve," he says. "We're going to follow the science."

Passive bioacoustic monitoring may become a game changer for monitoring the northern spotted owl, and it could extend to more species including marbled murrelet, corvids (jays, crows, ravens), sooty grouse, wolves, and others. The framework is adaptable to other survey methods such as high-frequency recorders for bats and camera traps for terrestrial mammals. With a growing network of recording units distributed from northern California to Canada, biodiversity can be monitored at multiple spatial scales to yield insights and inform management and policy in ways that were not possible a few years ago.

"For us to be able to pull all of these pieces together gives us insights into the ecosystems of the Pacific Northwest that are unprecedented," Lesmeister says. "That's what's really exciting––not only what we've been able to do, but the things that we're going to be able to do with these data in the future."

"I tried to discover, in the rumor of forests and waves, words that other men could not hear, and I pricked up my ears to listen to the revelation of their harmony."

—Gustave Flaubert

For Further Reading

Duchac, L.S.; Lesmeister, D.B.; Dugger, K.M.; Davis, R.J. 2021. Differential landscape use by forest owls two years after a mixed-severity wildfire. Ecosphere. 12(10): e03770. https://www.fs.usda.gov/treesearch/pubs/63622.

Duchac, L.S.; Lesmeister, D.B.; Dugger, K.M.; Ruff, Z.J.; Davis, R.J. 2020. Passive acoustic monitoring effectively detects northern spotted owls and barred owls over a range of forest conditions. The Condor. 122(3): 1–22. https://www.fs.usda.gov/treesearch/pubs/61400.

Lesmeister, D.B.; Appel, C.L.; Davis, R.J.; Yackulic, C.B.; Ruff, Z.J. 2021. Simulating the effort necessary to detect changes in northern spotted owl (*Strix occidentalis caurina*) populations using passive acoustic monitoring. Res. Pap. PNW-RP-618. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p. https://www.fs.usda.gov/treesearch/pubs/62862.

Ruff, Z.J.; Lesmeister, D.B.; Duchac, L.S.; Padmaraju, B.K.; Sullivan, C.M. 2020. Automated identification of avian vocalizations with deep convolutional neural networks. Remote Sensing in Ecology and Conservation. 6(1): 79–92. https://www.fs.usda.gov/treesearch/pubs/61582.

Ruff, Z.J.; Lesmeister, D.B.; Appel, C.L.; Sullivan, C.M. 2021. Workflow and convolutional neural network for automated identification of animal sounds. Ecological Indicators. 124(2): 107419. https://www.fs.usda.gov/treesearch/pubs/62310.

Writer's Profile

Sylvia Kantor is a science writer and editor based in Seattle, Washington.

Science FINDINGS

Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Avenue, Suite 1400
Portland, OR 97204

Official Business
Penalty for Private Use, $300

Scientist Profiles

DAMON LESMEISTER is a research wildlife biologist with USDA Forest Service Pacific Northwest Research Station. He has studied avian and mammalian predators, and their prey, in a variety of forest ecosystems. He earned his Ph.D. from Southern Illinois University.

Lesmeister can be reached at:

USDA Forest Service
Pacific Northwest Research Station
3200 SW Jefferson Way
Corvallis, OR 97331

E-mail: damon.lesmeister@usda.gov

RAY DAVIS is the monitoring lead for old forests and northern spotted owls for the Northwest Forest Plan Interagency Monitoring Program. He began a career with the USDA Forest Service as a district wildlife biologist. More than half of his career has been spent on-the-ground implementing the Northwest Forest Plan on the Siuslaw and Umpqua National Forests.

Davis can be reached at:

USDA Forest Service
Pacific Northwest Region
3200 SW Jefferson Way
Corvallis, OR 97331

E-mail: raymond.davis@usda.gov

Collaborators

Chris Sullivan, Cara Appel, and Leila Duchac, Oregon State University

Charles Yackulic, U.S. Geological Survey Southwest Biological Science Center

Zachary Ruff, USDA Forest Service Pacific Northwest Research Station, Oak Ridge Institute for Science and Education fellowship program

Julianna Jenkins, James Swingle, Alaina Thomas, Todd Wilson, USDA Forest Service Pacific Northwest Research Station