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Science FINDINGS

INSIDE

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

21st Century Computing for 21st Century Forest Management

A field technician with the USDA Forest Service's Forest Inventory and Analysis program measures the diameter of a tree in Coos County, Oregon. The Forest Service uses both boots on the ground and the latest technology to monitor old-growth forests in the Pacific Northwest. USDA Forest Service photo by Janelle Cossey.

"The general formula of [ecological] management for the future might be, think globally and act locally."

—René Jules Dubos, microbiologist

In the Pacific Northwest, old-growth forests and cutting-edge technology are intertwined. Since the adoption of the Northwest Forest Plan in 1994, the USDA Forest Service has invested in both data-collecting tools and data modeling to improve maps that are used to monitor old-growth forests. While on-the-ground observations are invaluable, land managers need maps to fully understand the extent of old-growth forests and related trends over time.

In the early 2000s, now retired USDA Forest Service, Pacific Northwest (PNW) Research Station research ecologists Janet Ohmann and Warren Cohen partnered with Oregon State University (OSU) colleagues to pioneer a new mapping technique. By combining the Gradient Nearest Neighbor (GNN) model with satellite images from the nation's Landsat program, they were able to integrate decades of satellite imagery with forest data from nearly 35,000 inventory plots in Oregon, Washington, and

IN SUMMARY

The USDA Forest Service uses many forms of technology to manage 193 million acres that comprise the National Forest System: handheld data-entry devices and satellites; modeling software and LiDAR (light detection and ranging) remote sensing; and desktop computers and servers. Collectively, these technologies power the models that create the maps land managers use to monitor and understand landscape changes. Adopting cloud-computing platforms, such as Google Earth Engine (GEE), offers potential to advance these monitoring efforts even further.

Researchers with the USDA Forest Service's Pacific Northwest and Rocky Mountain Research Stations and Google collaborated to customize GEE's cloud-computing capabilities. Their goal: develop a way to store and process the vast amounts of the remote-sensing data needed for the Gradient Nearest Neighbor (GNN) model that produces forest attribute maps.

The research team used the new process to create forest attribute maps for the recently published report, Northwest Forest Plan—The First 25 Years (1994–2018): Status and Trends of Late-Successional and Old-Growth Forests. *The researchers found that using GEE substantially decreased the processing time required to create the maps. Additionally, two new online tools, the Landscape Change Monitoring System Data Explorer and the Gradient Nearest Neighbor Trend Tool, allow users to see the most recent model results within the Northwest Forest Plan area.*

California. These advances enabled researchers to create forest attribute maps for any variable collected on the forest inventory plots, including changes in forest age class and disturbance for a given area over time.

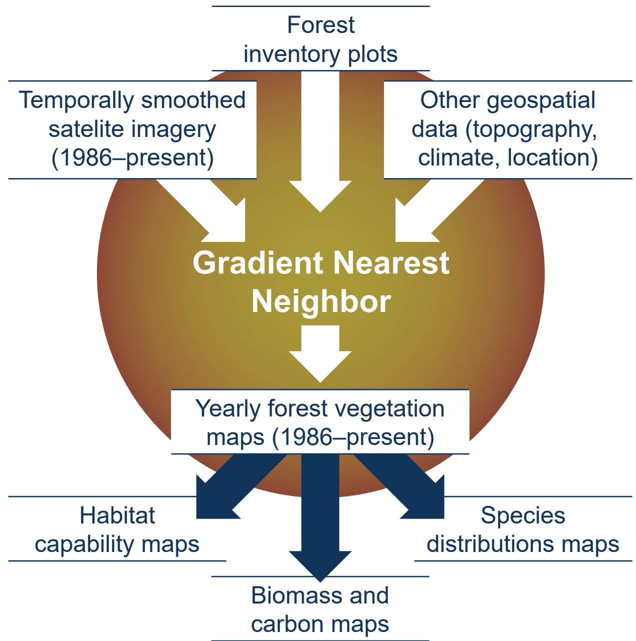
Fast forward 20 years to another significant improvement in combining satellite imagery, plot data, and cloud computing. These new techniques have the potential to enable the annual production of maps that capture the effects of wildfire the previous summer or other recent landscape changes. Researchers used this technology to create the maps in the recently published report, *Northwest Forest Plan—The First 25 Years (1994–2018): Status and Trends of Late-Successional and Old-Growth Forest.*

Taking Data to the Cloud

When it comes to mapping forest attributes or running data-heavy models for Northwest Forest Plan monitoring projects—such as modeling the changes in old-growth forests from the Canadian border to northern California—researchers turn to the Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) team. The LEMMA team is a collaborative working group of researchers from the PNW Research Station and OSU.

Matthew Gregory, a senior faculty research assistant with OSU, has been a LEMMA team member for more than 20 years and worked with Ohmann on the GNN model. In 2012, he learned of the cloud-based platform Google Earth Engine (GEE) from Zhiqiang Yang, an OSU colleague now with the USDA Forest Service, Rocky Mountain Research Station and Sean Healey, a Forest Service colleague with the Rocky Mountain Research Station, who were working on GEE with its lead developer Noel Gorelick.

Gregory and Yang were intrigued by GEE's computing power and storage capacity because LEMMA works exclusively with large quantities of data, including Forest Inventory and Analysis (FIA) plot data and Landsat satellite imagery. The terabytes (1 terabyte = 1000 gigabytes) of information included thousands of Landsat images spanning decades that would need to be processed before they could be combined with plot inventory data from the nationwide FIA program. Few programs within the Forest Service are able to process this quantity of data before making it available locally to researchers for modeling and mapping.



The Gradient Nearest Neighbor (GNN) model creates maps that make it possible for land managers to see landscape-level changes over time in the Pacific Northwest. GNN integrates Landsat satellite images and on-the-ground plot inventory data.

"Mind blowing" is how Gregory described the GEE beta version, compared to managing raster and plot data locally. "This new platform simplified many of the processes we were doing locally by managing the spatial data [such as the satellite imagery] on Google's servers," he explains. "This gave us a lot more computing capacity than we would have locally on our own workstations. It allowed us to do many of the tasks that were time consuming on their platforms instead."

For the next 2 years, the use of GEE for GNN mapping remained a pilot project. Then David Bell, a research forester with the PNW Research Station, joined LEMMA and began collaborating with colleagues to take GEE and GNN mapping from pilot project to real-world application.

Mapping Old Growth and Snags

When Raymond Davis joined the interagency federal monitoring program that oversees the implementation of the Northwest Forest Plan in 2005, the 10-year Northwest Forest Plan monitoring report had just been published. He recalls that the forest maps "were very rudimentary because Landsat was fairly underutilized and hard to get." Different datasets were also used to create the California and the Oregon/Washington vegetation maps.

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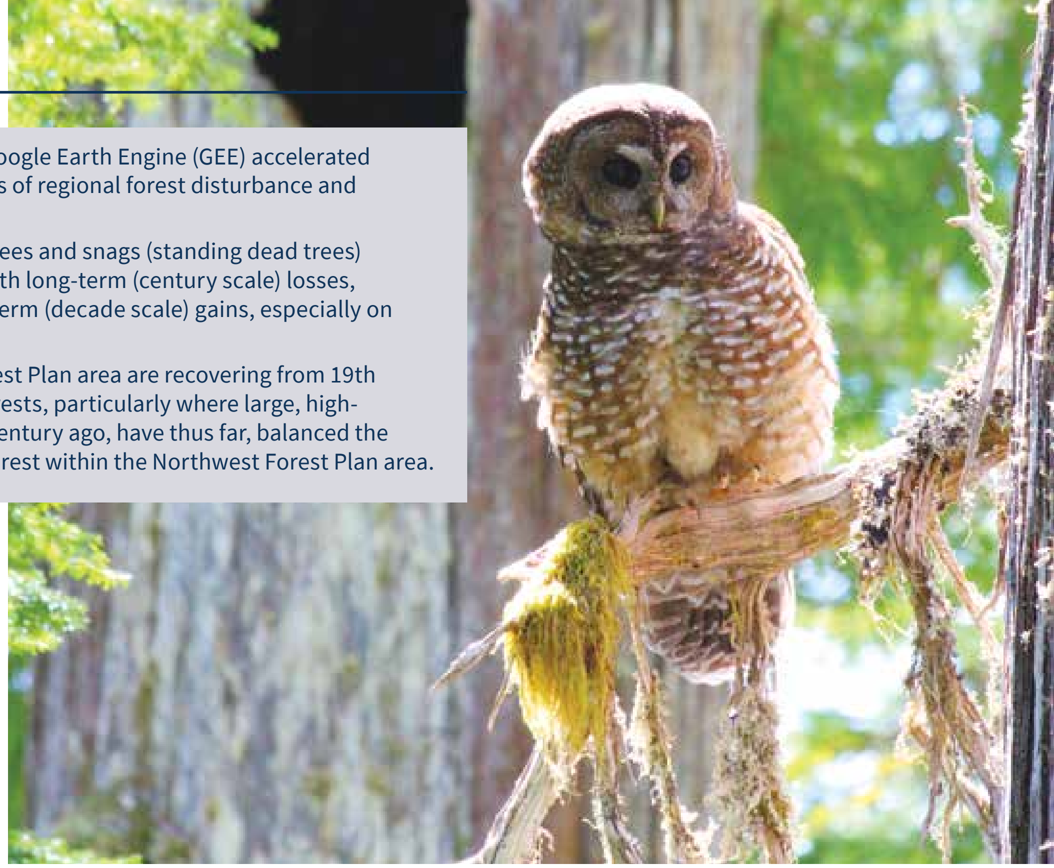
Older forest stands, such as this one in the Siuslaw National Forest, provide unique habitat for a variety of species. USDA Forest Service photo.

Key Findings

- Using the cloud-computing platform Google Earth Engine (GEE) accelerated development, distribution, and analysis of regional forest disturbance and attribute mapping.
- Mapping the distribution of large live trees and snags (standing dead trees) in Oregon and Washington highlight both long-term (century scale) losses, especially on private lands, and short-term (decade scale) gains, especially on federal lands.
- Older forests within the Northwest Forest Plan area are recovering from 19th century fires. Gains in older, moister forests, particularly where large, high-severity wildfires occurred more than century ago, have thus far, balanced the losses in older, drier, more fire-prone forest within the Northwest Forest Plan area.



The northern spotted owl is listed as threatened under the Endangered Species Act. Providing adequate amounts of suitable forest cover for the owl was a primary driver behind efforts to restore old forest under the Northwest Forest Plan. USDA Forest Service photo.

When it came time to develop the 15-year monitoring report, GNN was the foundation for all the forest attribute maps, which meant status and trends could be applied across all three states. However, there were still limitations to these forest attribute maps and the analyses that they could support.

"We just produced maps of what it looked like around when they designed the Northwest Forest Plan and then what it looked like at the end of the monitoring cycle," Davis explains. "We called those 'book-end maps,' and we analyzed differences between the two to see what was lost and gained."

As the monitoring lead for old-growth forest and northern spotted owl (*Strix occidentalis caurina*) within the Forest Service's Pacific Northwest Region, Davis has collaborated with the LEMMA team to develop and produce the GNN maps of the Northwest Forest Plan footprint for the 20-year monitoring reports and onward. These GNN maps are also used by the other Northwest Forest Plan monitoring modules, such as for the northern spotted owl and marbled murrelet (*Brachyramphus marmoratus*).

As with the prior monitoring reports, LEMMA provided support to create maps for the 25-year report. Bell saw this project as the ideal real-world test case for GEE. "We have this amazing forest inventory and remote-sensing data, and we want to create wall-to-wall support for monitoring old-growth forests," he says. "Can we leverage these newer developments in the processing of remote sensing, disturbance mapping, and the [GNN methodology] to turn them into maps?"

To answer Bell's question, Davis agreed to a test case. Learning to access and process the Landsat images, developing algorithms that power the models used to create the maps, and creating tools for analyzing and visualizing GNN maps took time and testing. By moving portions of the GNN workflows to the cloud instead of local processing, can data be accessed and maps be generated correctly?

The answer to that question was yes, both in creating the forest attribute maps for California, Oregon, and Washington for the 25-year monitoring report and substantially reducing the amount of time needed to generate the maps. One of the forest attribute maps the team produced for the report was of the distribution of older forests in areas affected by 19th century wildfires. This wall-to-wall map showed recovery of these old forests; however, this recent recovery is tempered by a risk of loss in the warmer and drier parts of the Northwest Forest Plan area by future disturbances, such as wildfires. Davis says the most important advance made in GNN was its ability to produce annual maps that showed both gains and losses over time.

On-Demand Forest Attribute Mapping

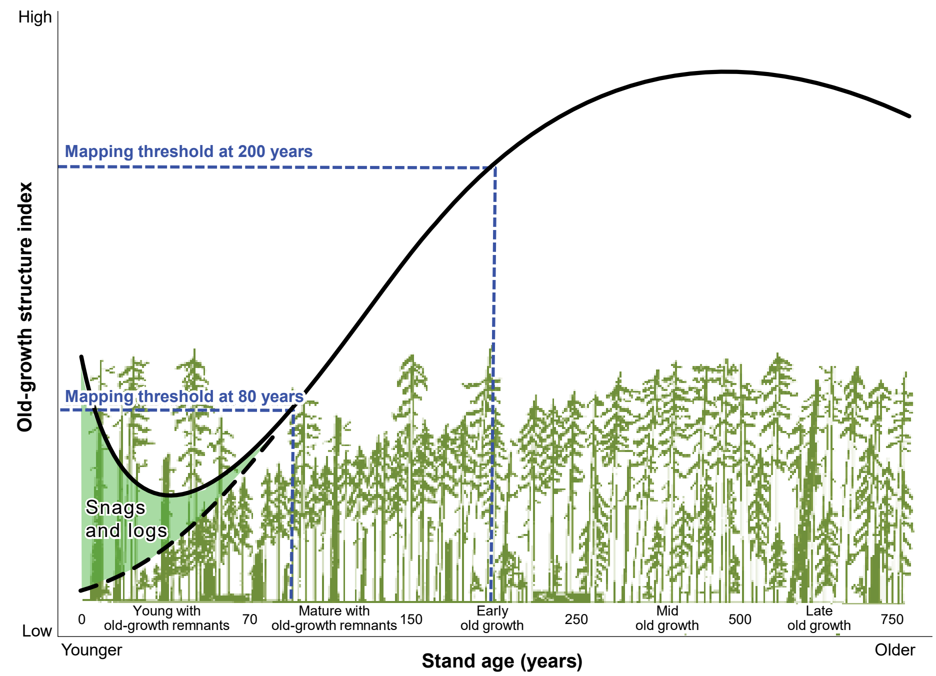
The Northwest Forest Plan federal interagency monitoring program isn't the only program that needs forest attribute maps. Marin Palmer is the regional biometrician for the Forest Service's Pacific Northwest Region and oversees vegetation inventories and strategic vegetation mapping. She is a liaison between agency staff who need forest attribute maps to answer management questions and the LEMMA team. Palmer worked with Bell to test how GEE could improve the workflow for producing maps.

"I frequently have conversations [with ecologists and biologists] about their needs on the ground and matching them with the data that are going to meet those needs," Palmer says. "These needs can include determining the distribution of other forest types and how climate change may affect this distribution."

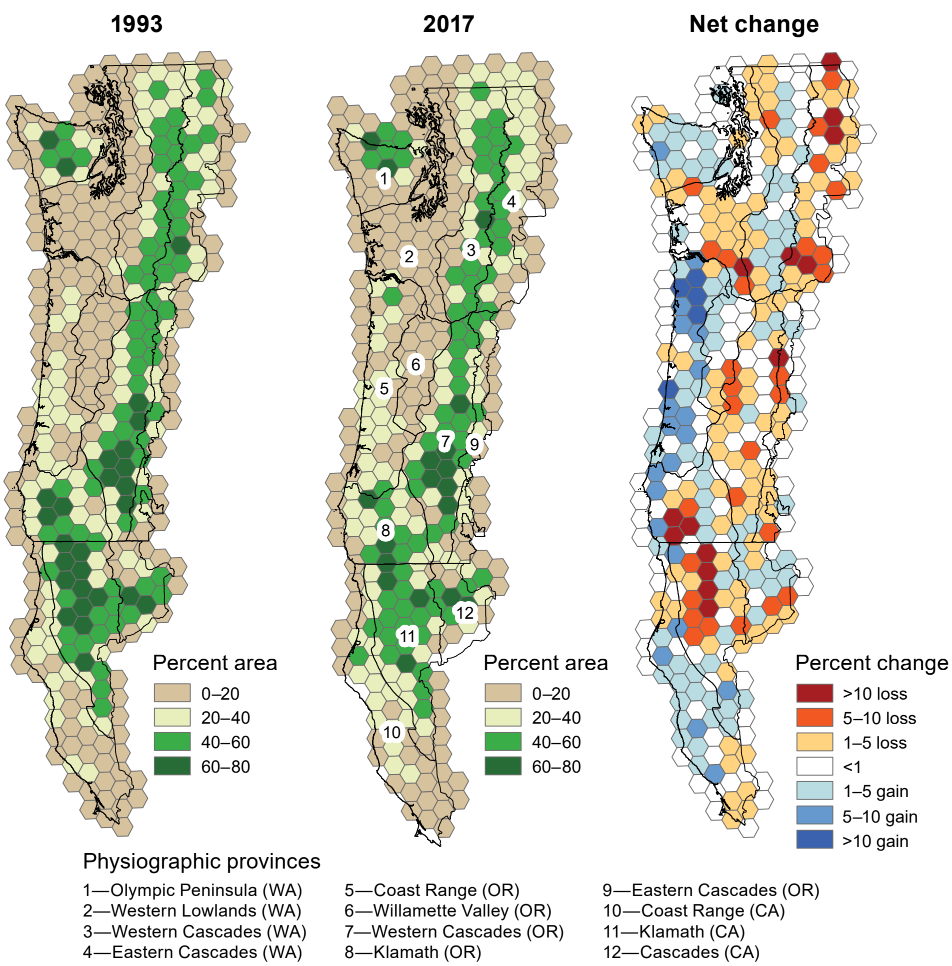
With improved computing power now available, Palmer adds, "We could start to visualize going back to the 1980s and forward. Having the information in easily summarized visual formats is far easier for more users to work with. We're in a place where we can have more of those conversations and be nimbler to meet those needs."

Although GNN had proven useful in broadly mapping forest conditions, such as the status and trends in old-growth forests, the computational power and flexibility offered by GEE increases the opportunities for biologists and ecologists to apply these vegetation maps to new questions, and it decreases the time spent revising and running the model.

Using GEE to analyze temporal and spatial patterns in the forest attribute data generated for the regional monitoring, Bell led an analysis of large live trees (>20" in diameter) and snags (>10" in diameter) to map their trends from 1993 to 2017 in 10 wildlife habitat types that included the Washington coast, eastern Cascades and Blue Mountains, and montane mixed conifer. The maps revealed that there



Conceptual diagram highlighting changes in forest structure as forests age, which are important to the mapping of late-successional and old-growth forests. From Davis et al. (2022).



These maps show how the distribution of older forests within the range of the northern spotted owl changed between 1993 and 2017. They were produced using the Gradient Nearest Neighbor model on the Google Earth Engine platform. From Davis et al. (2022).

were long-term losses, particularly on private lands; however, these losses were tempered by short-term gains, especially on federal land.

As the LEMMA team tests GNN accuracy and utility for other forest attributes, Palmer reviews the maps and suggests tweaks that can be readily incorporated into the model. Such a workflow wouldn't have been possible before GEE. "If I find an issue with a particular map, the LEMMA group can revise their models," she explains. "Whereas in the past they couldn't go back and start a 6-month process again."

The Future of the Cloud

As Davis, Bell, and the rest of the team were writing the 25-year monitoring report, *Northwest Forest Plan—The First 25 Years (1994-2018): Status and Trends of Late-Successional and Old-Growth Forests*, back-to-back, large-scale wildfires were ablaze throughout the Pacific Northwest. The team was acutely aware that the forest attribute maps about to be published depicted a reality that no longer existed on the ground. This highlighted the need to update maps on an annual basis; it has been a long sought-after goal but was operationally unrealistic until the introduction of GEE into workflows.

"One of the stories from the Northwest Forest Plan monitoring is that we see this long-term increase [in old forests], but since 2017, the major fires have wiped out a lot of that increase," Bell explains. "That's also highlighting why we consider it important to get to an annual reporting state. Even though those data have just come out, these big fires have changed the landscape at a scale and speed that we are just not used to."

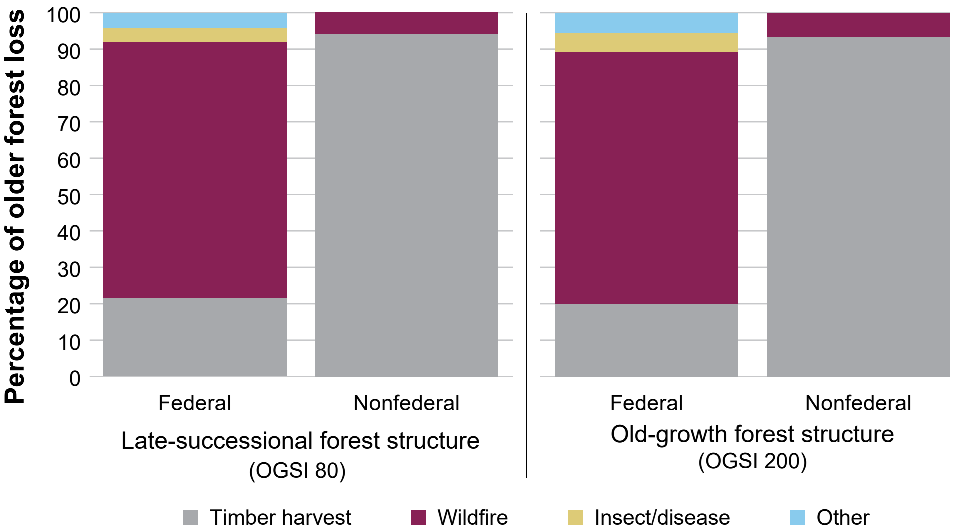
"What the annual maps do is really improve our ability to see trends, and so we can see places that are trending in a positive direction, or trending in a negative direction, or trending in a stable direction," Davis says. "It's a much richer dataset and allows us to see where things are trending."

Bell says the LEMMA team isn't quite at the point of updating annual maps past the 25-year monitoring 2017 bookend, but the use of GEE and other cloud-computing platforms that the Forest Service is exploring means the reality is close. "We're sort of at the beginning of how the Forest Service uses those. Where we go as an agency will be interesting to watch."

> *"Last time I checked, the digital universe was expanding at the rate of five trillion bits per second in storage and two trillion transistors per second on the processing side."*
>
> —George Dyson, historian

LAND MANAGEMENT IMPLICATIONS

- With data now stored in Google Earth Engine (GEE), researchers can focus on improving the Gradient Nearest Neighbor (GNN) imputation method so that maps of other forest attributes can be produced to answer management questions.
- Two online tools—the Landscape Change Monitoring System Data Explorer and the Gradient Nearest Neighbor Trend Tool—allow users to quickly interact with and run queries on landscape change and forest status maps, especially those associated with old forests.
- Due to more frequent natural disasters, such as large-scale wildfires, managers need up-to-date forest attribute maps to inform management decisions. The use of GEE can make monitoring efforts more nimble by shifting from 5-year reporting to producing annual maps.



Causes for older forest loss between 1993 and 2017 as determined by the Landscape Change Monitoring System Data Explorer. OGSI = old-growth structure index. Adapted from Davis et al. (2022).

FOR FURTHER READING

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Online Tools for Mapping Forest Attribute Trends

The Gradient Nearest-Neighbor (GNN) Trend Tool allows users to summarize temporal trends in forest attributes, such as large live trees and snags densities, occurring over decades, and visualize how those patterns differ across geographies or land ownerships.

The Landscape Change Monitoring System Data Explorer can be used to compare GNN-mapped changes with Landsat satellite-based disturbance mapping to interpret the potential drivers and consequences of change. Users can now get the data in the desired format much faster; and it saves time and is more efficient for everyone, according to Forest Service biometrician Marin Palmer: "These visual tools have a lot of potential to expand the user base."

With these online tools, "We're fulfilling our goal of monitoring, but we're achieving it in a better storytelling fashion and making it more user friendly," says Raymond Davis, the Forest Service monitoring lead for old-growth forest and the northern spotted owl. "We're also producing a treasure trove of data that scientists can use to dig into the dynamics of what's going on out there."

Writer's Profile

Andrea Watts is a freelance science writer who specializes in covering natural resources topics. Her portfolio is available at https://wattsinthewoods.com, and she can be reached at andwatts@live.com.

Area burned in the Willamette National Forest during the 2020 Riverside Fire. By incorporating new technology such as Google Earth Engine in their workflows, researchers hope to annually map forest changes, such as those resulting from large wildfires. USDA Forest Service photo.

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