PNW
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Science
FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

MONITORING FORESTS FROM SPACE: QUANTIFYING FOREST CHANGE BY USING SATELLITE DATA

LARSE is making progress in characterizing forest changes, such as this partial harvest, that remove only a portion of the canopy.

"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives."

—Carl Sagan, referring to the photograph of Earth taken from Voyager 1

Forests are changing everywhere, all the time. Understanding the extent and patterns of change often requires a step back from the trees—way back. To do this, researchers use what are essentially sophisticated digital cameras mounted aboard satellites orbiting hundreds of miles above the Earth. The cameras, or sensors as they are more technically known, repeatedly take snapshots of the Earth capturing not only the light that is visible to our eyes, but also the light outside our visible spectrum, such as infrared light. The science of interpreting these data is called remote sensing.

"Remote sensing is particularly useful in studying forest change because a region's forests can be studied comprehensively and uniformly across time and space," says Warren Cohen, a research ecologist at the PNW Research Station in Corvallis, Oregon. "It multiplies the value of field-plot data and permits complete wall-to-wall analyses."

Cohen is the director of the Laboratory for Applications in Remote Sensing in Ecology (LARSE), a research consortium of forest scientists working mainly at the PNW Research Station and Oregon State University. Over the last 15 years, LARSE scientists have made several important contributions to the development of the field of satellite-based change detection. Recently, their research has focused on two factors that have prevented expansion of the field beyond the research realm: the complexity of processing vast amounts of data, and an inability to describe partial forest disturbances, such as thinnings.

"Our research has been integral in both regional and national efforts to understand how harvests, fires, and other disturbances are changing our forests," says Cohen.

"We have tried in the last few years to make the process of forest change detection simpler and more inclusive of all types of forest change," explains Sean Healey, who spent several years working at LARSE but is now at the Rocky Mountain Research Station in Ogden, Utah.

IN SUMMARY

Change is the only constant in forest ecosystems. Quantifying regional-scale forest change is increasingly done with remote sensing, which relies on data sent from digital camera-like sensors mounted to Earth-orbiting satellites. Through remote sensing, changes in forests can be studied comprehensively and uniformly across time and space.

Scientists at the Laboratory for Applications in Remote Sensing in Ecology (LARSE) have pioneered several applications for mapping forest disturbances using Landsat satellite data. One such advancement is a mathematical transformation of multiple bands of Landsat data into one value that is most associated with a clearcut style of forest disturbance. LARSE scientists used the "Disturbance Index" to delineate every clearcut harvest completed in western Oregon and Washington and northern California from 1972 to 2004. This map revealed several differences in the patterns of harvest on public and private lands over the past three decades. They have also made several breakthroughs toward mapping and quantifying the extent of partial forest disturbances, such as thinnings. These advances have led to collaborations with the National Aeronautics and Space Administration and others to map disturbances at a national scale.

During his tenure, Healey developed some of the applications that transformed disturbance mapping at LARSE from a regional to a national concern.

Remote sensing may seem like the high-tech branch of forestry and ecology, but it would be a mistake to think that it was some newfangled approach. Aerial photography has been in use for almost a century, and satellites have been recording forest change for more than 35 years. Landsat, launched in 1972, was one of the first satellites widely used for remote sensing. Since then, Landsat has been a workhorse for scientists interested in measuring changes in the distribution and condition of forests.

Data are beamed down from Landsat in six channels, or bands. Each band describes the strength of the Sun's energy reflected off the Earth within a certain range of wavelengths. There are, for example, bands for blue, red, and infrared wavelengths. The wavelengths reflect off of different surfaces in unique and predictable ways. For example, green foliage on trees absorbs most red wavelengths, leaving little to be reflected back into space. In contrast, soil reflects much more of the red wavelengths.

A number of satellites have come online since Landsat; several are useful for monitoring forests. And although Cohen uses many of them, I think it is safe to say that Landsat is his favorite. The spatial resolution of Landsat—about one-quarter acre per pixel—combined with Landsat's repeated coverage of the same area several times per year makes it ideal for monitoring forest change over relatively large areas.

"Landsat data is phenomenally useful. We have relied on it for 15 years to understand where and when disturbance has happened in the forests of the Pacific Northwest," says Cohen. "Although the sensor hasn't changed too much over the years, we certainly have—both in terms of our thinking and our computing. The whole community has moved forward and, now, software has automated many things that were once difficult and time-consuming. We can now digest far more data and answer much larger questions then we could when we first started using Landsat."

KEY FINDINGS

- A map of stand-clearing disturbances in western Oregon and Washington and northern California was developed that shows significant differences in harvest practices among federal and private landowners over the last three decades. Although private harvest rates were higher than federal harvest rates throughout the study period, harvest within both categories steadily increased through the 1970s, peaking in the mid-1980s. However, whereas clearcutting on federal land was essentially eliminated after 1992, private harvest rates remained high.

- Partial harvests, such as thinnings, currently make up about 50 percent of the total harvest in the region. These harvests now can be mapped with Landsat satellite data using a method of change detection to estimate the total proportion of the canopy removed.

- Landsat satellite data can be mathematically transformed into a "Disturbance Index" that can accurately and efficiently detects stand-clearing disturbance over large areas and several points in time. Disturbance maps produced with this index are at least as accurate as maps produced with alternate transformations that take twice as long to produce and require three to six times the computing and data storage resources.

AN INDEX OF FOREST CHANGE

One advancement is the simplification and automation of mapping forest disturbances. Healey is the primary architect of an index designed for mapping clearcuts over a time series of Landsat data. It is appropriately named the Disturbance Index.

"It is a mathematical transformation of six of the Landsat bands into one value that represents how similar an area is to forest that has been cleared by disturbance," explains Healey. In the parlance of remote sensing, a cleared forest has low greenness, low wetness, and high brightness. Several accuracy assessments have since borne this out.

Once the six bands have been reduced to the one index, an analyst can put several dates of imagery on a computer monitor at one time. Forests that were cleared by harvest, fire, or another disturbance in the interval between images then pop out in stark contrast to their surroundings.

"This easy visualization of forest change allowed us to reduce processing time by over 50 percent. We found that disturbance maps produced with the Disturbance Index are at least as accurate as maps produced with previously used methods, which require three to six times the computing and data storage resources," says Healey.

LARSE used the Disturbance Index to complete a map of all the clearcut harvesting done in western Washington and Oregon and northern California dating back to 1972, the inception of Landsat. The map revealed significant differences in harvest practices among federal and private landowners. Although private harvest rates were higher than federal harvest rates throughout the study period, harvest within both categories steadily increased through 1970s, peaking in the mid-1980s. However, whereas clearcutting on federal land was essentially eliminated after 1992, private harvest rates remained relatively high.

The disturbance map was also central in three important monitoring efforts supporting the 10-year science review of the Northwest Forest Plan, which governs management on

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more than 24.5 million acres of federal forests in the Pacific Northwest.

"The map allowed an assessment of changes in the amount and distribution of late-successional forest, northern spotted owl habitat, and marbled murrelet habitat since the enactment of the plan. Because adaptive management is an important component of the Plan, future management of federal forests may be informed by historical disturbance trends identified by our research," says Cohen.

A BREAKTHROUGH IN MAPPING

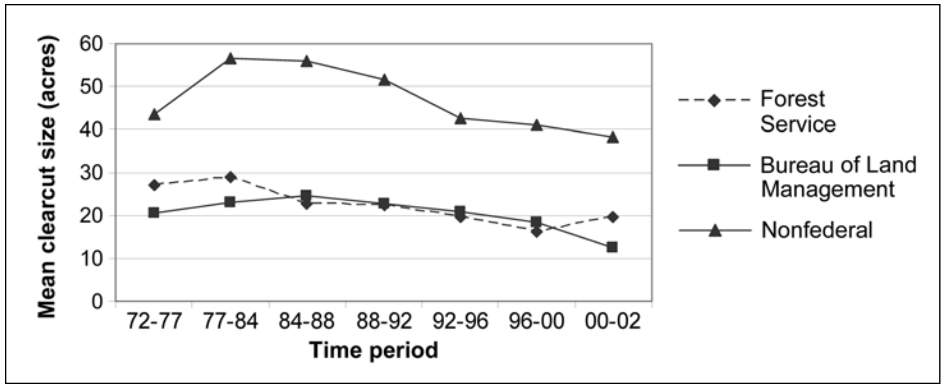
Throughout the history of remote sensing in forestry, mapping partial harvests, or thinnings, has been an elusive goal. Unlike clearcuts, which leave a distinct signature on the landscape, the imprint of partial cuts is subtle and ephemeral.

"There is a lot of noise in satellite data that obscures the signal from the vegetation data—noise from particles in the atmosphere, like clouds and haze, and noise from shadows and changes in the Sun's angle from image to image," explains Cohen. "This makes detecting subtle changes in forest canopy cover much more difficult."

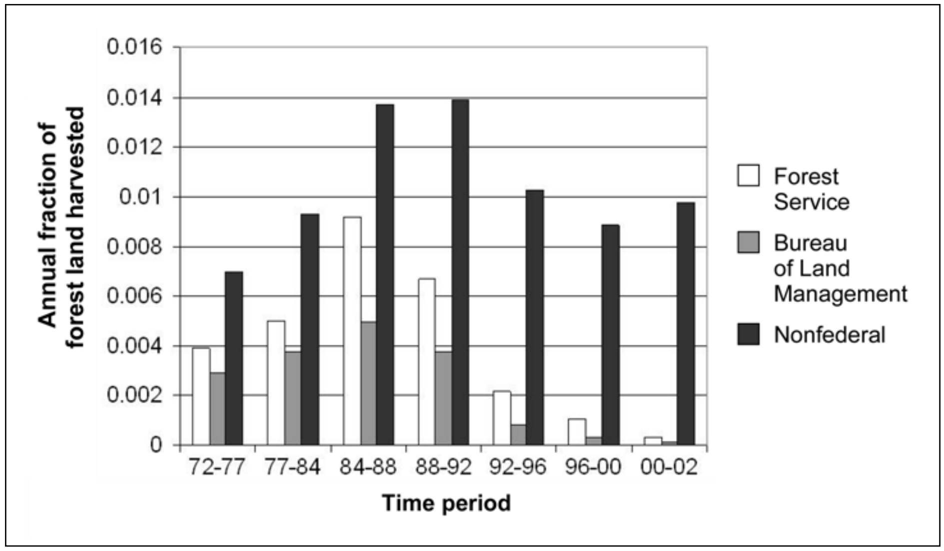
"Not only is the signature from a thinning difficult to detect, it also doesn't last very long," adds Healey. "The forest canopy is quick to grow into the gaps created by the thinning, erasing any evidence that harvest ever occurred within just a few years."

Three breakthroughs allowed the LARSE group to develop reliable methods for mapping partial harvests. The first came when they developed an automated and effective way to reduce the impact of the noise. Using statistical models, LARSE scientists now normalize each date of imagery to a common reference date, making the effects of clouds, haze, and shadowing consistent through time. This inhibits noise from showing up as change in the analysis. The second breakthrough came from using Landsat images of the same area taken closer together in time—every year or two, compared to the 5 or 6 used for mapping clearcuts. Partial harvests can then be detected while the imprint is still fresh. And the third breakthrough was the same one that buoys all research projects: They could now complete an indepth study of the problem.

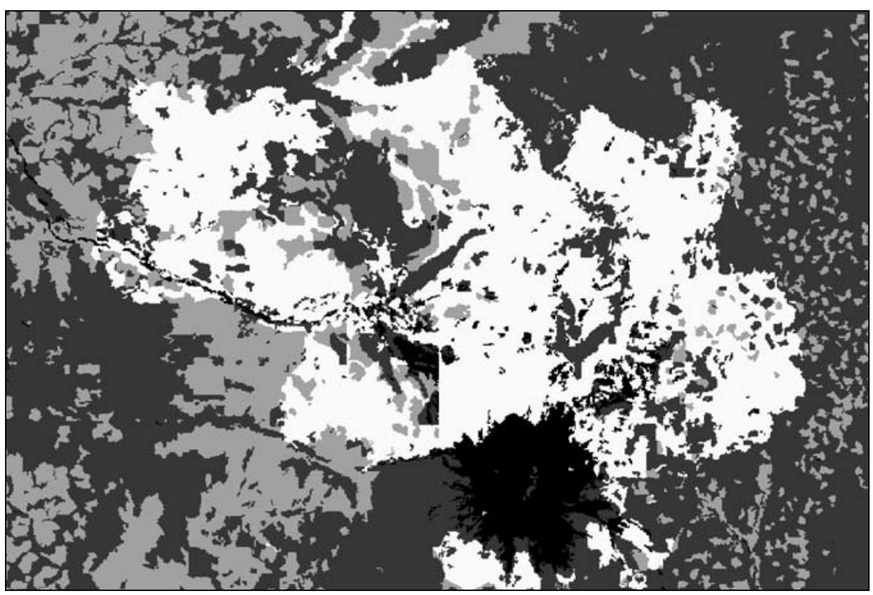
"Washington Departments of Fish and Wildlife and Natural Resources asked us to help them estimate the extent of partial harvests in relationship to habitat for spotted owls. We collected field data in central Washington, where we had access to detailed records about harvest activity. We counted and measured the diameter of stumps so that we knew exactly how much



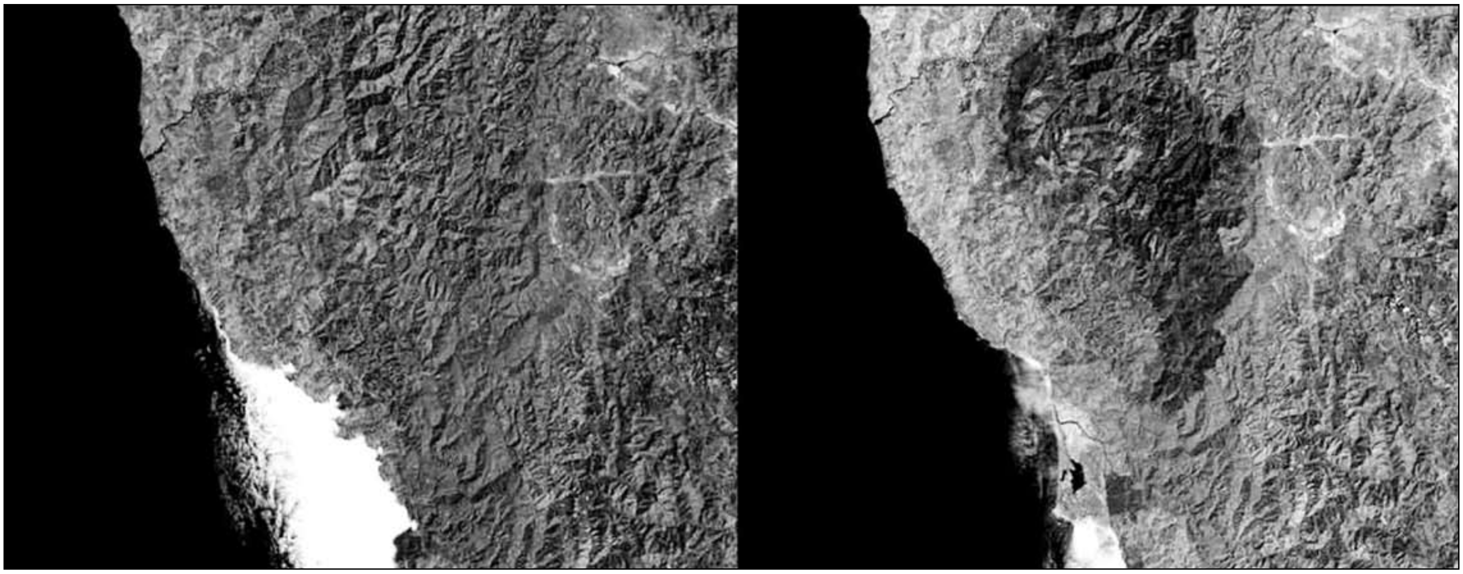
Average size of clearcuts produced by federal and nonfederal (state and private) landowners in western Oregon and Washington from 1972 to 2002. These data came from analysis of the stand-clearing disturbance map produced at LARSE in support of the Northwest Forest Plan.



Average fraction of forest land harvested annually by federal and nonfederal (state and private) landowners in western Oregon and Washington from 1972 to 2002.



Volcanic and harvest-related disturbances as recorded from space: forest loss (white areas) resulting from the 1980 eruption of Mount St. Helens was clearly captured by the Landsat record, as were stand-clearing harvests from 1972 to 2002 (light gray areas). Embedded within the blast zone are areas that were clearcut before the eruption.



Landsat 7 ETM+ images from before (August 2001) and after (September 2002) the Biscuit Fire that occurred on the border between Oregon and California in 2002. Significant changes in reflectance accompany disturbance such as this fire.

of the forest had been removed," explains Zhiqiang Yang, a LARSE researcher who was instrumental in this breakthrough.

Once they had ground data spanning several different intensities of forest thinning, they compared the changes on the ground to changes in the Landsat data over the same period. They then built statistical models correlating the two.

"These advances now allow us to better characterize the approximately 50 percent of the region's harvests that involve only partial canopy removal," says Healey.

LAND MANAGEMENT IMPLICATIONS

- A map of stand-clearing disturbances in western Oregon and Washington was central in three important monitoring efforts supporting the 10-year science review of the Northwest Forest Plan. The map was used to identify changes in the amount and distribution of late-successional forest, northern spotted owl habitat, and marbled murrelet habitat since the enactment of the Plan.

- The Forest Service Inventory and Analysis Program is currently studying ways in which their reporting of forest trends can be supplemented with information from disturbance maps created by using approaches pioneered at LARSE.

SCALING UP

Through advances such as the Disturbance Index and mapping partial harvests, LARSE has made a name for themselves in the field of forest change detection. So it's not too surprising that when the National Aeronautics and Space Administration (NASA) and the University of Maryland became interested in building a map of disturbance and recovery for most of North America, they came to LARSE to collaborate.

A national-scale project known as the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) is currently mapping disturbance using Landsat imagery across all of the contintental United States. The Disturbance Index developed at LARSE is central in the LEDAPS change detection algorithm and has contributed to the high degree of automation needed to work with the thousands of images involved. The primary goal of this project is to gain insight into continental-scale carbon fluxes, and ultimately to improve our understanding of the role of the forest in controlling the climate. The data eventually will be used by the North American Carbon Program.

Now, in conjunction with the carbon project, the LARSE team is taking the analysis one step further. "The LEDAPS project, due to its massive spatial scale, is limiting itself to three points in time between 1975 and 2000. The long lags between imagery mean that the analysis will miss a lot of disturbances," says Cohen.

With Cohen and Healey, Robert Kennedy and Scott Powell, all LARSE researchers, have developed a process for estimating just what was missed.

"The change detection approach we developed for measuring thinning and partial forest disturbance lies at the heart of a collaboration between NASA and the Forest Service to characterize the Nation's disturbance patterns. Detailed estimates of biomass loss and gain will be mapped over 30 to 40 full Landsat scenes (115 miles by 115 miles) by using biennial Landsat imagery and Forest Service inventory plot data. Whereas the LEDAPS program will map primarily clearcuts over the entire country, this program will focus on more subtle disturbances," says Powell.

Information from the high-resolution sample sites will eventually be extrapolated to the continental-scale analysis, using a sample design pioneered by Kennedy.

WRITER'S PROFILE

Jonathan Thompson is an ecologist and science writer. He lives in Corvallis, Oregon.

SUPPLEMENTING FOREST INVENTORIES

The integration between the Landsat imagery and the Forest Service inventory data has led to yet another collaboration. The Forest Inventory and Analysis (FIA) Program of the Forest Service collects and maintains forest data over the entire country. They report on changes in forest condition to Congress, the National Forest System, tribes, states, private industry, and the public. These groups have questions about how fires, harvests, insects, and storms have affected local forests. LARSE is now beginning to work with FIA to explore the possibilities of tracking the network of inventory plots from space.

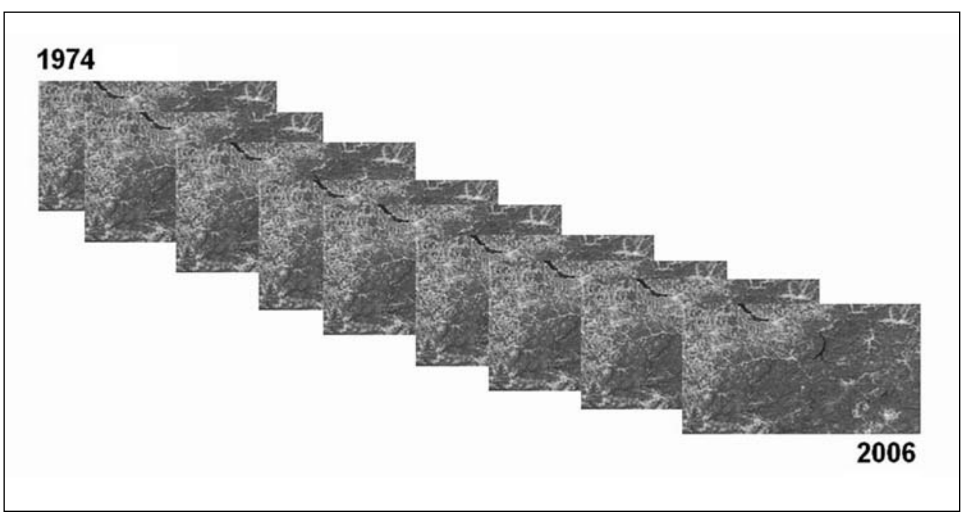
Although FIA can currently estimate the effects of disturbance at the state level, satellite mapping offers a spatially explicit view of disturbance patterns unavailable from FIA's sample grid. "FIA is beginning to see the power of remote sensing for forest change information," says Cohen. "By linking plot data to Landsat imagery we can then estimate the biomass on a plot, estimate the carbon stores, and monitor any changes over time."

Through the collaborations with FIA, NASA, the state of Washington, and many others, LARSE has emerged as a global leader in the use of remote sensing for forest change detection. Their methods have been expanded beyond the Pacific Northwest to answer disturbance-related questions at a national scale. They will no doubt continue to find unique and important applications for this technology.

"Nothing endures but change."

—Heraclitus, ca. 500 B.C.E.

Change detection algorithms take advantage of the difference in reflectance between predisturbance (forested) and postdisturbance conditions.



Time series of Landsat imagery. The consistency of the Landsat satellite series over time makes it an ideal tool for studying historical forest changes.

FOR FURTHER READING

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WARREN COHEN is a research ecologist with the PNW Research Station, USDA Forest Service, and Director of the Laboratory for Applications of Remote Sensing in Ecology at the Corvallis Forestry Sciences Laboratory in Oregon. Currently, he conducts research in remote sensing and related geographic and ecological sciences. His primary focus is translation of remote sensing data into useful ecological information, with significant activity in analysis and modeling of vegetation structure and composition across multiple biome types. Cohen's research involves spatially explicit modeling of ecological processes with significant attention to scaling from fine to coarse grain.

He is a Courtesy Professor in the Department of Forest Science at Oregon State University (OSU). Cohen is on the editorial board of the journal *Remote Sensing of Environment*, and has published over 100 peer-reviewed papers across a spectrum of forestry, ecology, and remote sensing journals. He now serves on the newly formed Landsat Data Continuity Mission Science Team in collaboration with the U.S. Geological Survey.

Sean Healey

SEAN HEALEY is a research ecologist in the Forest Inventory and Analysis Program at the Rocky Mountain Research Station in Ogden, Utah. He worked at the Corvallis Forestry Sciences Laboratory between 2002 and 2005.

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