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INSIDE

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

Innovation in the Interior: How State-of-the-Art Remote Sensing Is Helping to Inventory Alaska's Last Frontier

Ross Nelson

Interior Alaska remains the last portion of the United States to be systematically inventoried by the U.S. Forest Service Forest Inventory and Analysis program. A 10-year collaboration jointly funded by the Forest Service and NASA will inventory the 115 million acres through a combination of airborne remote sensing and field plots.

IN SUMMARY

Since the 1930s, the U.S. Forest Service Forest Inventory and Analysis (FIA) program has inventoried the nation's forests to produce "The Nation's Forest Census." This census provides valuable snapshots of forests in the lower 48 states, Hawaii, southeast Alaska, and the U.S.-affiliated Pacific Islands. Although select areas of interior Alaska have been inventoried, a systematic inventory hasn't been conducted due to the interior's remoteness and correspondingly higher inventory costs.

A team composed of researchers with the U.S. Forest Service Pacific Northwest Research Station, NASA's Goddard Space Flight Center, American University, and Michigan State University developed a remote-sensing and ground-based solution to inventory interior Alaska. In 2014, a pilot project conducted in the Tanana Valley demonstrated that the combination of Goddard's LiDAR Hyperspectral and Thermal airborne imager (G-LiHT), field-based plots, and a modified sampling protocol produced a dataset that managers could use with a high confidence in its accuracy.

Because of the pilot project's success, Congress provided funding to implement the FIA inventory in all of interior Alaska. The team is conducting inventories as part of a 10-year collaboration jointly funded by the Forest Service and NASA. The Tanana Inventory Unit, one of five units, was completed in 2018; also in 2018, the Susitna-Copper Inventory Unit was surveyed with G-LiHT, and FIA ground plot measurements will be completed in 2020.

"Start where you stand, and work with whatever tools you may have at your command, and better tools will be found as you go along."
—George Herbert, poet

Throughout the summer of 2014, anyone watching the Piper-Cherokee, single-engine, piston-powered airplane fly repeated passes over interior Alaska's Tanana Valley might have thought the airplane was like the other small planes that fly Alaska's skies. This was not a typical Piper-Cherokee though; it carried a state-of-the-art multisensor airborne imaging remote-sensing system that can measure the structure, spectral reflectance, and thermal emissions of the landscape at a tree-scale resolution. To answer the question of how forests are distributed and changing in interior Alaska, Forest Service and National Aeronautics and Space Administration (NASA) researchers are looking down from the skies and up from the ground.

The 1928 McSweeny-McNary Act mandates the U.S. Forest Service to inventory the forests of the United States. Since the first inventory in the 1930s and subsequent upgrades to a nationally consistent design in the early 2000s, the agency has established more than 125,000 permanent plots across the lower 48 states, Hawaii, and the U.S.-affiliated territories such as Guam and American Samoa. Based on these inventories, the Forest Service, state agencies, and nonprofit organizations can monitor national- and state-level status and trends in forest coverage, forest health, and forest ownership.

It wasn't until the 1990s, however, that U.S. Forest Service Forest Inventory and Analysis (FIA) plots were established in southeast and south-central Alaska. Still missing were 115 million acres of forest within interior Alaska.

"It was basically a big missing piece of our inventory that had always been a thorn in the side of our program nationally," explains Hans-Erik Andersen, a research forester with the U.S. Forest Service Pacific Northwest (PNW) Research Station. "We had this big area that is a fifth of the forest area of the United States that was a blank spot in terms of our national inventory"

Information about Alaska's interior forests are needed for several reasons. "We have wood-based biomass projects in communities that are located in remote areas, and we're trying to generate some inventory data to make sure the projects are sustainable for the long term," says Doug Hanson, the statewide inventory forester with the Alaska Division of Forestry. "It's always a bit of a struggle because we don't really have any reliable data in these remote areas."

Knowing the biomass volumes will also allow interior Alaska to participate in the carbon markets. "We can't participate in the interior because we don't have the FIA data, which is what's accepted by the California Air Resources Board," Hanson explains. In contrast, because FIA data are available for southeast Alaska, this region is already enrolled in the carbon markets.

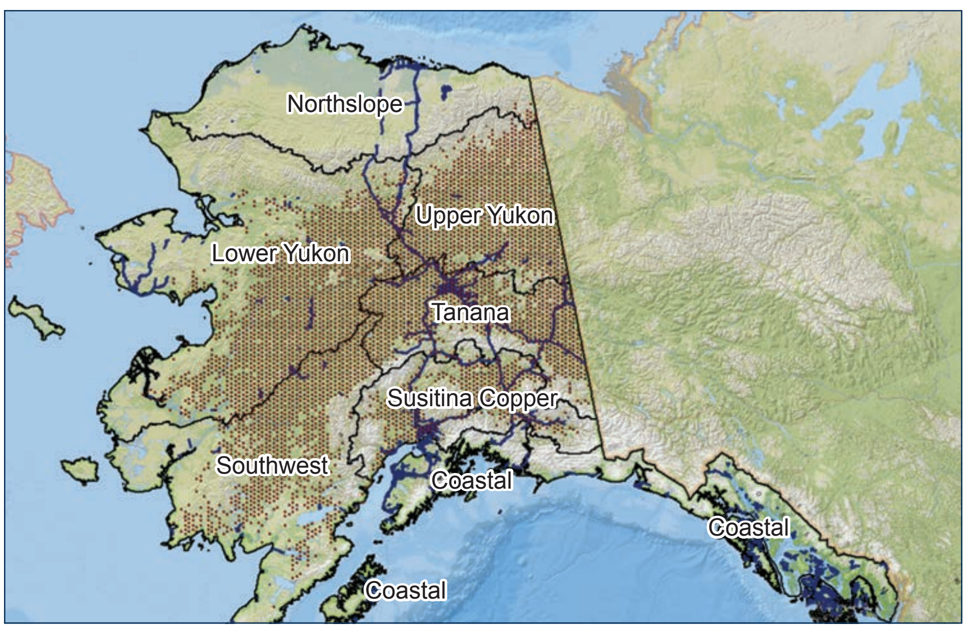
Another reason for inventorying interior Alaska is for improved monitoring of ecological changes. "There's the obvious spruce bark beetle outbreaks that are spreading into the south-central region of Alaska, which is leading to widespread mortality," says Andersen. "There's a number of interactions related to permafrost melting out in some areas, which leads to drying out in some areas and increased moisture in other areas. We're getting these strange, changing forest conditions in terms of soil moisture and hydrology, which are having interesting effects on ecological dynamics."

These ecological changes have the potential to negatively affect wildlife habitat, which in turn can affect remote, subsistence-based communities that rely on game species, such as moose and caribou.

As team leader for the vegetation monitoring and remote-sensing team at the PNW Research

KEY FINDINGS

- New statistical approaches that integrate ground-based and remote sensing data significantly improve the precision, accuracy, and spatial estimates based on Forest Inventory and Analysis (FIA) data.
- High-resolution imagery collected by drones is a potential valuable link between field measurements and airborne or satellite data, particularly for estimating the growth and expansion of woody shrub biomass; loss of tree and organic soil carbon due to fire; and tree mortality due to the spread of insects and disease. Airborne remote-sensing data also captures plots that are otherwise inaccessible to FIA crews due to their remoteness and wilderness classification.
- New protocols to obtain precise GPS locations enable field-based and remotely sensed information to be tightly integrated. This enables more sophisticated sampling designs and modeling techniques.
- When calculating carbon budgets is a management goal, repeated LiDAR sampling of a given area can be used to calculate burn severity and consumption of organic layers where there is sparse field data available.



By 2028, field crews will have inventoried about 4,860 forested plots in interior Alaska. That amounts to one plot per 30,000 acres and encompasses an area larger than California and Texas combined.

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Station, Andersen has spent over 10 years developing remote-sensing applications, both satellite and airborne based, to support the FIA inventory specifically for interior Alaska. Inventorying the forest from overhead was necessary because of the vastness of forest area needing to be inventoried. With a sampling intensity of one plot per 30,000 acres (in the lower 48 states and southeast Alaska, the sampling intensity is one plot per 6,000 acres), there was a lot of area that wouldn't be inventoried, which would lower the certainty of the biomass estimates.

"We knew we were going to want to use state-of-the-art remote-sensing technology to augment the plots in order to fill in the large gaps between the plots on the ground," Andersen explains.

LAND MANAGEMENT IMPLICATIONS

- The state of Alaska uses Forest Inventory and Analysis data and analyses to inform wood-based biomass projects, monitor forest health, and support subsistence-based economies.
- Following the success of the Tanana pilot project, Congress provided annual funding to implement forest inventory in interior Alaska.
- The high-resolution, remote sensing-based products developed for the Tanana pilot project are helping field crews more efficiently assess forest vs. nonforest conditions prior to field sampling.
- Remote sensing is not intended to replace field crews but rather to supplement inventory data that can only be collected by people on the ground. This inventory data includes soil measurements and ground cover estimates.

In 2011, Andersen heard that the Biospheric Sciences Laboratory at NASA-Goddard Space Flight Center had developed a cutting-edge, state-of-the-art sensor package dubbed the Goddard LiDAR Hyperspectral and Thermal (G-LiHT) airborne imager. What made this piece of equipment cutting edge was the combination of 3-D LiDAR (Light Detection and Ranging) and 2-D hyperspectral, and thermal imaging technology.

A hyperspectral sensor sees in both the visible and infrared spectrums and is often used to classify different types of tree species. Trees also exhibit signs of stress in the infrared spectrum before their symptoms are evident to the human eye, so hyperspectral data are valuable for monitoring forest health. LiDAR is light in the form of a pulsed laser, and the distance that the laser travels before hitting an object, such as a tree's branch, and returning is converted into points. Collectively, these points create a 3-D point cloud that allows researchers to calculate tree heights and count tree species; it's even possible to detect minute changes in elevation. "Our instruments are capable of measuring differences in the ground elevation of 10 centimeters," says Bruce Cook, a terrestrial biologist and earth scientist in the Biospheric Science Laboratory and principal investigator of the G-LiHT project.

When these spectrum data and height measurements are combined with a high-resolution camera and on-the-ground plot data, researchers have a powerful dataset from which to estimate, through statistical modeling, the volume of aboveground biomass, whether in the form of trees or shrubs, and monitor forest health.

U.S. Forest Service

A field technican takes measurements within a study plot in interior Alaska. Data about the forest understory—vegetation, downed wood, soil for example—can only be collected by people on the ground. Field data on larger elements such as tree size are essential for vaildating remote sensing data.

Andersen approached Cook to ask whether NASA could provide support for the FIA effort to inventory interior Alaska. Cook was intrigued by the research challenge. Although NASA is typically associated with studying outer space, the agency invests heavily in researching Earth. The agency's Earth Science Division seeks to understand our planet's natural processes, ranging from a planetary-scale down to minute ecosystem level. To accomplish this goal, NASA develops and uses technology that can map terrestrial vegetation and track changes that occur due to changes in climate, resource consumption, and disturbance events.

"At NASA, we see the Earth as a planet just like any other planet out there," Cook says. "We study everything from the atmosphere and wind circulation, to the ecology of plant communities and how ecosystems respond to disturbances and global environmental change."

With NASA and the Forest Service both seeing the value of the proposed collaboration, the joint NASA-FIA pilot project was born.

A Cutting-Edge Inventory

The pilot project kicked off in 2014 in the Tanana inventory unit in eastern Alaska. It initially included the Tanana Valley State Forest and Tetlin National Wildlife Refuge. Field crews from the Alaska Division of Forestry placed plots in areas that had never been inventoried. Along with the standard FIA protocol of measuring trees and coarse woody debris and collecting soil samples, additional measurements were taken of lichens and moss, which can store substantial amounts of carbon.

Mikhail Yatskov

Boreal forests often have a dense ground layer of lichens, mosses, and other vegetation, which provides forage for caribou and can store substantial amounts of carbon.

"The abundance of lichens, moss, and shrubs is also directly related to the quality of habitat for game species such as caribou and moose," Andersen says. "Those variables are of interest to the subsistence economies."

Cook and his crew arrived toward the end of June. During July and August, the Piper-Cherokee flew 68 passes that were 5 miles apart; within these strips were the 800 ground plots. "What we did was fly a line that connects those plots," he explains. "We obtain the information over the plots because we know exactly where the plots are, and we obtain information between the plots."

The exact location of the ground plots was known because the field crews had recorded these locations using precise global navigation satellite systems (GNSS): GPS (US), GLONASS (Russia), Galileo (EU), and BeiDou (China). Realizing this would be critical for pairing field data with G-LiHT data, Andersen and his team had tested a variety of instruments and configurations to determine what setup had the capability to obtain signals from the satellites even through the dense boreal forest and provide accurate field plot positions. The resulting equipment had less than 3 feet of error and is now being used not only in Alaska but in other western states as well.

By the end of the summer, the G-LiHT system had acquired data for approximately 34 million acres of the Tanana inventory unit. Cook was one of two instrument operators aboard the aircraft monitoring the equipment. While the sensors were recording their data, Cook was continuously evaluating the image data and landscape with his eyes. "When you look out the aircraft, you're seeing the forest in a different perspective than you are when you're just seeing data on a computer screen," he explains. "For me, as a scientist, being there when the data is collected is helpful for thinking about the data and interpreting the data."

To estimate the volume of biomass within the Tanana inventory unit, the team developed new statistical estimators. This involved carrying out extensive statistical analyses and running simulations where the values are known to determine how accurate they are. The result was a set of procedures that produced biomass estimates the researchers had a high degree of confidence in.

Bridging Observation From Ground to Sky

Another priority for the team, which expanded beyond the Forest Service and the NASA-Goddard Space Flight Center to include collaborators with American University, and Michigan State University, was testing how existing remote sensing methods could support the FIA inventory work. While a postdoctorate in the Biospheric Sciences Laboratory, Mike Alonzo, now an assistant professor at American University, experimented with how previously collected LiDAR datasets and drones could answer new research questions. "We're trying to bridge this scale gap between intensive but difficult plot studies, and extensive but less information-rich satellite studies," he explains.

In 2005, the Fox Creek Fire burned nearly 26,300 acres of black spruce forest on the Kenai Peninsula. This same area had LiDAR data collected in 2004 and 2009. Alonzo saw an opportunity to use LiDAR to estimate changes in the forest structure and the soil's organic layer; in a forest, the organic layer is composed of twigs and decomposing vegetation. The reason for wanting to know how much organic layer was lost due to fire is important, because "that's where most of the carbon lives," says Alonzo. "It's in the first [1 to 40 inches] of organic layer of this rich soil. If that's getting burned up and sent up into the atmosphere, that's the real game-changer, carbon wise."

By subtracting the 2004 LiDAR-derived tree heights and elevation measurements from the 2009 LiDAR-derived tree heights and elevation measurements, Alonzo found that the highest organic layer loss was observed in the lowland black spruce stands, and that the loss of canopy and organic layer was linked to pre-fire forest conditions.

For his second study, Alonzo experimented with combining photographs taken by an unmanned aerial vehicle, more commonly known as a drone, and FIA data. "One of the ideas with using a drone is that you can collect extremely high-resolution data such as photographs that may provide a scaling bridge between plot-based field data and G-LiHT data," Alonzo explains.

Although an airplane equipped with G-LiHT can travel farther, it is more costly to fly. While a drone must remain within line of sight of its operator, even a model purchased at a local consumer electronics store, once outfitted with a camera, can collect ultra-high-resolution images and make 3-D models similar to more expensive LiDAR systems.

Mike Alonzo

A researcher catches a drone outfitted with a camera. The resulting images were converted to a 3-D point cloud from which the researchers could calculate tree density, species composition, and aboveground biomass with a high degree of accuracy.

Alonzo conducted the experiment by flying a drone over five FIA plot clusters in the Bonanza Creek Experimental Forest, which is southwest of Fairbanks. He flew the drone in a grid pattern that captured the trees from all four sides. From these images, the photos were then turned into a 3-D point cloud by which the tree density, basal area, species composition, and aboveground biomass were estimated. A cross validation against the plot data yielded results that had a high degree of accuracy.

Because of these successful results, Alonzo sees drones as a tool to augment and cover more ground surrounding FIA ground plots: "You get a more objective top-down view on things like canopy cover that are traditionally based on visual estimates, which is hard to do well."

The Next Phase of Inventorying

With the G-LiHT pilot project regarded as a success, in 2016 Congress allocated funding to implement the FIA inventory in interior Alaska. The interior was divided into five inventory units, and according to Andersen, "each of these units is about the size of a large state in the lower 48, just to give you an idea of the scale."

Airborne and ground measurements of the Tanana inventory unit were completed during 2016–2018, and the team is now developing the estimates and expects to deliver a forest resource summary report. During summer 2018, Cook and his team flew the G-LiHT system over the Susitna-Copper Inventory Unit, and FIA ground measurements will be completed by 2020. Half of the southwest inventory unit was surveyed with G-LiHT during 2019, with the remainder of the unit to be flown in 2020.

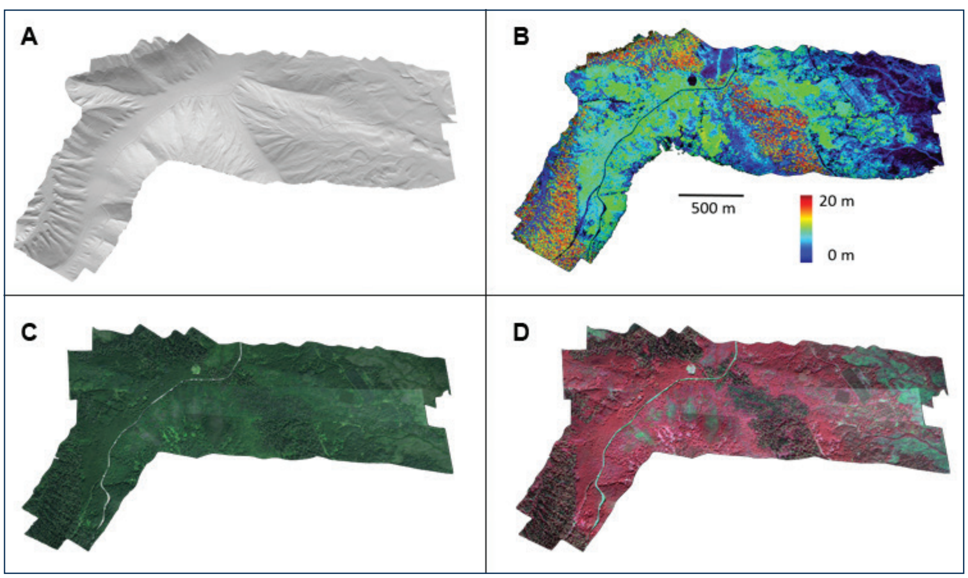
In the southwest inventory unit, the field crews will find themselves in a completely roadless area that hasn't been inventoried beyond the rivers. "There has been some inventory work performed by the (Alaska) Native corporations, but when you start getting out beyond the river systems, plots haven't been placed in those areas," Hanson says. "There's going to be timber that hasn't been inventoried before."

Given the difficulty in installing ground plots in these remote areas, some might wonder if installing ground plots is needed when G-LiHT captures a 3-D image of the forest. "What remote sensing does really well is cover more ground than you can with plot data. We can come up with estimates, but those are never as good as collecting measurement on the ground," Cook cautions.

"There will always have to be a field component," adds Andersen. "We know there are certain measurements you cannot collect from an airborne platform. The soil sampling, the understory vegetation component. We're not getting understory composition from G-LiHT if it's under a canopy."

Andersen sees the new frontier of remote sensing being used in the last frontier as a continuation of a long tradition. "Alaska has a history of using aerial photos to support forest inventory efforts," he says. "It's neat to be part of the next generation of state-of-the-art airborne sensors. The information and the insights we're able to gain from this unique combination of field sampling and the rich remote-sensing data is allowing us to ask different questions than we were able to previously."

"Knowledge is power."
—Francis Bacon, philosopher and statesman



Examples of Goddard-LiDAR/Hyperspectral/Thermal measurements for an area within Bonanza Creek Experimental Forest: (A) Detailed terrain surface measurements derived from LiDAR flown above the forest canopy. (B) LiDAR-derived canopy height measurements at the scale of individual trees. (C) This normal color image obtained from hyperspectral imagery can be used to interpret forest type. (D) This color-infrared image (green reflectance = blue, red reflectance = green, near infrared reflectance = red) can help to detect dead trees and measure live tree health.

WRITER'S PROFILE

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For Further Reading

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