DNR Resource Assessment Program Forest Inventory Program FAQs

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Overview

To enhance forest inventory, keep the information up to date, and reduce costs, the Resource Assessment Program (RAP) conducted a pilot project from 2016-2019 funded by the Environment and Natural Resources Trust Fund (ENRTF), with collaborators from Cass County, USFS Superior and Chippewa National Forests, University of Minnesota, and Northland Community and Technical College. This study compared traditional forest inventory methods in the field to modern remotely sensed methods to determine the most cost-effective approach, while also meeting the highest number of business needs. The results showed that lidar derived grid metrics and precisely located larger fixed radius field plots (1/10th acre) produce accurate forest inventory models at the stand to landscape scale.

Today, RAP is expanding the Plot Based Inventory (PBI) effort across all lands and has a private landowner sign up campaign, also funded by ENRTF. Through this project, RAP will be making concerted efforts towards sustaining a reduced inventory cost by combining the efforts of PBI and leveraging enhanced USFS Forest Inventory and Analysis (FIA) data, planned to be collected using a high-precision GPS and an even denser spatial distribution of plots in the future (e.g., 1 plot for every 2000 acres). The two agencies are working in tandem for the upcoming cycles to serve both the national and state business needs.

In addition, new lidar data has been collected throughout Minnesota thanks to the USGS 3D Elevation Program (3DEP), the efforts of the Minnesota Geospatial Advisory Council's 3D Geomatics Committee (links to: https://lidarhub-minnesota.hub.arcgis.com/), and the dozens of local partnerships raising millions of dollars together. RAP is taking advantage of this lidar data collection effort and the result will be a complete, updated, wall-to-wall inventory (all lands and ownerships) within the areas where lidar and high precision field data collection are taking place.

Overall, PBI and lidar derived forest inventory reduces inventory costs - from currently six to eight dollars per acre to two to three dollars per acre, including PBI data collection, processing, and the Resource Assessment Program's investment in lidar data. While there is more work per plot, there is less work overall and at a reduced cost.

Plot Based Inventory (PBI) Background

What is PBI?

PBI is a dense network of one-tenth acre forest inventory plots (fixed radius = 37.2 feet) distributed statewide across all ownerships in forested conditions. Each PBI plot is approximately 1 mile apart from the next plot, and each effectively represents 1,500 acres in a statewide network.

On mobile devices using Survey123, detailed measurements on all trees ≥ 5" DBH within the plot area are recorded (DBH, species, status, total/merchantable height). A YouTube video explains and demonstrates the data collection protocol: Plot Based Inventory (PBI) Data Collection Tutorial - YouTube

(links to https://www.youtube.com/watch?v=zcSPPY8XniU). A detailed procedural manual is also available: Plot Based Inventory Manual (links to: https://files.dnr.state.mn.us/forestry/pbi-field-manual.pdf).

Where is PBI?

The proposed original PBI network of plots were distributed on a grid across all forested land in Minnesota, regardless of land ownership. The plots will always be marked as *proposed* until there are official plans to target data collection. Therefore, not every PBI plot on the grid will be visited, because not all forest land ownerships are partners of PBI yet.

RAP has been expanding PBI involvement with partnerships across Minnesota, now including both Superior and Chippewa National Forests, nine counties, two municipalities, one private industrial company, and one Tribal Nation. Efforts are now underway to expand outreach for private forest land involvement. Landowners, businesses, and local governments interested in getting involved in PBI should contact the RAP.

Who collects PBI plot data?

PBI data is collected by a variety of professional foresters including internal DNR staff, partnering forestry organizations and private consulting foresters. Training and specific equipment is required, as well as a minimum number of plots being collected due to mobilization and equipment costs/logistics.

How do I become a PBI data collector?

Those interested can register as a State Authorized Bidder by vising this website: Registration (state.mn.us)

The workflow to register is self-directed, and there is minimal information needed. When you register as a Bidder, be sure to enter the services you provide to be notified when those contracts are out for bid. Should you become the successful bidder, and prior to bid award, you will need to register as a Supplier. At that time, you'll need to provide more information. There is a Bidder helpline available in the portal as well.

For more information about eligibility requirements to become a contractor collecting PBI plots, please contact us at: ForestInventory.dnr@state.mn.us.

I am familiar with Cooperative Stand Assessment (CSA), is PBI going to replace CSA?

Yes and no. Cooperative Stand Assessment (CSA) is really a reference to forest inventory measurements using either Variable Radius (VR) or Volume to Basal Area Ratio (VBAR) data collection methods for stand level inventories. On varying electronic devices and paper systems, these forest inventory methods were used on some County partner lands in the past, hence the "Cooperative" part of the title. Today, electronic devices are used to collect activity code types like VR or VBAR for DNR's forest inventory. The previously used CSA manual will not be explicitly used anymore, and we will retire the phrase "CSA". Fixed radius plot data collection, such as PBI or FIA, may be collected using a similar device, but not necessarily using the same software systems.

A combination of field inventory techniques (VR, VBAR, and fixed radius) will need to be used to keep our forest stand information up to date. PBI has taken a front seat, due to our commitment to developing lidar derived forest inventory baseline models. Ideally, PBI plots are collected during an approximately 2-year window surrounding the collection of an area's lidar data. The models developed produce wall-to-wall forest inventory information, which is summarized at the stand scale. By focusing on PBI data collection instead of VR or VBAR during this window, 100% of the stands in a lidar acquisition area get updated. Should a stand need to be updated after the PBI and lidar derived forest inventory data collection effort is complete, VR or VBAR fieldwork can be utilized to update individual stands.

Products from this remotely sensed forest inventory may be highly useful when planning stand-level forest management, particularly when landscape scale considerations are warranted. The PBI and lidar derived forest inventory data does not replace on the ground appraisals for timber sales, it is utilized for inventory only.

Why PBI instead of USFS Forest Inventory and Analysis (FIA)?

The USFS Forest Inventory and Analysis (FIA) program is a tremendous data resource providing forest inventory estimates at county to statewide scales. However, there are significant considerations to be made when lidar derived forest inventory models are the main purpose, necessitating our investment in PBI to create a baseline.

The number and distribution of FIA plots is different than PBI. In general, an FIA plot is representative of about 3,000 acres, in contrast to PBI that has intensity of one plot for every 1,500 acres. The size of an FIA sub-plot (a plot consists of four sub-plots where trees five inch and larger in DBH are measured) is much smaller (1/24 acre) compared to PBI plots (1/10 acre). Larger plots minimize edge effects and provide better correlation between field-based data and lidar grid metrics. The field protocol of PBI requires a high-accuracy GPS plot center point, but FIA does not require strict location precision. In addition, PBI field data is collected within a relatively short window of time from when the lidar is

collected (approximately two years), reducing any temporal mismatch (FIA may be up to 5 years of difference since the lidar acquisition).

As a result of these differences, when attempting to use FIA data for both lidar derived model creation and forest inventory estimates at small geographic scales (e.g., stands or parcels), the data does not support the creation of baseline models within a reasonably acceptable level of variance and model fit statistics. Regardless, FIA data is still highly valuable to the state, holding great importance for several activities including first and foremost maintaining timely updates to the baseline forest inventory data and performing strategic landscape level planning.

Are forest inventory models available everywhere, even where PBI was not collected?

Yes. Analogous to cruising timber in a forest stand, PBI plots are samples laid out on a grid across the whole state. The forest inventory models are produced across a lidar acquisition area using the PBI plots within that region. The result is wall-to-wall inventory for the areas where both lidar and PBI are taking place. Without the PBI plots collected in a region, the models may not accurately represent the forested conditions of that region. It is important that as many PBI plots from the proposed grid network are collected to ensure this modeling capability.

Once both PBI and lidar are available for an area, the forest inventory models produced can also be summarized at the stand level. If an area does not yet have stand boundaries, lidar derived information can be valuable to creating those features. A YouTube video explains and demonstrates some basics behind our lidar data processing workflow protocol: Lidar applications for Plot Based Forest Inventory (PBI) at Minnesota DNR - YouTube (links to https://www.youtube.com/watch?v=-oisFShM6Nw)

How can the public get involved in PBI?

PBI involvement occurs at different levels depending on role or interest in the forest inventory program. If there is a private landowner interested in getting involved and having a PBI plot collected on their property, there is a different path to getting involved, compared to a consulting forester looking to be a contractor collecting PBI plots, or a partner interested in using data or learning more about the processes involved in creating lidar derived forest inventory data.

Regardless of your affiliation and interest level in PBI the best place to start is the Resource Assessment Program (RAP) website or contacting RAP staff with your questions!

https://www.dnr.state.mn.us/forestry/resource-assessment.html

Will PBI data be collected again in the future?

The Division may consider several options after the completion of the current round of PBI collection. Some examples include, but are not limited to:

- Acquire new PBI data on a cycle, every 5 years.
- Use growth and yield modeling to track growth throughout the forest, and within stands. Target areas that are not well understood or are experiencing faster rates of change.
- Track harvests and other changes to forest canopy through remote sensing and inventory data.
- Utilize stereo photogrammetry for height-based models in between lidar collections.
- Integrate FIA with high precision GPS and larger plots sizes to supplement PBI, particularly on other ownerships.
- Conduct VR and VBAR inventory activities where necessary.

Most likely, a combination of all the inventory activity types and ideas bulleted above will be used to keep our forest stands up to date. Keeping all our forest inventory up to date is an operational change and continues to be a high priority for the Division.

PBI data collection on Survey123

Why do I need to log in to Survey123 on the tablet with my username@mndnr?

When you log in to the Survey123 app using your username and send in a survey, your username information automatically gets associated with that PBI entry. If an error is found during the QAQC process, the right person can be contacted quickly. The PBI data being collected is in a secured environment, and you will be unable to access most features without logging in. This includes some necessary features of our Survey123 setup.

Do I need to log in to Survey123 every day before going into the field?

No. Generally there are two times you will need to be logged in to Survey123: 1) when you are sending in a survey at the end of the day, and 2) when you receive an email from RAP staff letting you know an update has occurred to the form, or when you are prompted by the application that an update is available. However, it is good practice to regularly check for updates. If a survey is updated and you have not downloaded the update, upload issues can occur. Refer to the “Survey123 Tutorial” on how to update the form.

Survey123 will leave you logged in for extended periods of time and you may not need to log into the application every time you submit or update a survey. Note: there may be other times when logging in

may be necessary, contact RAP via email (mailto:forestinventory.dnr@state.mn.us) if you have any questions.

Do I need to do anything in Survey123 after submitting my plots?

Once your plots are submitted, the data will be added to the PBI database and available for review by Resource Assessment Program staff. The review process includes two parts: GPS and Survey Data review. These review steps take place on different timelines.

GPS review is typically completed at the beginning of every month. Any issues with GPS data are identified and the forester collecting the data should be notified relatively quickly.

Survey Data review is a longer process and involves collection of Quality Assessment data, reviewing submitted plots for missing data and looking for incorrect plot information. QA is typically done within the month or two following collection and any issues that are identified during that process will be addressed with the forester.

Survey123 retains "sent" surveys within the application, stored on the device until they are deleted. It is good practice to keep your survey data on the device until review for the plot is complete. Submission errors, questions about the plot, or new GPS files may be needed, and keeping the survey available for your review can make resolving any issues much easier.

What kind of height measurements are collected on a PBI plot?

Total and merchantable heights are both needed for estimating standing biomass and volume. While lidar can estimate the height of an object very accurately, the length of the merchantable portion of the tree continues to be an important measurement in the field. Volume equations rely upon DBH and merchantable height, and above ground biomass requires the total height. This, along with the other measurements collected on plot are critical to our modeling efforts. If we were to use only heights from lidar our models would overestimate timber volume and be less accurate.

GPS for PBI data collection

Why are we using a high precision GPS?

GPS accuracy is critical to PBI and lidar derived forest inventory, as models are built from precise locations collected in the field. The Emlid Reach RS2 GPS is different from your typical recreation grade GPS. A recreation grade GPS uses one frequency of the GPS signal to determine location. The Emlid Reach RS2 GPS is a dual-frequency GPS, meaning it has two measurements of location to compare to each other. These two measurements are used to remove multipath errors (GPS signals that have bounced around in the canopy or hit a thick part of the atmosphere), resulting in a much more precise

location. This provides a more accurate location, capable of collecting your plot center to within a meter of accuracy. Without precision GPS, tree level measurements and plot level summaries from field data may be correlated to completely different trees in the lidar data, producing inaccurate model results.

Does it matter where I place the GPS within the plot area?

The location of the GPS within the plot area is an important consideration when collecting a PBI plot. Placing the GPS at plot center may cause issues when trying to collect plot data at the same location. Placing the GPS directly under low or dense canopy may have impacts on precision. The best location for the GPS on PBI plots is in an area that is relatively open and near plot center. If the GPS is not located at plot center, you must also record the azimuth and distance from the plot center to the GPS. The farther you move off plot center, the more potential error in measuring the azimuth and distance you introduce. Following collection of the GPS data, Resource Assessment Program adjusts the plot location back to the plot center using a correction formula, meaning that if the azimuth is recorded incorrectly, the final location will also be less precise.

How Long does the GPS location need to be collected?

Depending on the GPS there are minimum collection times needed to achieve the precision required for modeling.

If you are using the ***Emlid Reach RS2 GPS***, the minimum collection time is ***30 Minutes.***

If you are using the ***Trimble R2 GPS***, the minimum collection time is ***40 Minutes.***

At a typical plot location that has a fully stocked forest condition, starting the GPS prior to measuring the remaining plot attributes will almost always be enough time.

You may have plots that are not fully stocked, and the remaining data can be collected relatively quickly. In these conditions, you may need to wait until the GPS has collected data for long enough.

Lidar and derived products

When will new lidar be collected, when will the lidar data be available, and how do I access it?

Updates and information about lidar data collection can be found on the Minnesota Lidar Hub (links to: https://lidarhub-minnesota.hub.arcgis.com/). The status of lidar acquisition is shared on a Status Map on the Lidar Hub site. In this map, you can see where lidar has been acquired, where collection is anticipated, and whether the data are available. When lidar data becomes available, it is accessible

through The National Map (TNM Download v2 (nationalmap.gov) links to: https://apps.nationalmap.gov/downloader/).

Lidar grid metrics and lidar derived forest inventory products, on the other hand, will need to be disseminated in a different way. The Minnesota Geospatial Information Office (MnGeo) has been conducting a needs assessment and project definition for a new system to deliver lidar point cloud data and lidar derived products to the public. In addition, RAP is beginning the process of developing a new web application to host lidar derived forest inventory datasets alongside aerial photography resources. For more information about forest inventory products, see below.

The MN Lidar Plan can also be found on the Lidar Hub site. This Plan has been adapted as the partnerships have formed across the various Lidar Acquisition Blocks (LABs). The future of the USGS 3D Elevation Program will involve continued collection of lidar over time, though the specifics of when an area will have new lidar collected is unknown.

What forest inventory products will be available?

Lidar derived forest inventory is a current work in progress and these data are not yet widely available. As processing is completed, certain products will become available as data services on the Minnesota DNR Geospatial Data Resource Site (GDRS) and the Minnesota Geospatial Commons. In addition, RAP is beginning to develop a new web application to host a small list of these forest inventory datasets alongside aerial photography resources.

RAP develops several types of forest inventory products. Definitions of these products can be found in the Forest Inventory Program Glossary. These include but are not limited to:

- **Canopy height model:** a raster of absolute canopy height above ground created by subtracting a digital elevation model from a digital surface model.
- **Stand based inventory estimates:** vector dataset of stand level summaries on structural and composition variables. It is obtained by running zonal statistics on forest inventory model results using stand polygons or any geographic area. RAP populates the stand polygons with stand-level summaries for a given forest inventory model, as well as provides a 95% confidence interval for the inventory model estimate.
- **20-meter forest inventory models:** raster datasets of the forest inventory models are outcome of integration of plot level PBI data with lidar derived grid metrics and other remote sensed predictors. Models include: max (merchantable) height, basal area weighted height, trees per acre (TPA), stand basal area (BA), gross standing volume, above ground biomass (AGB), above ground carbon, site index (SI), stand age, and quadratic mean diameter (QMD).
- **Lidar grid metrics:** computed (binned) statistical metrics based on the elevation distribution of lidar returns falling within 1-meter resolution grid cells. RAP has produced more than 50 different lidar grid metrics (at 1-m) several of which will be made available to stakeholders via a new web application. The metrics selected for web publication may include: maximum

canopy height (canopy height model), average canopy height, 95th percentile of height, percentage canopy cover, standard deviation of lidar return (all) heights, and vertical strata densities (proportion of lidar returns) for horizontal slices from ground to 1.37 m, 1.37 to 5 m and from 5 to 10 m (see the list of individual metric definition in the Forest Inventory Program Glossary).

- **Stand segmentation:** This is a derived product that groups forest canopy features together into homogenous forest stand segments (biological objects) based on a variety of metrics. This product may look very different from our administrative boundaries, as they represent what is structurally there at the time of the lidar collection, as opposed to reflecting ownership boundaries, stand management history and goals.
- **Other remote sensing products:** Cover-type map produced from multi-temporal, multi-spectral satellite data; tree object segmentation.

*PBI plot level information is made available by request only.

Updates will be made to the RAP website (links to: https://www.dnr.state.mn.us/forestry/resource-assessment.html) as more information about derived product status and access information becomes available.

How can I use the lidar derived products?

Forest inventory data is delivered in both raster and vector format. The stand level polygon summaries can be used in the same way that forest inventory data is currently organized.

The forest inventory raster products provide a wealth of information which can show how variable the forest resources are across and within a stand. The raster-based products can be thought of like a digital photograph, just in terms of a forest metric as opposed to an optical image.

Aside from providing up-to-date stand-level summary data for use in forest management planning, the data provides sub-stand analysis capabilities. Determining the variation of modeled stand attributes within a stand boundary and across a broader landscape beyond the stand boundary will assist staff in field work planning, cut-out analysis, feasibility and re-delineation of boundaries, and cross-boundary collaboration. All the uses may not be immediately obvious, but with time, training, and research, the broader forestry community will fully realize a great return on investment.

The full scope of the uses of lidar derived information is still yet to be discovered, not just by RA, but the broader forestry community. Keep an eye and ear out for events and workshops sponsored by the Society of American Forestry (SAF) or University of Minnesota Extension, as well as trainings conducted by RAP.

If you need additional training on the use of raster layers, manipulation, and how to work with spatial data within a GIS program, RAP is available for longer training sessions, consultation services, and data analyses with a defined project funded through a professional contract or Service Level Agreement (SLA).

Will there be photography available with the lidar?

No, not exactly. Resource Assessment Program's peak fall color photography program has been on a cycle following the lidar data collection for the last several years. Fall color imagery is available for several overlapping dates in areas with new lidar, but the imagery is not likely from the same calendar year. USDA NAIP photography has been collected every other year for the last several years as well. So, chances are there is a photo available for every forested area only one year apart from the lidar data collection year, if not on the same year.

Why do we have a 1 meter Canopy Height models and 20 meter inventory models?

Lidar data can produce canopy height models with high resolution, 1 meter (or higher). However, our forest inventory models are limited to the size of the plot level data collected in the field. Using a combination of the more detailed canopy height information alongside the forest inventory models is highly valuable when planning forest management activities.

Why do the models say Version 1, will there be other versions of the forest inventory models?

Modeled forest inventory is viewed as a continual process, and within that process multiple versions of results will be created. Initial plot collection took place on State administered and partner lands. Version 1 may include plot data on public lands only. A subsequent version may include data collected on private lands. Refer to metadata and stand attributes to understand the "vintage" of the data you are viewing. Ultimately versions will be replaced and updated infrequently, but as we evaluate the first version of model results and modify the process and the data that is included, additional versions may provide more accuracy and confidence.

Will there ever be a higher resolution set of Inventory Models?

Forest inventory models are produced at the resolution equivalent to the size of the PBI plots. Because PBI plots have 22.6-m diameter, the closest pixel size is 20 m. Producing certain forest inventory models such as volume or biomass at 1-m or 5-m pixel sizes does not make sense because even a single tree crown can be spread horizontally over 10-m or larger diameter.

How is the forest cover type data produced?

The location and forest cover type information from PBI point data were utilized to develop a machine learning model approach for estimating statewide forest inventory models. To characterize the spectral

signatures of vegetation for the model's training samples, the Sentinel 2 satellite imagery dataset was primarily employed over PBI plot locations. Due to the seasonal variation in vegetation spectral signatures, the training samples comprised multi-year images, enhancing their variability. A random forest classifier was employed to construct the machine learning model using these training samples. The model's output includes 13 forest cover types and was evaluated with the original PBI data after processing.

Is Age in the modeled results?

A forest inventory model for age is under development, awaiting the completion of a cover type model. To produce this model, every PBI plot has had one tree cored with rings counted while in the field. Cover type specific age models will be built using lidar derived information and PBI tree core data.

How are you determining the statistical accuracy of the models?

Forest inventory model accuracy is determined in two ways. The first is by using model fit statistics such as root mean square error (RMSE) and R^2. The Random Forest modeling approach uses about one-third of the training data as out-of-bag (OOB) sample, and the OOB data are used for internal cross validation to calculate RMSE and R^2. The other way we check our model accuracies is by compiling something called a companion dataset, which looks at the stand level information from remotely sensed models and compares them to a business-as-usual approach, using VR or VBAR sampling.

Why can’t we click on a pixel and see the tree species associated?

Lidar informs about structure not about composition. RAP will produce a cover type model and summarize the most common cover type in the Remotely Sensed (RS) Inventory activity level. Stand level forest inventory database will maintain the main species information from previous field based inventories and updated using VR or VBAR at the stand summary level.

Resources and references

Funding sources

Environment and Natural Resources Trust Fund (ENRTF), as recommended by the Legislative and Citizen Commission on Minnesota’s Resources (LCCMR), 2016-2019:

- Title: Development of Innovative Cost-Saving Methodology for Forest Inventory.
- Summary: The MNDNR’s Resource Assessment Program studied using light detection and ranging (LiDAR) technology to innovate how forest inventory is conducted. The study found that

using LiDAR can cut costs by as much as 55%, enables the collection of this valuable information across all lands, and makes data available much faster.
- Final report: https://www.lccmr.mn.gov/projects/2016/finals/2016_03o.pdf

Environment and Natural Resources Trust Fund (ENRTF), Legislative Addition, 2022:

- Title: Forest Data Inventory
- Appropriation language: $500,000 the second year is from the trust fund to the commissioner of natural resources for an enhanced forest inventory on county and private lands. Project due to be completed: 6/30/2025.

References and manuals

Forest Inventory email: ForestInventory.dnr@state.mn.us

Forest Inventory website: https://www.dnr.state.mn.us/forestry/resource-assessment/forest-inventory.html

Forest Inventory Intranet Page: Forest Inventory: Minnesota DNR (state.mn.us)

How-To video about PBI data collection: https://www.youtube.com/watch?v=zcSPPY8XniU

Lidar Processing Video: https://www.youtube.com/watch?v=-oisFShM6Nw

Natural Resources Research Institute (NRRI) Atlas: https://mnatlas.org/

Private PBI Landowner sign up: https://www.dnr.state.mn.us/forestry/forest-inventory.html

Plot Based Inventory Field Manual: https://files.dnr.state.mn.us/forestry/pbi-field-manual.pdf

Resource Assessment Program website: mndnr.gov/resource-assessment

Instructional videos

How-To video about PBI data collection: Plot Based Inventory (PBI) Data Collection Tutorial - YouTube (links to: https://www.youtube.com/watch?v=zcSPPY8XniU)

Lidar Processing Video: Lidar applications for Plot Based Forest Inventory (PBI) at Minnesota DNR - YouTube (links to: https://www.youtube.com/watch?v=-oisFShM6Nw)

Conference presentations and posters by RAP staff

2022, MN GIS/LIS Consortium Conference & Workshops, Bemidji, MN. Title: Forest biomass inventories based on integration of strategic plot data with lidar and stereo NAIP imagery in Minnesota.

2021, MN GIS/LIS Consortium Conference & Workshops, virtual (recording posted on their YouTube channel: https://tinyurl.com/2t2w5uwt

2020, Operational Lidar Inventory (OLI) Conference, Olympia, WA. Title: Enhanced forest inventories and new LiDAR plan in Minnesota.

2020, MN SAF Winter Meeting, Brainerd, MN. Title: LiDAR based enhanced forest inventory modeling across three sites in Minnesota.

2019, FIA Stakeholder Science Meeting, Knoxville, TN. Title: Evaluating different resolutions of LiDAR and ground sampling data in spatial forest inventories.

2019, SAF National Convention, Louisville, KY. Session title: How MN DNR Is Using LiDAR to Transform Their Inventory, Presentation Title: Evaluating Spatial Biomass Inventory Models Based on Different Types of LiDAR and Photogrammetric Metrics; Title: Development of Innovative Cost-Saving Methodology for Forest Inventory in Minnesota; and Title: Pre- versus Post-stratification in an Operational LiDAR Inventory

In the media

America's Forests with Chuck Leavell – short segment on lidar and forest inventory: America's Forests with Chuck Leavell Episode 10: America's Forests in Minnesota - YouTube (links to: https://www.youtube.com/watch?v=vOqiu99Qras)

WCCO Interview The Quest To Count Every Single Tree In Minnesota Just Got A Lot Easier - CBS Minnesota (cbsnews.com) (links to: https://www.cbsnews.com/minnesota/news/minnesota-tree-tracking/)