The Evolution of Forest Inventory

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For nearly two centuries' foresters have worked within the constraints of data and time to build representative 'inventories' that describe the spatial and structural variations of a forest to make actionable decisions. At the core of describing these variations are tree size, number, spatial distribution and species which all vary across any landscape and are essential components of a working forest inventory.

The quantification of forest density and structure comprises assessing forest stands across the landscape to provide a baseline set of functional metrics that describe the standing volume of similarly forested areas. Describing forests as 'stands', and including multiple parameters expressed on a per acre basis, has provided a long and very successful foundation for communication throughout the forestry profession for more than a century.

Stands are defined as forested areas stratified into similar tree sizes by density and species class. These are often the result of judgments made by an experienced field forester with the aid of available maps and aerial imagery. The value of differences in height and/or density tallied by stand, and occurring between stands, is by design and helps to define components of the forest to achieve management objectives. These 'stand-based' metrics, when presented on a per acre basis, continue today to constitute the primary means of communicating forest conditions between ownerships and across geographic regions.

Traditional forestry has based nearly every actionable decision on stand-based inventory data, often summarized by species in 1-inch diameter classes. This convention has provided sufficient detail to characterize the differences between even-aged and multi-aged stand structures necessary for silvicultural planning. This convention also allows for the inclusion of a parameter (or parameters) that define the degree of uniformity or spatial clumping within each stand.

These conventions play significant roles in the design and development of a stand-based forest inventory. Primary factors are 1) the sampling design and intensity applied to the forested landscape, and 2) the total cost and time (annual and multi-year) required. The first factor is conventionally defined as cruising portions of the forest as stands, where there is typically only a single variable radius plot for every three to five acres within each stand. This approach would install a minimum of 6 – 15 uniformly distributed plots to estimate the spatial uniformity (clumpiness) within each sampled stand.

The second factor (cost and time) provides the greatest motivation for considering alternative inventory methods. Traditional inventory is commonly between \$4 – \$11/acre and completed over a span of 5-years where 20% of the property is sampled as stands the first year. These cruised stands are then extrapolated to the remainder of the property in order to provide a complete inventory.

It is with these aspects in mind that we suggest some newly available methods for developing a forest inventory. There are two main approaches suggested here, one is founded on satellite derived data providing an inventory at an area-based scale (10m or 20m pixels). The second centers on aerial Lidar systems that may or may-not also include satellite data and provide information at a tree-based scale (single-tree or near-census resolution).

Satellite-based Inventory

TOne satellite-based method uses 10 spectral bands (visible, infrared and short-wave) regressed against observed 1/5th acre ground plots of single species, height classes and density classes. These regressions provide mappings of species, height and stand density at a resolution of 10-meters (40 observations / acre) across the landscape. Stand polygon boundaries are created using three (or more) height classes by three (or more) density classes. Species-specific tree lists within each polygon are then generated at a frequency of 40 observations per acre. The variation in stand density among these observations and within each stand is then used to compute the degree of spatial clumpiness. Satellite pixels representing high density ground

plots are observed to characterize much more slender tree taper profiles than pixels over low density plots. These samples gathered by stand are then aggregated into standard species by 1-inch DBH classes to be loaded into the FPS Management System for growth and yield analysis and standard reporting.

This satellite method results in stand polygons typically 5 to 100 acres in size, with unique identities by species, 1-inch DBH classes, ranges in tree taper profiles and differences in degrees of stand clumpiness. This method provides a complete inventory by stand across an entire ownership in a single year. Every stand structure is defined by direct observation as opposed to traditional ground-based inventory sampling as described previously where an initial measurement on 20% of the property is extrapolated to the remaining 80%. Traditional inventory then requires additional measurements of 10% of the total property acreage annually thereafter. Traditional ground cruising methods require many years to match the coverage provided by this single-year satellite method and never achieve the same level of stand structure definition.

Lidar-based Inventory

MThroughout the academic communities and commercial forestry industry, the development of forest inventories using remotely sensed data has become the most heavily researched topic in forestry. While satellite methods emphasize "area-based" measurements on ground plots, Lidar methods emphasize "tree-based" measurements on single trees. High density and multi-pass Lidar responses are used to map individual tree profiles to obtain precise estimates of tree total height. Further analyses of groups of tree profiles provide estimates of stand density and tree taper classes. Species estimates are derived from these structural metrics and satellite-based methods as described previously.

The Lidar-assisted inventory methods of Northwest Management Inc's ForestView™ focus on mapping every visible tree to create a pseudo-census across the landscape with minimum bias, and to a minimum height of six feet tall. A measurement of the total height of each tree (+/- 6 inches) is obtained as well as crown area and metrics describing social position. Existing stand polygons can then be populated by the tree lists generated from the Lidar-assisted structural analysis. This Lidar-assisted method matches the precision of tree heights to high-precision field data for the estimation of tree DBH and many other forest metrics. The ancillary value of Lidar-assisted processing comes in the form of forest-level information, beyond tree volume and density, covering multiple other resource-values and completed at county-level sized landscapes all within 12 to 14 months.

Summation

Without a doubt, there has been a pivotal shift in the focus regarding inventory and forest sampling over the past few years. Most of this new focus is on satellite imagery classification and Lidar-based mapping of forest conditions. These approaches can produce a forest-wide, stand-based inventory in a single year where every stand has been characterized for species, size and structure on its own merits. This is economically not feasible using traditional inventory approaches. Some challenges facing remote sensing inventory methods include tree taper estimation and volume mapping. Tree taper is not easily obtained using satellites or Lidar and variations in tree taper can result in substantial variation in estimates of total standing volume. Stand clumpiness and the variations in tree spatial uniformity within a stand can also result in substantial variations of stand growth and yield over relatively short periods of time. These are only a few of the challenges facing the evolution of forest inventory.

Both satellite imagery (area-based) and Lidar (tree-based) approaches offer significant reductions in total cost (10% to 50% of traditional) and time (12 months as compared to 5-years) before a complete forest-ownership inventory is available. Additionally, these technologies provide significantly greater sampling and/or measurement intensities at the landscape, stand, acre, and even plot resolution, therefore offering a significantly more robust dataset for forest management planning.

As always, the inventory resolution and accuracy each landowner needs are determined by their management objectives. Resource managers now have more access to forestry tools for decision-making than were available in the recent past.