CATALOGING AND VISUALIZING COMPLEX FOREST STANDS USING LIDAR DATA

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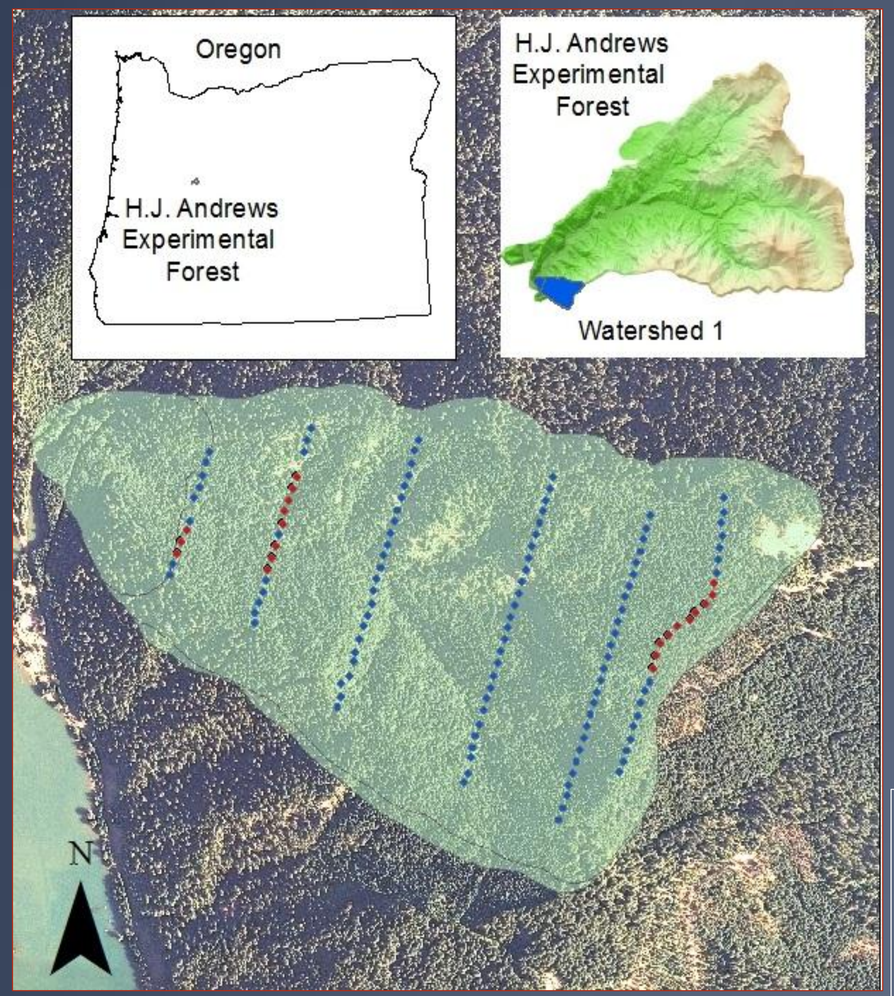
ABSTRACT: Aerial LiDAR data have been used extensively for describing and quantifying canopy cover and forest structure because they provide a scale-invariant estimation of forest biomass. Additionally, LiDAR visualizations can help illustrate forest structure and composition. However, validating remotely-sensed LiDAR metrics against ground-truthed measurements and developing analytical tools and visualizations are critical for both research and management. We analyzed tree height and stand composition on long-term re-measurement plots on a small watershed in the Oregon Cascades. We identified individual trees and inventoried tree heights using a LiDAR tree-delineation approach (*TreeVaW*), comparing our results with field catalogued individual trees. *TreeVaW* identified 2,810 of the 3,407 trees observed in surveys (82.48%). Since landscape simulations can help assess the potential impact of land-use decisions, e.g., forest harvest or mitigation, we also visualized the LiDAR returns as a simulated landscape. Using individual tree measurements from *TreeVaw*, we created conical models of trees with the *Processing* computer graphics language and visualized stand composition, stem position, and canopy gaps at a plot scale. We observed that *TreeVaw* identified more trees and predicted heights more accurately where the overstory is homogeneous and where canopy gaps are present than where stand composition is complex, Researchers might use these findings to further refine analysis software such as *TreeVaW* and visualizations such as ours might improve communication between researchers and decision-makers. We conclude that LiDAR data with tools such as *TreeVaW* and *Processing* produce simple 3D visualizations that could sometimes replace expensive stand-level surveys, but that further refinement is needed for complex stands or topography.



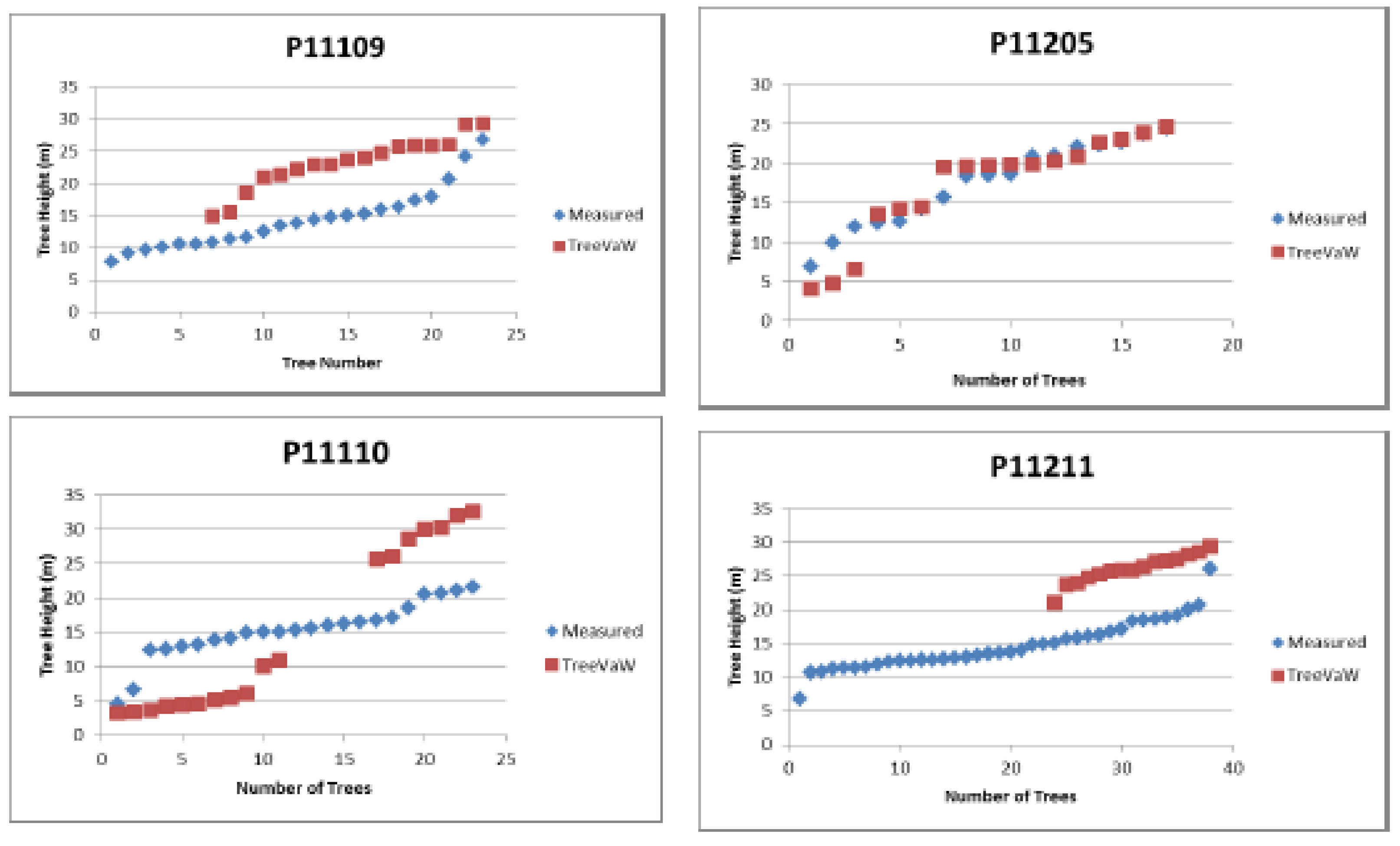
Plot	Observed Trees	Predicted Trees	% Trees Identified
P11108	28	12	42.86
P11109	23	17	73.91
P11110	23	18	78.26
P11205	17	17	100.00
P11206	17	15	88.24
P11207	15	18	120.00
P11208	12	14	116.67
P11209	25	11	44.00
P11211	28	15	39.47
P11212	46	22	47.83
P11213	28	17	60.71
P11608	24	16	70.83
P11609	15	12	80.00
P11610	18	14	77.78
P11611	19	14	73.68
P11612	21	17	80.95
P11613	30	15	50.00
P11614	19	15	78.95
P11615	25	20	80.00
P11616	21	14	66.67
P11617	13	14	107.69

(Left)Watershed 1 is located on the H.J. Andrews Experimental Forest and has 133 sample plots on 6 transects.; red plots were categorized and visualized in our study. (Above) The percent of trees correctly identified varied greatly by plot.

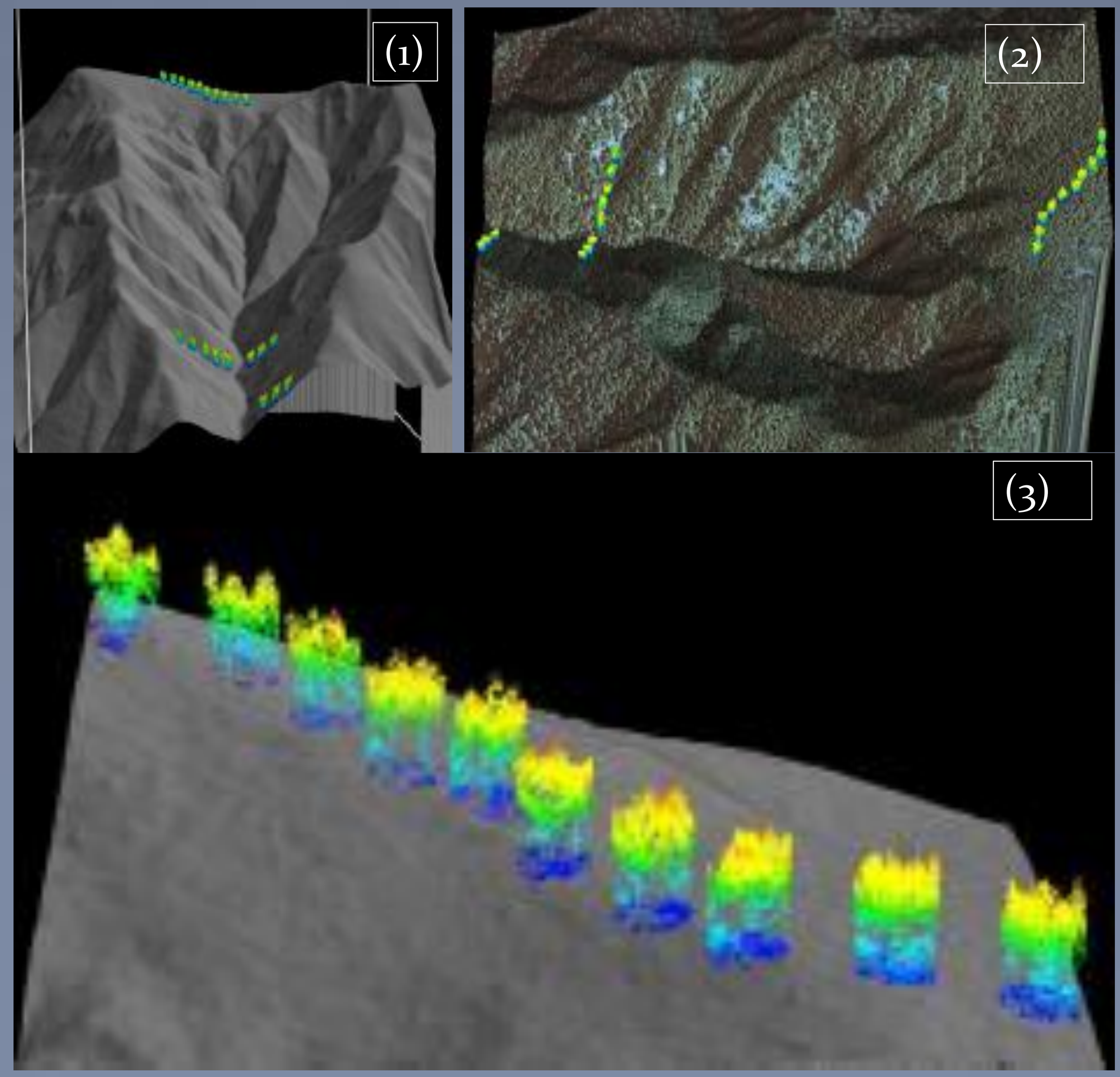
SITE: The H.J. Andrews Experimental Forest is located in the Western Cascades range, OR. WS1 is a small watershed (~96 ha) located on a first order stream draining to Lookout Creek along the McKenzie River. The minimum elevation on WS1 is 450 meters, maximum elevation is 1027 meters, the mean slope measured using ground based clinometry is 59.35%, and the watershed outlet faces an aspect of 286º. Mean January temperature is 35 F (1.6 C); mean July temperature is 69 degrees F (20.6 C). WS1 has both basaltic and andesitic mineralogy; soils vary from shallow and stony to moderately deep with well-developed profiles. WS1 was harvested using clear-cut and burn techniques between 1962-1966. Prior to logging, Douglas-fir (*Psuedotsuga menziesii*) was the dominant species, ranging in age from 100 to 500 years. Western Hemlock (*Tsuga heterophylla*) was intermixed and generally younger; some western red-cedar (*Thuja plicata*) was also present, mostly in drainage areas. Following logging, WS1 was replanted with Douglas-fir seedlings and saplings, although hardwood establishment prevailed on poor soils and steep slopes. Long-term re-measurements of DBH began on 133 vegetation plots arrayed across six transects in 1980; approximately once every 6 years; all trees on each plot are tagged and inventoried. These data are allometrically converted to height using georegion specific equations.

HEIGHT METHODS: Heights for trees on selected WS1 plots were calculated using (1) allometric equations (from DBH) specific to the region and (2) a difference between the first and last LiDAR (light detection and ranging) pulses. LiDAR was flown in 2008; the most synchronous forest measurement was taken in 2007. *TreeVaw* was used to calculate the LiDAR height difference. The above table displays the percent of heights correctly identified by *TreeVaw* on our selected plots. Overall, TreeVaW identified 2,810 trees of the 3,407 trees observed (82.48%).

Height (m) versus individual trees for four sample plots. Observational categories exist.



RESULTS OF HEIGHT CATEGORIZATION: We compared the heights (m) of identified individual trees across several plots and versus the allometric predictions. In general, tall trees were identified more readily than shorter ones. For example, in plot P11109 TreeVaW identified 17 of 23 live trees present (73.91%). The 17 trees identified by TreeVaW were the tallest in the plot. Additionally, we saw three categories of identification; trees were either well-predicted, over-estimated, or systematic gaps in the height range were observed. For example, in plot P11205, TreeVaW identified 100% of live trees. The heights of all the trees identified by TreeVaW were very similar to the actual tree heights from the vegetation survey. In plot P11211, TreeVaW identified 15 of 38 live trees present (39.47%). The trees identified by TreeVaW were the tallest trees present according to the vegetation survey, and the heights of the trees identified were consistently 7-8 meters taller than the trees present. Plot 211 is a particularly unique plot on WS1 because a mortality event occurring on the plot P11212 above it. In plot P11110, TreeVaW identified 18 of 23 live trees present (78.26%), but not trees in the middle of the height range. As a basis for visualization, we suggest that complex stand structure and age-dynamics are responsible for these categories.



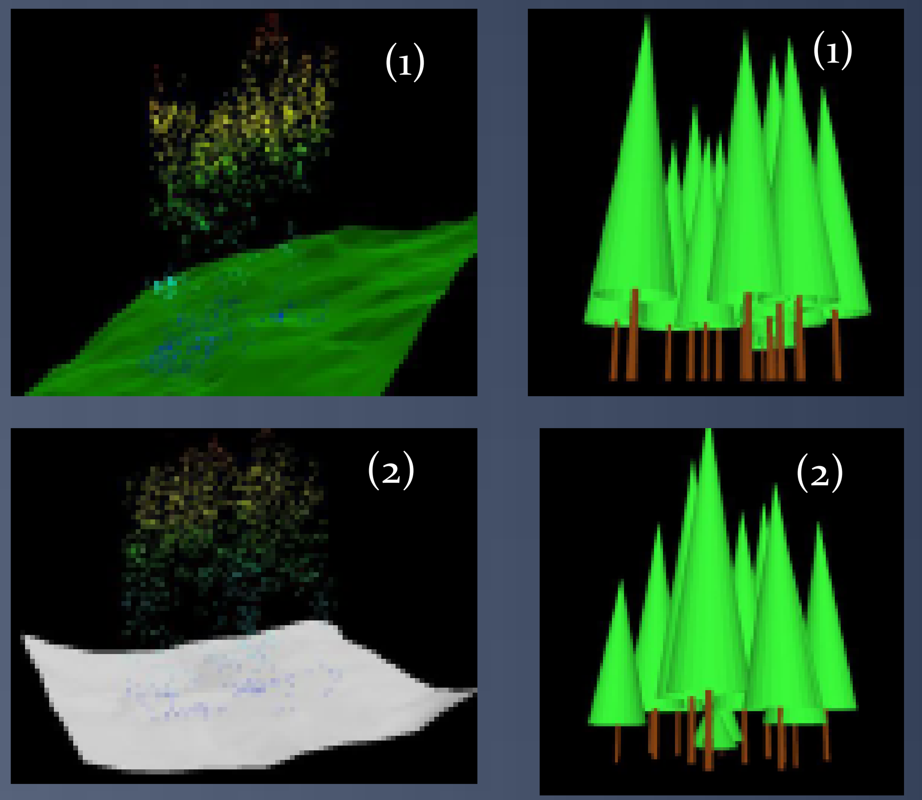
(Left) The *FUSION* software was used to visualize the LiDAR returns on our plots over (1) bare earth, (2) the LiDAR return profile, and (3) at a high resolution.

VISUALIZING HEIGHT IDENTIFICATION CATEGORIES: We used *FUSION* software to visualize LiDAR height returns of trees on our plots in order to link (1) the height identification categories (well-predicted, over-estimated, or systematic gaps) and (2) field observations of stand structure and age-dynamics.

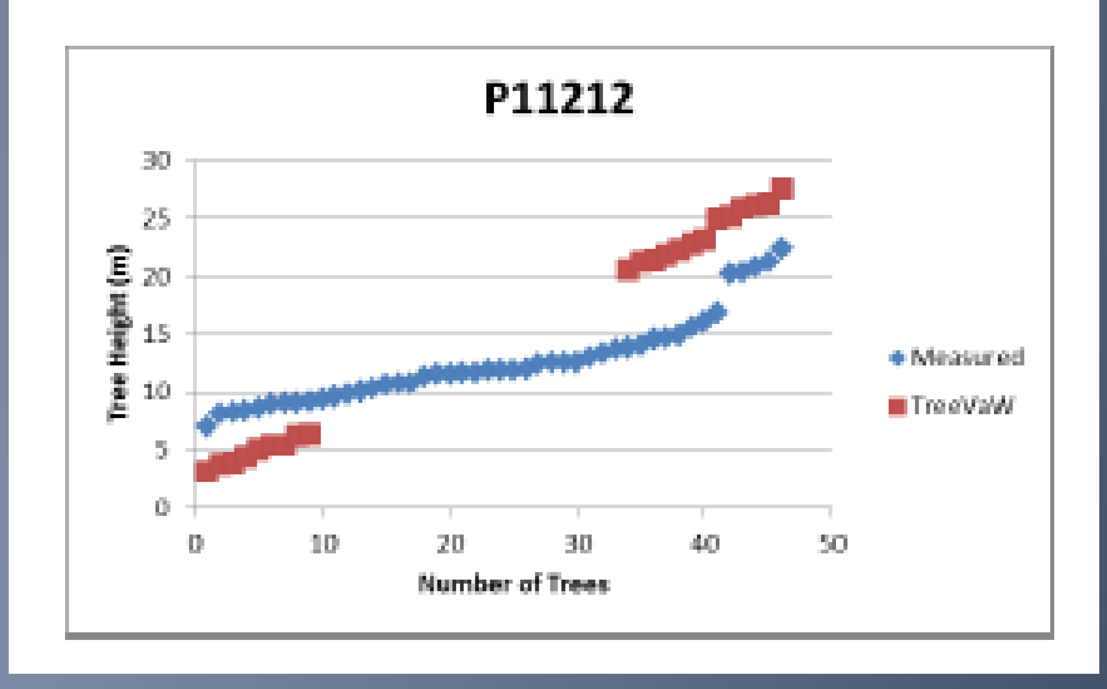
VISUALIZATION METHODS: After loading the raw LiDAR data files into *FUSION*, the stoking technique was used to select circle s for the known plots and LiDAR Data Viewer (LDV) to automatically loads the selected data as a colored point cloud based on the density of returns. Using the computer graphics language *Processing*, we also developed simplified conical models of the position; heights of the trees were read from *TreeVaW*'s output files. All trees were assumed to be Douglas-fir. *FUSION* outputs were compared with the more recognizable *Processing* models in order to suggest potential biological mechanisms for tree identification categories.

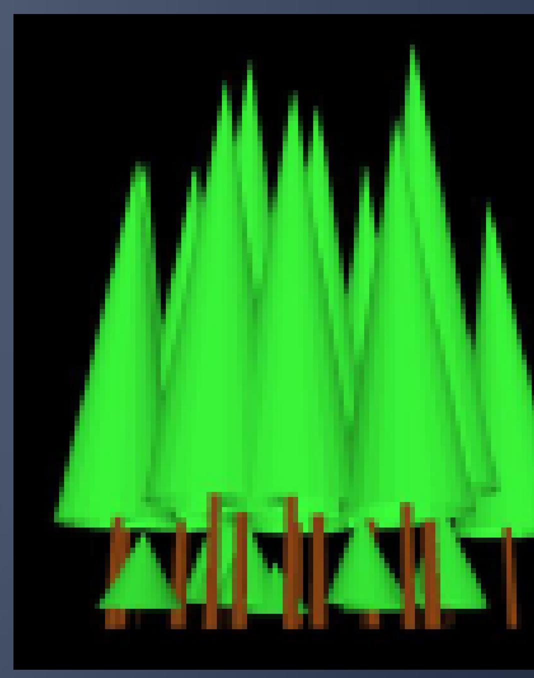
VISUALIZATION RESULTS: We used the *TreeVaW* output to visually examine the trees that *TreeVaW* identified. With those visualizations, it became clear that where a thick over story of taller trees is present, *TreeVaw* is able to identify more trees and predict their heights more accurately than where stand composition is complex and understory trees are present. However, where there were gaps present in the taller trees, *TreeVaW* was better able to identify the smaller trees found within these gaps. In both cases, the simplified output from *TreeVaW* is more "user-friendly" than the point clouds from *FUSION.*

(Right) The visualization on the left is produced with FUSION, and on the right is the visualization of trees identified using *TreeVaW*, created using *Processing* from data output by *TreeVaW*. P11109 (1) and P11205 (2) shown.



RESULTS FROM CATEGORIZATION AND VISUALIZATION: An example (below) is presented to summarize the usefulness of our new technique. In plot P11212, *TreeVaW* identified 22 of 46 live trees present (47.83%). *TreeVaW* identified both the tallest and the shortest trees in this plot. For the shorter trees, *TreeVaW* consistently underestimated the height of the trees and consistently overestimated the height of the tallest trees. A local mortality event on this plot had caused canopy gaps. Additionally, many trees have poor morphology (broken or leaning). While large and small trees might have survived the event due to structural resilience or flexibility, respectively, mid-sized trees might have been damaged to the extent that they are unrecognizable in LiDAR imagery. *TreeVaw* visualizes this structure in a simple cone diagram using *Processing*.





CONCLUSION: Using *TreeVaW*, LiDAR data for forests can be categorized into meaningful and structurally representative categories. Simplified visualizations provide a basis for easier visual interpretation of the predictive capacity of LiDAR returns than viewing point clouds.