Supplementary Materials

Table S1. Derivation of structural diversity metrics from aerial laser scanning (ALS). The functions and R packages used to calculate each metrics is listed (*lidR* [1], *rLiDAR* [2]).

ALS metric	Description	Function
Mean canopy height (H)	Mean of return heights within the plot	*LASmetrics: rLiDAR*
Mean outer canopy height (MOCH)	Mean of maximum height in $1m^2$ grid of plot	*grid_canopy: lidR*
Maximum canopy height (Hmax)	Maximum height within the plot area	*grid_canopy: lidR*
Deep gaps (DG)	The number of 1 m^2 canopy gaps in the plot	*grid_canopy: lidR*
Deep gap fraction (DGF)	Fraction of 1 m^2 canopy gaps in the plot	*grid_canopy: lidR*
Cover fraction (CF)	1 minus deep gap fraction	*grid_canopy: lidR*
Gap fraction profile (GFP)	Distribution of gaps in the point cloud 3 m above the ground	*gap_fraction_profile: lidR*
Top rugosity (TR)	Standard deviation of out canopy heights in 1 m^2 of plot	*grid_canopy: lidR*
Rumple (Rumple)	Area of canopy surface relative to plot area	*rumple_index: lidR*
SD of vertical SD (StdStd)	Plot level- standard deviation of the standard deviation of heights within 1 m^2 voxels in plot	*grid_metrics: lidR*
Entropy (Entropy)	Diversity and evenness of heights within the plot	*entropy: lidR*
Height SD (HSD)	Standard deviation of heights within plot area	*Lasmetrics: rLiDAR*
Height SD (StdH)	Standard deviation of heights within the plot	*lasmetrics: lidR*

Vertical complexity index (VCI)	Normalization of diversity and evenness (entropy) of height within the plot	*VCI: lidR*
Vegetation area index (VAI)	Sum of the 1 m horizontal slices (starting 3 m above the ground) of leaf area density in the plot	*LAD: lidR*

1. Spatial stability of ALS metrics estimated from the TLS 2D canopy slice approach

We quantified the ability to directly compare the TLS canopy slice approach to ALS point clouds by assessing the width (m) at which structural diversity metrics calculated from ALS slices of varying width stabilized. ALS data density is much lower than that of TLS, but TLS is more spatially constrained, so we first sought to determine the minimum slice-width of ALS point cloud necessary to calculate structural metrics that did not differ from those calculated using the entire 40m x 40m point cloud. This allowed us to demonstrate that TLS slices are representative of the structure of a larger volume of forest canopy from ALS. Values of the 15 ALS structural diversity metrics were calculated for 14 slice widths ranging from 0.5 m to 40 m. The center of each slice width was determined by randomly selecting a distance from the plot edge; this was repeated for 10 iterations for each slice width per plot. We used breakpoint analysis to determine widths at which ALS structural diversity metrics stabilized. Breakpoints were derived using a moving window coefficient of variation (n = 3) for each transect for each plot using the *segmented* package in R [3,4] and then averaged to the site level.

Structural metrics calculated from variable-width slices extracted from the 40x40m ALS point clouds were not significantly different from structural metrics calculated using the whole point cloud (Fig. S.1). ALS metrics from the categories of structural diversity always stabilized with means of less than 20 m and standard deviations that overlapped at less than the total 40 m plot width (Fig. S.1 - S.3). The standard deviation of metrics from the seven sites overlapped showing that there were no significant differences in the stability of the ALS transect width due to differences in forest type. The results of this analysis support our approach of averaging multiple 2D canopy slices of TLS data to estimate whole-plot canopy structure and comparing these values with whole-plot 3D point cloud from ALS.

References

1. Roussel, J.R.; Auty, D. LidR: Airborne LiDAR data manipulation and visualization for forestry applications. *R Packag. version* **2018**, *1*, 1.
2. Silva, C.A.; Crookston, N.L.; Hudak, A.T.; Vierling, L.A.; Klauberg, C.; Cardil, A. rLiDAR: LiDAR data processing and visualization. *R Packag. version 0.* **2017**, *1*, 1.
3. Muggeo, V.M.R. Estimating regression models with unknown break-points. *Stat. Med.* **2003**, *22*, 3055–3071.
4. Muggeo, V.M.R. Segmented: an R package to fit regression models with broken-line relationships. *R News* **2008**, *8*, 20–25.

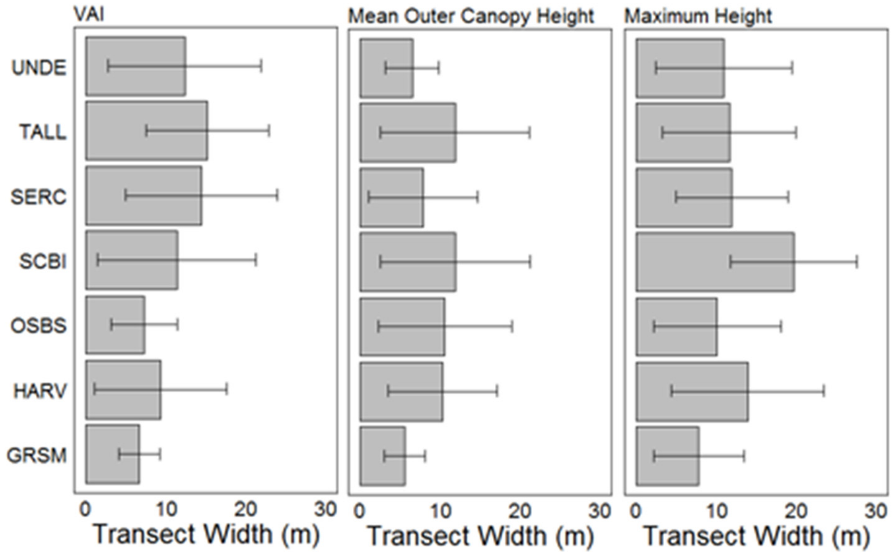

Figure S1. Breakpoint analysis for VAI, mean outer canopy height, and maximum canopy height. Transect widths ranging from 0.5 m to 40 m on the x-axis with sites along the y-axis. Each bar represents the mean transect width at which each metric is equal to the full-plot value for all plots at each site. Standard deviation represented by error bars.

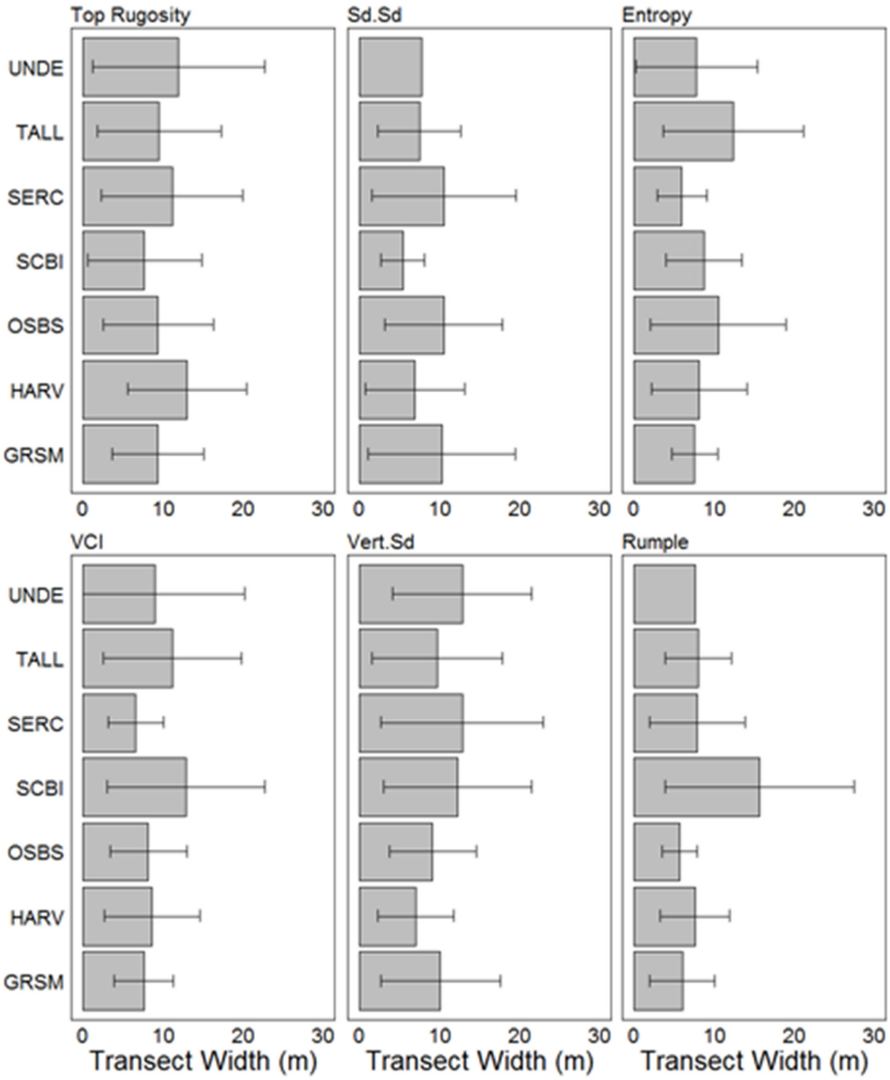

Figure S2. Breakpoint analysis for top rugosity, standard deviation of standard deviation of height, entropy, VCI, standard deviation of height, and rumple. Transect widths ranging from 0.5 m to 40 m on the x-axis with sites along the y-axis. Each bar represents the mean width at which each metric stabilizes to the full-plot value for all plots at each site. Standard deviation represented by error bars.

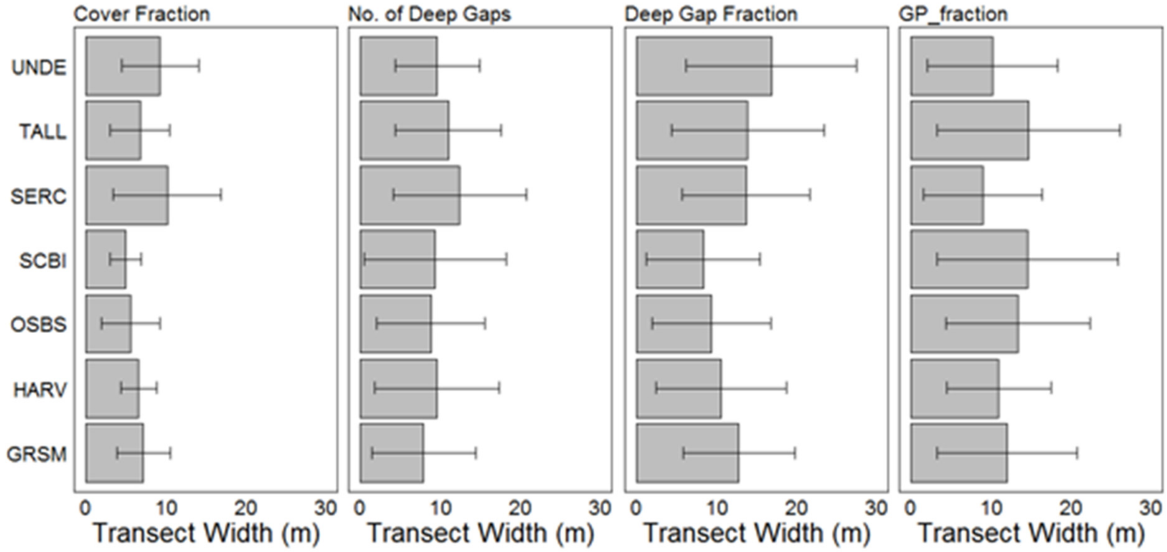

Figure S3. Breakpoint analysis for cover fraction, deep gaps, deep gap fraction, and gap fraction profile. Transect widths ranging from 0.5 m to 40 m on the x-axis with sites along the y-axis. Each bar represents the mean width at which each metric stabilizes to the full-plot value for all plots at each site. Standard deviation represented by error bars.