

Hardenbol A.A., Ørka H.O., Gobakken T., Kostensalo J. (2026). Optimising rare tree species detection for large-area mapping: a case study on European aspen (*Populus tremula*). *Silva Fennica* vol. 60 no. 3 article id 26012. <https://doi.org/10.14214/sf.26012>

Supplementary file S3

A list of all features for the classification into European aspen and other tree species that were extracted from the fused airborne laser scanning data and multispectral imagery. These features were derived from the individual segments, except for the plot-level category features.

Category	Features	Description	Returns
Intensity	I Mean	Mean	All
	I SD	Standard deviation	
	I Median	Median	
	I Min, I Max	Minimum and Maximum	
	I P10, P25, P50, P75, P90, P95	Percentiles	
	I IQR	Interquartile Range	
	I Skew, I Kurt	Skewness and Kurtosis	
	I CV	Coefficient of variation	
	I Total	Sum of intensities for each return	
	lpcumHq10, lpcumHq30, lpcumHq50, lpcumHq70, lpcumHq90	Percentage of intensity returned below X percentile of height	
Height	Relative H mean	Mean (normalised, divided by maximum height)	All / First of many and single
	H SD	Standard deviation	
	H Median	Median	
	H Min, H Max	Minimum (normalised, divided by maximum height) and Maximum	
	H P10, P25, P50, P75, P90, P95	Percentiles (normalised, divided by maximum height)	

Category	Features	Description	Returns
	H IQR	Interquartile Range	
	H Skew, H Kurt	Skewness and Kurtosis	
	H CV	Coefficient of variation	
Additional height	Hpcum1 - 9	Cumulative percentage of returns in the i^{th} layer according to (Woods et al., 2008)	All
	H Entropy	Entropy of height distribution	
Spectral	R/X band Mean and Median	Mean and Median of Red / other bands	First of many and single
	G/X band Mean and Median	Mean and Median of Green / other bands	
	B/X band Mean and Median	Mean and Median of Blue / other bands	
	NDVI Median, NDVI WMean, NDVI SD	Median, weighted mean, and standard deviation of NDVI	
	NIR Median	Median	
	R/NIR Max	Maximum R / Maximum NIR	
	R/NIR SD	Standard deviation R/NIR	
Tree structure	XY Mean	Mean distance from center in XY plane	All / First of many and single
	XY SD	Standard deviation in XY plane	
	XY Skew, XY Kurt	Skewness and Kurtosis in XY plane	
	Y IQR	IQR on Y-axis	
	Crown diameter	Crown diameter estimate based on a 2D spread	

Category	Features	Description	Returns
	Echo count	Number of echoes (points)	
	Echo count proportion	Echo count / maximum height	
	Hull area	Area of convex hull for the tree crown	
	Hull area proportion	Hull area / maximum height	
Status	Live branch points, Dead branch points	Count of live branch/dead branch-classified points	All / First of many and single points
	Percentage dead	Percentage of dead branch points	
Tree shape	Eigenvalue largest, Eigenvalue medium, Eigenvalue smallest, Curvature, Linearity, Planarity, Sphericity, Anisotropy, and Horizontality	Eigenvalue-based feature set described in (Lucas et al., 2019)	All
Return patterns	First fraction	Fraction of first returns	All
	Second fraction	Fraction of second returns	
	I ratio 2, I ratio 3plus	Intensity ratio for second/third+ over first of many returns	
	I ratio last	Intensity ratio of last of many over first of many returns	
	RN Mean, NR Mean	Mean return number and mean number of returns	
	Ground hits, Low hits	Proportion of hits below 2m / 6m	
	Medium hits, High hits	Proportion of hits below 10m / 18m	
	%Returns above H Mean	Percentage of returns above H Mean	
	p1th – p5th	Percentage x th returns	
Plot-level	Plot R/NIR Median	Median R/NIR	

Category	Features	Description	Returns
	Plot R, G, B, NIR Median	Medians of bands	First of many and single
	Plot NDVI Mean	Mean	
	Plot I Mean	Mean	

Abbreviations: G=green, H=height, I=intensity, NDVI=normalised difference vegetation index, NIR=near-infrared, R=red. Equation for NDVI: $NDVI = (NIR - R) / (NIR + R)$.

References

- Lucas C, Bouten W, Koma Z, Kissling WD, Seijmonsbergen AC (2019) Identification of linear vegetation elements in a rural landscape using LiDAR point clouds. Remote Sens 11(3), article id 292. <https://doi.org/10.3390/rs11030292>.
- Woods M, Lim K, Treitz P (2008) Predicting forest stand variables from LiDAR data in the Great Lakes – St. Lawrence forest of Ontario. The For Chron 84: 827–839. <https://doi.org/10.5558/tfc84827-6>.