Individual tree properties from ALS data as input to habitat analysis in boreal forest

Eva Lindberg [1,2], Jean-Michel Roberge [3], Therese Johansson [3],
Markus Hollaus [2], Johan Holmgren [1] and Joakim Hjältén [3]

[1] *Department of Forest Resource Management, Swedish University of Agricultural Sciences (SLU),*
901 83 Umeå, Sweden; E-mail: eva.lindberg@slu.se, johan.holmgren@slu.se
[2] *Vienna University of Technology, Department of Geodesy and Geoinformation, Research Group*
Photogrammetry, Gußhausstraße 27 –29, 1040 Vienna, Austria;
E-mail: markus.hollaus@geo.tuwien.ac.at
[3] *Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences (SLU),*
901 83 Umeå, Sweden; E-mail: jean-michel.roberge@slu.se; therese.johansson@slu.se; joakim.hjalten@slu.se

Highlights: This study shows examples of detailed analysis of forest canopy from ALS data with potential use as input to habitat analysis in forests. This includes delineation of individual tree crowns and analysis of the distribution of tree heights and the tree species composition.

Key words: *canopy structure, forest age, biodiversity, species richness, LiDAR.*

Introduction

Planning and management of forests for biodiversity conservation requires knowledge about local stand conditions such as forest structure and tree species composition in relation to habitat demands for different species, as well as the amount and distribution of diversity hotspots in the surrounding landscape [1] Airborne laser scanning (ALS) have proven useful for predicting species richness and composition in a range of taxonomic groups [e.g., 2] Until now, habitat studies including ALS data have mostly used area-based analysis where features are extracted as statistics from the ALS data in raster cells with size corresponding to field plots, typically in the order of 100-400 m^2. However, more detailed information about objects and structures can be derived from the ALS data. With dense ALS data (>5 returns/m^2), individual tree crowns (ITC) can be delineated from the data.

The objective of this study is to show examples of detailed analysis of the forest canopy from ALS data and use the derived information for habitat analysis. The canopy analysis includes identification of individual tree crowns and estimation of the height distribution and information for tree species classification. This information can be used, for example, to predict patterns of species richness in the forest landscape.

Materials

The study area is a 30 × 40 km forest landscape in the middle boreal zone of northern Sweden (64°05' - 64°10'N, 19°05' - 19°30' E). The age of the forest stands was 8-130 years and the dominating tree species were Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) with a minor component of deciduous trees. Two ALS datasets were included: dense ALS data (5 returns m^{-2}) and sparse ALS data (0.5-1 m^{-2}). We sampled species richness and abundance of flying and epigaeic (i.e., ground-living) beetles in 33 study stands and birds in 47 study stands, all covered with dense ALS data.

We have used the same study area in an earlier study where we derived area-based metrics from dense ALS data and forest estimates from satellite images [3]. This provided insights in the approximate suitable scale and relevant variables for habitat analysis. The most important variable for species richness and abundance of both birds and insects was the maximum height of the forest, which was correlated with the total stem volume. For birds, the second most important variable was the amount of low vegetation (0.5-3 m) with positive sign, while for beetles the second most important variables was the proportion of Scots pine with negative sign.

For the analysis in this pilot study, we compared two middle-aged pine-dominated forest stands with labels S-M03 and S-M06. According to field observations, these two forest stands had similar basal area. The area-based variables derived from remotely sensed data (e.g., maximum height and fraction of returns between 0.5 and 3 m above the ground) also had similar values for the two stands. However, the species richness of flying and epigaeic beetles was higher in S-M03 (Table 1).

Analysis

Delineation of individual tree crowns (dense ALS data)

The delineation was done by segmentation of a correlation surface (CS) model followed by ellipsoidal tree model clustering of the ALS data in 3D (Figure 1). More details are given in [4]. The aim of the segmentation was to establish one segment for each tree in the topmost canopy layer. The aim of the clustering was to establish one cluster for each tree in the topmost canopy layer as well as one cluster for each tree below. The algorithm was based on k-means clustering using ellipsoidal tree crown models. Two categories of clusters were defined: Fixed clusters corresponding to trees already identified by segmentation of the CS and additional flexible clusters corresponding to trees below the topmost canopy layer. For each cluster, the mean height above the ground (i.e., the centroid) as well as the maximum and minimum height above the ground of the ellipsoid was calculated. The maximum height was assumed to be the tree height and the minimum height was assumed to be the crown base height.

Summary variables (i.e., individual tree-based variables) were calculated from the clusters in circles with a radius of 50 m centred on the field plot in each study stand. The variables were the mean and standard deviation of the centroid and maximum height above the ground of the returns assigned to each cluster as well as the relative live crown height, which was calculated as the height of the lowest point of each ellipsoid divided by the highest point of each ellipsoid (Table 1).
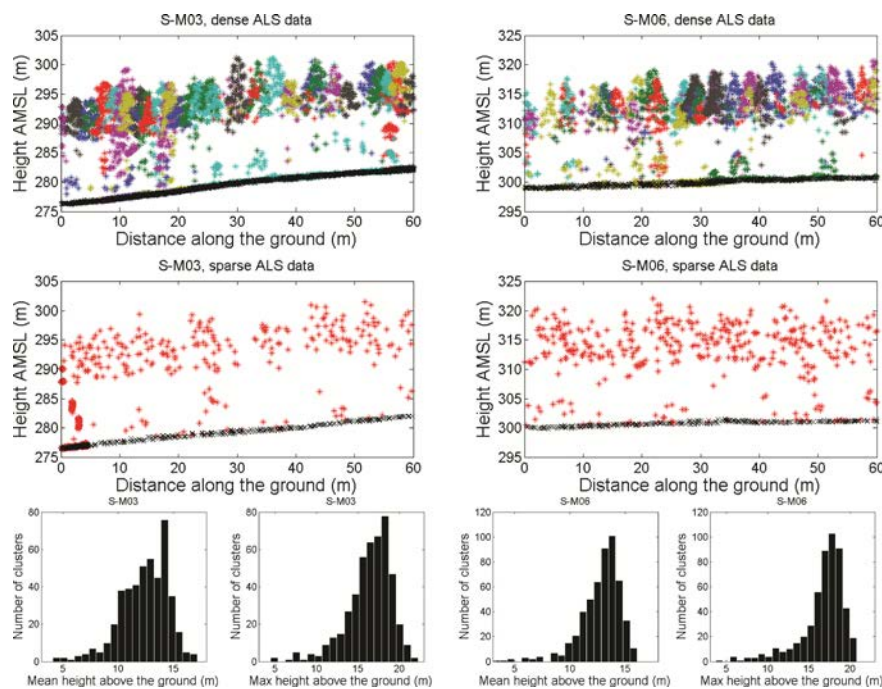

Figure 1: Transects with width 10 m from dense ALS data in S-M03 (top left) and S-M06 (top right) and sparse ALS data in S-M03 (middle left) and S-M06 (middle right) and histograms of centroid and maximum height of clusters in S-M03 (bottom left) and S-M06 (bottom right). The dense ALS data have been delineated into individual tree crowns. The ALS returns assigned to one cluster are shown in the same colour.

Area-based analysis (sparse and dense ALS data)

Area-based metrics were derived from the sparse and dense ALS data in raster cells including all returns (i.e., first and last). The maximum height above the ground was derived in 2.5×2.5 m raster cells and the number of returns was derived in 12.5×12.5 m raster cells. Summary variables were calculated as the mean of the metrics in circles with a radius of 50 m centred on the field plot in each study stand (Table 1).

Table 1: Field observations and variables derived from ALS data for the two forest stands.

Field observations	S-M03	S-M06
Basal area (m²/ha)	25.7	28.3
Proportion of basal area pine/spruce/deciduous	83.2%/15.6%/1.2%	90.5%/3.5%/6.0%
Bird species richness	5	5
Flying beetle species richness	151	96

Epigaeic beetle species richness	75		56	
Area-based variables	Sparse	Dense	Sparse	Dense
Maximum height (m)	13.5	15.4	14.9	15.7
Low vegetation < 3 m	5.0%	3.7%	6.2%	5.4%
Middle vegetation 3-10 m	9.8%	10.8%	7.1%	5.3%
High vegetation > 3 m	46.7%	55.6%	52.6%	57.0%
ITC-based variables				
Mean of centroid height (m)	-	12.40	-	12.80
Standard deviation of centroid height (m)	-	2.14	-	1.87
Mean of maximum height (m)	-	16.43	-	16.73
Standard deviation of maximum height (m)	-	2.70	-	2.72
Mean relative live crown height	-	0.52	-	0.55

Conclusions

The result of the individual tree-delineation was a representation of each tree crown in three dimensions. Based on this, various properties of the trees can be derived such as height, live crown height, crown diameter, and crown shape. This can in turn be used for classification of the species of the individual trees using allometric relationships [5]. Area-based analysis of ALS data alone does generally not allow for tree species classification since the height distribution of a forest stand with vertically elongated tree crowns (e.g., spruces) might be similar to that of a forest stand with dense low vegetation.

The area-based variables in the two study stands were similar despite that the species richness of flying and epigaeic beetles was higher in S-M03. However, S-M06 was more pine-dominated, while S-M03had a higher proportion of spruce, and tree species diversity is known to affect overall species diversity. Visual inspection of the ITC revealed more trees with vertically elongated tree crowns and more low vegetation in S-M03. This resulted in a different distribution of the height above the ground of the returns assigned to each cluster and a different mean relative live crown height (Table 1). This means that the ITC provides additional information to separate these two stands, which is not feasible only from the area-based variables.

In our previous area-based study, the most important variable for both birds and insects was the maximum height of the forest. This was consistent with other studies showing a positive correlation between forest age and the species richness of these species. In the current study, ITC delineation made it possible to derive the distribution of tree heights, which can be used as a proxy for the age distribution of the trees. The height distribution is also a measure of the layering, which is important for birds in boreal forests. Additionally, tree species composition is important for habitat analysis. To study the importance of information derived from the ITC clusters, we will derive ITC-based variables for all study stands and relate them to the field observations of birds and beetles.

Acknowledgments

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