Estimation of crown coverage using airborne laser scanning

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Abstract

Vegetation mapping for environmental monitoring is today conducted by manual photo-interpretation combined with field surveys. This study is the first attempt in Sweden to investigate the potential of using Airborne Laser Scanning (ALS) for the estimation of crown coverage of tree crowns and shrubs. Thirty field plots were randomly allocated within a 1×1 km^2 area in southern Sweden. All plants with any part inside the 10 m radius and with a height greater than 0.3 m were measured. The field data were used to derive crown coverage for each plot. Proportions of laser returns within height intervals were derived from ALS data and used as explanatory variables in simple linear regression models for estimation of crown coverage of trees and shrubs. For estimation of tree crown coverage (> 3.0 m height) the root-mean-square-error (RMSE) was 4.9%. For estimation of total (trees and scrubs) crown coverage (> 0.3 m height) the RMSE was 6.3%. These RMSE values were achieved despite a mixture of tree species on the field plots. However, the analysis was not sufficient for high accuracy estimations of the amount crown coverage from shrubs (0.3-3.0 m height interval) below a tree canopy.

Keywords: crown coverage, shrubs, vegetation mapping, LiDAR

1. Introduction

Detailed vegetation mapping for selected areas is, in Sweden, conducted by using field surveys in combination with manual photo interpretation. The manual photo interpretation technique is however costly and the results are dependent on the interpreter. It is therefore difficult to obtain objective quantitative measurements that are suitable for comparisons over time. In addition, aerial photo interpretation will only provide information about the uppermost layers of a vegetation canopy.

Use of aerial photo interpretation for vegetation assessment in Sweden includes: (1) the general vegetation map that is created on a regional basis, (2) the sample based National Inventory of Landscapes in Sweden (NILS) program (http://nils.slu.se/), and (3) the mapping and monitoring of Natura 2000 sites. For both the NILS program and for the Natura 2000 monitoring there is a need to develop objective and cost efficient methods for following changes in different layers of the vegetation canopy. A study of the early specifications for monitoring of Natura 2000 sites in Sweden (Naturvårdsverket 2005) revealed that vegetation cover and height are of high relevance for monitoring of more than 40 Natura 2000 nature types.

In Scandinavia, Airborne Laser Scanning (ALS) is now an operational technique for producing maps of forest timber and pulp resources. ALS data based methods for estimation of variables of relevance for the forest industry, such as tree heights, stem volume, and stem diameter, have already been successfully developed. These methods have also been introduced as commercial services that are provided by forest inventory companies (Næsset *et al*. 2004). However, there are so far only limited developments of laser remote sensing for vegetation mapping in the context of habitat monitoring. For example, canopy height derived from ALS was found to be a strong predictor of bird species richness in the temperate forests of Maryland, USA (Goetz *et al.* 2006). Some of the variables that are important for vegetation mapping have been estimated in several studies, for example above ground biomass (*e.g.*, Nelson *et al*. 1988; Means *et al*. 1999; Lefsky *et al*. 2002a; Lim and Treitz 2004). The height and cover of the canopy surface are usually estimated but it is also possible to estimate canopy gaps and canopy height profiles (Lefsky *et al*. 2002b). Some studies reports estimates of Leaf Area Index (LAI) (*e.g*., Parker *et al*. 2001; Hagiwara *et al*. 2004; Morsdorf *et al.* 2006, Solberg *et al*. 2006), as well as the canopy fraction (*e.g.*, Hopkinson and Chasmer 2007).

The current pilot study is the first Swedish attempt to asses ALS based vegetation mapping for environmental monitoring. The study was limited to investigating the ability to estimate crown coverage of tree crowns and shrubs using ALS data. The objective was to build regression models based on ALS data for estimation of crown coverage on field plots, and validate these models.

2. Material and Methods

2.1 Study area

The study area is located in southern Sweden (Lat. 56º 41' N., Long. 13º 9' E.). The area is the inner 1×1 km^2 of a NILS-survey-unit (Essen *et al*. 2007).

2.2 ALS data

The study area was laser scanned the 28th of October 2006 by using a LiteMapper 5600 ALS system operated from a fixed winged aircraft, Partinavia P68B, with an altitude of 180 m above ground level and a flight speed of 75 ms^{-1}. The strip side overlap was 80% and the field of view was 45 degrees, but by not using overlapping data the maximum used field of view could be reduced to 35 degrees. The pulse repetition rate was 100 kHz. The pulse density was approximately 20 returns per square meter. Each emitted laser pulse could result in three different return pulses: single return pulse (P0), first return pulse of a double return (P1), or second return pulse of a double return (P2). ALS data were processed in order to provide measures of vegetation height above ground level by first classifying each laser return as either ground or vegetation using the TerraScan software (Soininen 2005). Interpolation was then performed, by using the laser return classified as ground hits in order to create a Digital Elevation Model (DEM). Laser canopy height, *i.e.* the vertical distance to ground (DEM-value), was derived for each laser return.

2.3 Field data

A total of 30 circular field plots with 10 m radius located within the laser scanned area were field surveyed from June to August 2007. The aim of the field survey was to describe the three dimensional structure of trees and shrubs with high accuracy. Prior to the field survey, homogenous polygons (forest stands) had been delineated and for each polygon tree crown coverage had been estimated by photo-interpretation. For the allocation of field plots, the polygons were classified according to tree crown coverage and field plots were randomly placed within each class. The position of the field plot centre was measured using Global Navigation Satellite System (GNSS). The GNSS data were post processed by using data from a reference station. After post processing sub-meter accuracy was expected for open areas, *i.e.* areas with no tree cover. However, position data could be less accurate due to poor satellite configuration and a dense tree cover. All plants with a height greater than 3.0 m were classified as trees, and all plants with a height of 0.3 to 3.0 m were classified as shrubs. A tree or shrub was measured if it had at least some part that could be projected on the ground within the circular field plot. There was a mixture of several species on each field plot (Table 1).

2.3.1 Tree crown coverage

For all trees on a field plot, stem diameter was measured and species registered. The azimuth and distance from the plot centre to the centre of the tree stem was measured by using a compass and an ultrasonic distance measuring device, respectively. Tree height was measured for a sample of five trees from each of the tree species groups: Scots Pine (*Pinus silvestris*), Norway spruce (*Picea abies*), and deciduous trees, on each field plot, or less if there not were enough of trees of a particular tree species group. For each tree, major and minor axes were measured for an ellipse describing the extent of the living part of the crown. One axis of the ellipse was in the direction to the plot centre in order to make it possible to calculate the proportion of the ellipse that was within the field plot. For each tree individual, the ellipse coverage, a value between 0 and 1, was estimated as the projected area on ground of all leaves and branches inside the ellipse that were alive divided by the total area of the ellipse.

2.3.2 Shrub crown coverage

All shrubs were measured that were totally or partially situated within the field plot. For all individuals, species were registered and height was measured. The distance and azimuth from the plot centre to the centre of a shrub was measured in the same way as for the trees. For each shrub, major and minor axes were measured of an ellipse that describes the extent. One of the axes of the ellipse was in the direction to the plot centre. For each shrub individual, the ellipse coverage, a value between 0 and 1, was estimated as the projected area on ground of all leaves and branches inside the ellipse that were alive divided by the total area of the ellipse.

2.3.3 Calculation of crown coverage

For each field plot, a raster image with 0.1 m raster cell size was created and all cell values were first set to zero. For a specific raster cell, estimates of crown coverage were accumulated by using the crown coverage value of all ellipses that covered the raster cell. If the accumulated value of a raster cell was greater than one, the raster cell value was set to one. This procedure resulted in 30 field-survey data generated images of crown coverage (see Figure 1), one for each field plot. The crown coverage area C for height interval h and for plot i was calculates as

$$C_i = \sum_{k=1}^{m} \sum_{l=1}^{n} A_{kl} \times L_{kl} \times P_{kl} \tag{1}$$

where A_{kl} is the raster cell area, L_{kl} is the accumulated ellipse coverage values from trees or shrubs with height within height interval h and with ellipses covering the raster cell of column k and row l for the $m \times n$ raster. The value of P_{kl} was set to one if the raster cell was inside the 10 m radius plot, otherwise zero. Field measured tree crown coverage (C_c) was derived for plot i by using $h \geq 3$ m and dividing C_i with the total plot area. Field measured total crown coverage (C_v) was derived for plot i by using $h \geq 0.3$ m and dividing C_i with the total plot area.

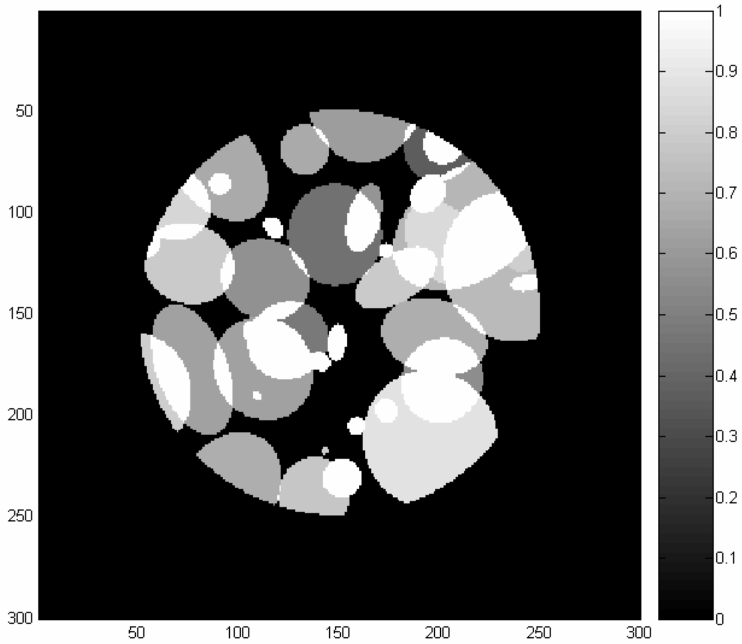

Figure 1: Raster image (1 dm resolution) for one of 30 field plots with measured ellipses that describe extent and proportion of projected area of leaves and branches (crown coverage).

Table 1: Number of shrubs and trees grouped into Norway spruce, Scots pine, and deciduous trees for 30 field plots, and mean height and mean stem diameter (range within brackets) for shrubs and trees, respectively

Plot	Shrubs (0.3-3.0 m height)				Trees (> 3.0 m height)			
	Pine	Spruce	Deciduous	Height (cm)	Pine	Spruce	Deciduous	Diameter (mm)
1	0	3	1	137 (59-230)	16	1	4	244 (40-488)
2	1	1	2	51 (32-67)	0	25	0	126 (50-312)
3	0	22	2	154 (42-300)	8	14	0	197 (36-600)
4	0	14	1	144 (60-271)	18	4	3	241 (30-520)
5	0	0	6	69 (46-97)	9	0	8	285 (41-457)
6	0	32	0	117 (34-270)	4	18	3	247 (41-545)
7	0	5	3	113 (34-265)	9	6	2	307 (74-620)
8	0	3	2	130 (43-250)	13	4	11	235 (61-429)
9	0	21	15	144 (47-299)	18	5	12	245 (69-436)
10	0	1	31	111(34-246)	10	2	26	202 (19-417)
11	0	4	15	52 (36-89)	15	11	1	261 (29-520)
12	0	41	0	114 (37-300)	11	11	5	285 (30-585)
13	0	8	3	195 (112-297)	3	9	29	184 (40-603)
14	0	12	11	134 (59-264)	17	16	9	232 (36-456)
15	0	2	11	191 (48-290)	0	49	0	162 (98-248)
16	20	4	31	90 (33-243)	0	0	1	46 (46-46)
17	88	21	86	92 (32-280)	3	0	0	70 (66-74)
18	30	3	19	70 (32-162)	0	0	0	0
19	189	6	65	70 (27-208)	0	0	0	0
20	114	6	34	69 (31-193)	0	0	0	0
21	14	5	63	101 (31-291)	12	1	13	147 (18-330)
22	14	4	102	124 (33-298)	46	1	22	106 (19-363)
23	72	16	116	105 (38-269)	3	0	13	65 (30-147)
24	133	19	127	78 (30-298)	7	0	1	121 (61-149)
25	155	35	55	71 (30-271)	9	0	1	143 (73-224)
26	5	16	63	129 (36-286)	7	1	39	86 (20-267)
27	21	16	73	105 (31-281)	11	16	5	142 (39-355)
28	127	15	113	109 (31-297)	17	4	21	80 (21-282)
29	84	13	124	81 (31-287)	11	1	8	111 (26-227)
30	19	6	49	87 (34-297)	16	1	19	131 (35-351)

2.4 Correction of field plot positions

Tree crowns of an area of 50×50 m^2 around each plot were automatically delineated by using an earlier developed algorithm (Holmgren and Wallerman 2006). The delineation of tree crowns from laser data was based on template matching. First, from a Digital Canopy Model (DCM) that was derived from laser elevation data, a binary crown area image was derived with value one for crown area, and closing (dilation followed by erosion) was performed on this image. A new height value was then interpolated for the DCM at cells with zero height value, but crown area according to the crown area image. Templates were tested at each raster cell of the DCM by setting the height of the template to the value of the DCM value. There were some restrictions when calculating the correlation between templates and laser elevation data: only realistic width-height ratios of the templates were allowed, and no template was tested with less than 25 laser returns. For a correlation image, the value of a raster cell was set to the highest found correlation at that location. The correlation image was then smoothed and used for segmentation: A seed was placed at each raster cell, with a DCM value greater than a height threshold and with a positive correlation value, and was allowed to climb to the neighbour raster cell with the highest correlation value. The raster cells with seeds climbing to the same local maximum defined a tree crown segment.

The result was crown segments; each included an individual tree or a group of trees. The tree position was estimated by taking the x, y-position of the maximum canopy height value within the segment, and a measure of tree height was achieved from the value of the maximum. A crown area of an individual tree was derived by counting the number of raster cells of the crown segment but was not used in this study for further analysis.

The three dimensional spatial pattern of the laser detected trees were matched with the spatial pattern of field measured positions of individual trees on a plot. A matching algorithm was used for this task (Olofsson *et al.* 2008). The plots were both translated and rotated until the best match, *i.e.* maximum correlation value, between the spatial tree-patterns were found. In this way the position of field plots with poor GNSS data could be corrected.

2.5 Statistical analysis

Different combinations of laser return types (first return, second return, or only return) were grouped. The corrected locations of the field plots were used to extract ALS data within the 10 m radius field plots. The proportions of laser returns on a plot that were located 3.0 or 0.3 m above ground level were derived, and used for estimation of tree crown coverage (C_c) and total vegetation coverage (C_v) (trees and shrubs), respectively. The field estimated crown coverage values versus proportions of laser returns within the different height intervals were plotted. Simple linear regression models with and without an intercept were tested for estimation of crown coverage.

3. Result

The proportion of laser returns from the tree canopy was highly correlated with the field measured tree (h > 3.0 m) crown coverage C_c. The best tested explanatory variable D_c was the proportion of first and only returns (P0+P1) above the height threshold 3.0 m. The best model found was simple linear regression without intercept (Equation 2). The root-mean-square-error (RMSE) was 4.9%. The sizes of residuals (ε) were about the same for the full range of tree crown coverage (Figure 2A). The correlation coefficient was 0.98 between estimated and field measured tree crown coverage.

$$\hat{C}_c = 0.77 \times D_c + \varepsilon \qquad (2)$$

There was a low correlation with the crown coverage of only shrubs and the proportion of laser returns within the corresponding height interval, *i.e.* between 0.3 and 3.0 m distance from the ground. No attempts were therefore made to estimate this fraction separately

The proportion of laser returns from the vegetation was highly correlated with the field measured total crown ($h > 0.3$ m) coverage C_v. The best tested explanatory variable D_v was the proportion of first and only returns (P0+P1) above the height threshold 0.3 m. The best model found was a simple linear regression with an intercept (Equation 3). The RMSE was 6.3%. The sizes of residuals (ε) were about the same for the full range of total crown coverage (Figure 2B). The correlation coefficient was 0.96 between estimated and field measured total crown coverage.

$$\hat{C}_v = 0.079 + 0.68 \times D_v + \varepsilon \qquad (3)$$

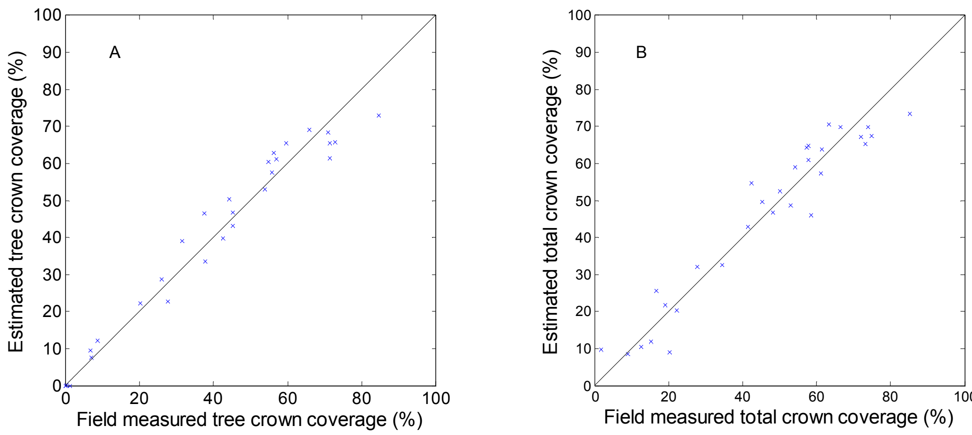

Figure 2: (A) Estimated tree crown coverage versus field measured tree crown coverage (trees with a height above 3.0 m); (B) Estimated total crown coverage versus field measured tree crown coverage (trees and shrubs with a height above 0.3 m).

4. Discussion

The results of this study indicate that it is possible to use airborne laser scanning to obtain objective measurements of vegetation crown coverage. Despite a diverse composition of tree species on the plots, simple regression models could be used to estimate crown coverage with high accuracy.

Morsdorf *et al*. (2006) used the proportion of pulses above a height threshold to estimate fractional cover, *i.e*. crown coverage, but used hemispherical photographs as ground truth data. They derived laser variables, first and last returns separately, and found the highest explanation power for the first return data. They argued that one source of error could be the difference of view angles between the hemispherical camera and the laser scanner sensor. For the simple field method of the present study, different view angles were not a problem because crown coverage was estimated separately for each plant. However, different view angles of the ALS data could be an error source that needs to be accounted for if the method is used operationally.

There might be several reasons for the low correlation of the present study between laser derived variables (proportions within height intervals) and the crown coverage of shrubs (plants within 0.3 and 3.0 m). There are problems in distinguishing small plants and other low objects, *e.g*., stones, grass, blueberry shrubs. The classification algorithm only uses the position of reflection locations. It would probably be possible to improve the classification if also full waveform laser data would have been used.

In the present study, only a first attempt was done to estimate crown coverage. It might be possible to improve estimates by extracting more information from ALS data. For instance, Hopkinson and Chasmer (2007) found that intensity based power distribution has higher correlation with the canopy gap fraction than just the laser pulse return distribution for the subclasses single, first, intermediate and last laser returns.

Full waveform data have earlier been used to estimate the vegetation structure at different height levels. For instance, Parker *et al*. (2001) studied the correlation between the power (*i.e.* the waveform) of the accumulated laser pulse return at different heights and the irradiance at the same heights. The use of full waveform data should therefore also be suitable to use in estimating of the amount of shrubs below a tree canopy.

The possibility of using ALS data for estimation of crown coverage should be studied further in order to develop tools for the monitoring of vegetation. It would for instance be of interest to study in more detail how well a layer of bushes might be detected, given different types of over storey. Since the proportion of laser returns also will be dependent on factors such as sensor settings, flight altitudes, *etc*., there will during the foreseeable future also be a need to use a limited set of field data for the calibrations of the measurements and a suitable design for this field sample should also be studied. It would also be important to carry out real tests of change assessments, where experiments with both increased and decreased canopy coverage between several time points of laser scanning is evaluated.

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