Mapping Natural Regeneration in Canopy Gaps from Seedlings to Saplings in Uneven-Aged Deciduous Forests using ALS Data

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1. Introduction

Assessing regeneration state is essential for forests sustainable management. However, field surveys to collect data on regeneration are time consuming and difficult to implement. Remote sensing could therefore be an effective way to characterize regeneration.

Only few studies focused on forest regeneration characterisation using ALS data: understory coverage estimation (Latifi et al. 2017, Venier et al. 2019), post-fire vegetation characterization (Martin-Alcon et al. 2015), regeneration stems density and height estimation (Debouk et al. 2013, Imangholiloo et al. 2020).

Regeneration dynamic depends on the characteristics of canopy gaps. They increase availability of understory light, which is beneficial for regeneration development, especially for less shade-tolerant species (Ligot et al. 2014). Moreover, the regeneration that develops within canopy gaps is not overtopped by dominant trees and is therefore favourable to the production of high value wood. Some studies focus on the identification of understory types in canopy gaps (Vehmas et al. 2011). Another method was developed to distinct non-regenerating gaps from regenerated ones (Sénécal et al. 2018). The height growth of regeneration saplings within canopy gaps was also estimated using ALS time series (Vepakomma et al. 2008).

Using ALS data, the study's objectives were (i) to detect and map canopy gaps, (ii) to characterize and delineate four regeneration development stages within these canopy gaps and (iii) to differentiate ligneous stems from herbaceous and soil for the first development stage (height < 1.5 m).

2. Data and Methods

2.1 Study area

The study area was a forest of 1,708 ha located in Wallonia (southern Belgium) (Figure 1A). The mean annual rainfall was 1170 mm year^{-1}. The mean annual temperature was 8.7 °C. The altitude ranged from 263 to 478 m. The mean terrain slope was 7.8°. Mixed uneven-aged deciduous stands corresponded to 51% of the study area. Oak (*Quercus robur L.* and *Quercus petraea (Mattuschka) Liebl.*) corresponded to 35% of the total basal area, and beech (*Fagus sylvatica L.*), to 55%. The regeneration (i.e. from seedlings to established saplings) was composed of 83% of beech, 10% of spruce (*Picea abies (L.) Karst.*), 2% of sycamore maple (*Acer pseudoplatanus L.*), and 2% of oak.

2.2 ALS data

ALS data were acquired using the Teledyne-Optech Titan dual-wavelength sensor between the 6th and 9th May 2018 (leaf-on). The sensor allows the acquisition of both topographic and bathymetric point clouds (wavelengths equal to 1064 nm and 532 nm, respectively). The mean flight altitude was 684 m above sea level. The resulting recorded topographic and bathymetric point clouds density were 56 pts/m² and 48 pts/m², respectively. The raw point cloud was classified into ground and above-ground hits. A CHM at a spatial resolution of 0.5 m was generated.

2.3 Mapping of canopy gaps

Canopy gaps were detected and mapped using a thresholding method (Bonnet et al. 2015). The canopy gaps mapping was implemented using the CHM for uneven-aged stands.

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Coniferous plantations representing 42 % of the forest area were discarded. A canopy gap was defined as a forest area with a maximum vegetation height of 10 m, a minimum surface area of 50 m² and a minimum width of 4 m. A fourth criterion (slope, calculated on the CHM, lower than 80°) was also applied to discard areas corresponding to low branches of neighbouring trees around gaps. All the threshold values were defined based on the literature, forest management inventories or field observations.

2.4 Mapping of regeneration development stages

Four regeneration development stages were defined based on vegetation height using CHM within canopy gaps (Table 1). It was assumed, and verified in the field, that there were no non-ligneous elements higher than 1.5 m. The first stage (s1) included seedlings, young saplings, herbaceous vegetation, litter and soil. The other stages ($1.5 \leq$ height < 10 m) corresponded to older established saplings but not recruited trees.

Table 1. Height thresholds of regeneration development stages.

Development stage	Definition
First stage (s1)	CHM < 1.50 m
Second stage (s2)	1.5 ≤ CHM < 3
Third stage (s3)	3 ≤ CHM < 6
Fourth stage (s4)	6 ≤ CHM < 10 m

2.5 Modelling ligneous stems cover for the first development stage

The ligneous stems cover (%) within the first stage was modelled using random forest and ALS data. The data used was collected in the field: 103 circular plots with a 2 m radius were set up on transects. Each plot was positioned with a high precision using an Emlid Reach RS+ GPS and the ligneous stems cover (%) was estimated visually.

A series of 86 ALS metrics was calculated considering point height, topographic and bathymetric intensities within plots (Latifi et al. 2017, Imangholiloo et al. 2020). Using *VSURF* (Genuer et al. 2015), the 11 metrics with the highest explanatory power (e.g. the mean, standard deviation and kurtosis of ALS point height) were selected and a random forest model was trained using the whole field dataset. This global model was assessed considering R^2, RMSE and bias.

A simple cross-validation was also applied to evaluate the model's accuracy: 100 iterations with 80% of the field data plots for training and 20% for validating. For each iteration, R^2, RMSE and bias were calculated.

After validation, the global model was used to predict the ligneous stems cover for the first development stage class on the entire study area using a regular grid.

3. Results and Discussion

Canopy gaps were detected and mapped using the thresholding method, and development stages were characterized and delineated within canopy gaps (Figure 1B).

The R^2, RMSE, and bias of the ligneous stems cover model (random forest) were 0.92, 0.09 and 0.00, respectively. The R^2, RMSE and bias of the cross-validation were 0.49 (± 0.17), 0.21 (± 0.04) and 0.01 (± 0.05), respectively. The ligneous stems cover for the first development stage class was predicted on the entire study area (Figure 1C).

A straightforward method was developed to detect canopy gaps and map regeneration development stages located within these gaps using ALS data. The method was applied to the entire forest area excluding coniferous plantations. The random forest model satisfactory predicted the ligneous stems cover within the first development stage. Accuracy values were comparable to those of other similar studies (Latifi et al. 2017, Venier et al. 2019).

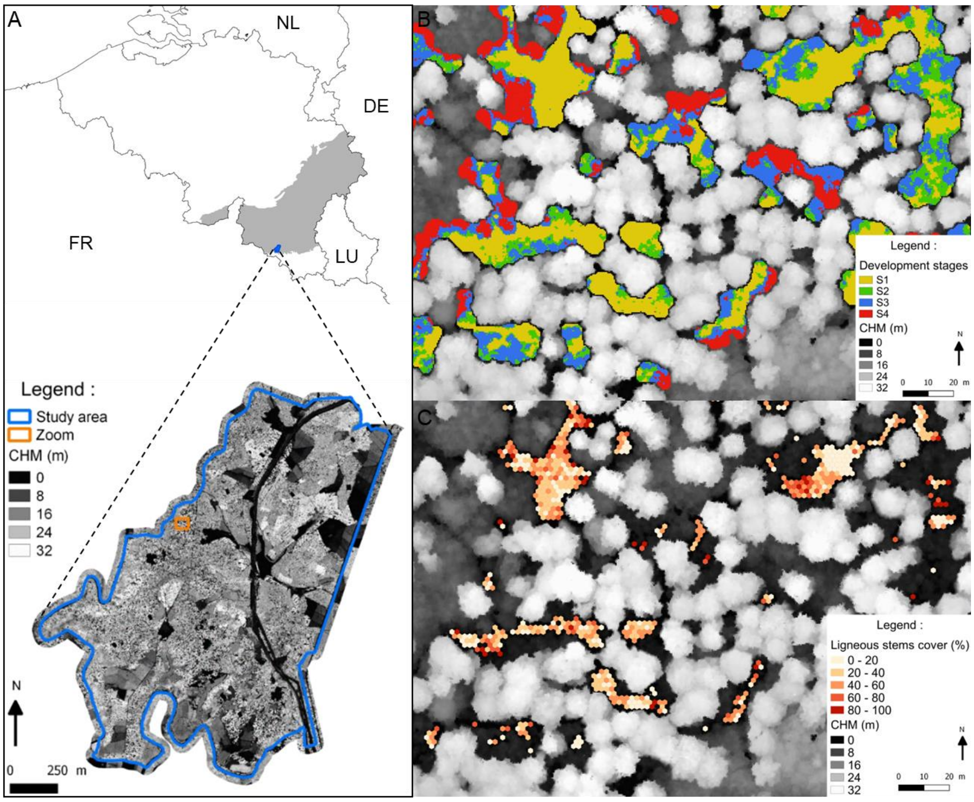

Figure 1. Study area location and maps. Panel A: Study area located in Belgium and study area's CHM. Panel B: Map of development stages within canopy gaps. Panel C: Map of ligneous stems cover for the first development stage.

5. Conclusion

The proposed method using ALS data is straightforward. It allowed to identify canopy gaps and map four regeneration development stages within these gaps at high spatial resolution (GSD = 0.5 m). The method also differentiates ligneous stems from herbaceous for the first development stage. This detailed regeneration mapping is really promising for forest management.

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References

Bonnet S, Gaulton R, Lehaire F, Lejeune P, 2015, Canopy gap mapping from airborne laser scanning: An assessment of the positional and geometrical accuracy. *Remote Sensing*, 7(9) 11267–11294.

Debouk H, Riera-Tatché R, Vega-García C, 2013, Assessing Post-Fire Regeneration in a Mediterranean Mixed Forest Using Lidar Data and Artificial Neural Networks. *Photogrammetric Engineering & Remote Sensing*, 79(12) 1121–1130.

Genuer R, Poggi JM, Tuleau-Malot C, 2015, VSURF: An R Package for Variable Selection Using Random Forests. *The R Journal, R Foundation for Statistical Computing*, 7(2), 19–33.

Imangholiloo M, Saarinen N, Holopainen M, Yu X, Hyyppä J, Vastaranta M, 2020, Using leaf-off and leaf-on multispectral airborne laser scanning data to characterize seedling stands. *Remote Sensing*, 12(20) 1–20.

Latifi H, Hill S, Schumann B, Heurich M, Dech S, 2017, Multi-model estimation of understorey shrub, herb and moss cover in temperate forest stands by laser scanner data. *Forestry: An International Journal of Forest Reasearch*, 90(4) 496–514.

Ligot G, Balandier P, Courbaud B, Jonard M, Kneeshaw D, Claessens H, 2014, Managing understory light to maintain a mixture of species with different shade tolerance. *Forest Ecology and Management*, 327 189–200.

Martín-Alcón S, Coll L, De Cáceres M, Guitart L, Cabré M, Just A, González-Olabarría J R, 2015, Combining aerial LiDAR and multispectral imagery to assess postfire regeneration types in a Mediterranean forest. *Canadian Journal of Forest Research*, 45(7) 856–866.

Senécal J F, Doyon F, St-Onge B, 2018, Discrimination of canopy gaps and non-regenerating openings in old-growth temperate deciduous forests using airborne LiDAR data. *Canadian Journal of Forest Research*, 48(7) 774–782.

Vehmas M, Packalén P, Maltamo M, Eerikäinen K, 2011, Using airborne laser scanning data for detecting canopy gaps and their understory type in mature boreal forest. *Annals of Forest Science*, 68(4) 825–833.

Venier L A, Swystun T, Mazerolle M J, Kreutzweiser D P, Wainio-Keizer K L, McIlwrick K A, Woods M E, Wang X, 2019, Modelling vegetation understory cover using LiDAR metrics. *PLoS One*, 14(11) 1–17.

Vepakomma U, St-Onge B, Kneeshaw D, 2008, Height growth of regeneration in boreal forest canopy gaps-does the type of gap matter? An assessment with lidar time series. In: *SilviLaser 2008*. Edinburgh, UK, p. 9.