USING AIRBORNE SMALL-FOOTPRINT LASER SCANNER TO ASSESS THE QUANTITY OF SEEDLINGS IN AN UNEVEN-AGED SPRUCE FOREST

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ABSTRACT:

The relationships between measures of forest structure as derived from airborne laser scanner data and the variation in quantity of young trees established by natural regeneration in a size-diverse spruce forest were analyzed. A regeneration success rate (RSR) was regressed against 27 different laser-derived explanatory variables. The 27 different models were ranked according to their Akaike information criterion score. Each laser variable was then associated with two categories. These were return and type. Within the return and type categories, the variables were grouped according to if they originated from first or last return echoes and if they were canopy height or canopy density metrics. The results show that the laser variables strongest correlated to the quantity of small trees could be attributed to last return and density metrics.

1. INTRODUCTION

The number of seedlings in uneven-aged forest types is influenced by several factors. An essential requirement for regeneration is a source of seeds. Furthermore, the establishment of a seedling from a seed is dependent on the properties of the humus layer, competition from other plants, nutrient availability, and microclimate (moisture and light/heat) at the specific site. Many of these factors are directly or indirectly influenced by stand structure. For instance, stand structure will affect below canopy light levels, which not only determine energy input but also influence temperature, the composition of the bottom- and field layer species, humus layer processes and so on. Thus, under varying forest structure, the quantity and vitality of the young growth will be expected to vary accordingly.

Small footprint airborne laser scanning has shown to produce good data for reproducing forest structures. The laser depicts the canopy by transmissions of geo-referenced laser pulses, recording vegetation heights at the hit point of each pulse. Structural characteristics of the canopy have been modelled from discrete laser returns by several authors (e.g. Maltamo et al., 2004; Parker and Russ, 2004; Tickle et al., 2006). The results have been good because laser pulses can penetrate at least 40 % of maximum canopy height (Næsset, 2004a) and therefore account for much of the variation in canopy structure. However, the retrieval of small trees (say diameter less than five cm in breast height) under a dominating canopy by means of laser scanning is challenging. Still, even though there are several factors that influence establishment and growth that are not, or only partly, affected by the stand structure, it is likely that there exist some relationship between the laser-depicted canopy and the variation in young growth. We believe that utilization of laser data describing canopy structure to detect young growth could be a valuable contribution for improving existing recruitment models or constructing new ones based solely on laser variables.

The objective of the present study was to analyze the relationship between measures of forest structure as derived from airborne laser scanner data and variation in the quantity of young trees in the height range of 0.1 to 3 m in a size-diverse spruce-dominated forest. The focus was on exploration and identification of laser-derived variables that have a potential for development of future prediction models that might be used in operational forest management.

2. MATERIALS AND METHODS

2.1 Field inventory

The data were collected on 72 circular field plots of 25 m^2 each. The plots were located in 18 clusters comprising four plots in a boreal forest reserve outside Oslo (59º 50´N, 11º 02´E, 190–370 m a.s.l). Stand characteristics appear in Table 1. The forest area is further described by Bollandsås and Næsset (2007). From the centre of each cluster, one plot of 25 m^2 was located 12 meters from this centre in each cardinal direction. The position of each cluster centre was determined by differential GPS+GLONASS measurements. Each plot was split into four by two perpendicular lines through the plot centre in a north/south and east/west direction. In each of these resulting 6.25 m^2 quadrants, the number of seedlings between 0.1 and 3 m were recorded. A regeneration success rate (RSR) was computed from these records by first counting seedlings in each quadrant (n_i). However, we stopped counting if the number reached a limit considered sufficient on an area of 6.25 m^2 (n_{suf}). This limit was set to three seedlings. Then we summed n_i for the four quadrants and RSR was computed as this sum relative to a number of seedlings considered sufficient for the entire plot ($4n_{suf}$). The reasons for using RSR instead of the actual number

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are that above a certain number, the establishment is most likely dependent on growth factor variations on a very small spatial scale, for instance the occurrence of partly decomposed downed logs or bare mineral soil, but also that RSR will be more representative of the number of seedlings needed for the regeneration to be successful.

Characteristic[a]	n	Mean	STD	Range
Minimum diameter (cm)	18	3.2	0.3	3.0 - 4.0
Maximum diameter (cm)	18	47.0	7.3	33.3 - 60.6
Diameter range (cm)	18	43.8	7.3	30.3 - 57.1
Mean diameter by basal area (cm)	18	21.11	3.8	14.60 - 30.32
Lorey`s mean height (m)	18	21.65	3.7	15.20 - 28.90
Dominant height (m)	18	26.27	3.3	19.80 - 32.00
Number of stems (ha^{-1})	18	1033	308	630 - 1780
Stand basal area (m^2ha^{-1})	18	34.2	5.7	21.6 - 45.5
Volume (m^3ha^{-1})	18	360.7	110.4	171.9 - 634.8
Species distribution (%)				
Spruce	18	90		71 - 100
Pine	18	0		0 - 2
Deciduous	18	10		0 - 28

Table 1. Forest data by clusters.

2.2 Laser scanner data

A Hughes 500 helicopter carried the ALTM 1233 laser scanning system produced by Optech, Canada. The average footprint diameter was approximately 18 cm. The mean number of pulses transmitted was 5.0 m^{-2}. First and last returns echoes were recorded.

First and last pulse height distributions were created for a circle (r=8.46 m) around each sample plot centre from the laser echoes considered to be reflected from the tree canopy, i.e., echoes with height values of >3 m. The radius of 8.46 is the maximum radius that could be used without having overlap between laser data from adjacent plots. The tree canopy threshold value of 3 m was set to correspond to the maximum height of trees belonging to the understorey. From these distributions a total of 27 variables were derived. Three percentiles of 10%, 50%, and 90% of maximum height characterized both first and last return laser heights. We labelled these as the height variables. Accordingly, measures of canopy density were derived by dividing the range between the lowest laser canopy height (>3 m) and the maximum canopy height into four uniform fractions. Cumulative canopy densities, henceforth called density variables, were then computed as the proportions of first and last pulse laser hits between the lower limit of each fraction and maximum laser height to total number of pulses. Moreover, maximum and mean height values, standard deviations and coefficients of variation were derived. Further details are provided by Næsset (2004b).

2.3 Data analysis

Because the data originate from clustered plots, there exists spatial dependency between plots within clusters. Thus, data analysis was carried out by means of the PROC MIXED procedure of the SAS statistical software package (Anon., 1999), estimating random coefficient models. Each variable extracted from the laser data were regressed against RSR. Subsequently, each of the models was ranked by their Akaike information criterion (AIC) (Akaike, 1974) score. This yielded a rank of each laser variable according to the goodness of fit of each model.

Then, each laser variable was attributed to groups of first- or last return; and height- or density variable. The first- and last return groups constitute what we labelled the return category. Similarly, the height- and density groups constitute the type category.

3. RESULTS

Table 2 displays the results from the ranking of the laser variables according to the AIC values. The table shows the modus group (most frequent group of variables within the category) with the corresponding frequency for both variable categories. The best explanatory variables for RSR according to these rankings are attributed to last return echo and density metrics. Of the five highest AIC-ranked variables 80% were related to last return echo and 100% to density metrics.

	Return [a]		Type[b]	
# of ranked variables	Modus group	Freq. (%)	Modus group	Freq. (%)
5	Last	80	Density	100
10	Last	70	Density	100
15	Last	60	Density	100

Table 2. The most frequent group of variables (modus group) of the best AIC-ranked 5, 10, and 15 variables assigned to return and type categories.

[a] First or last laser echo.
[b] Type of laser variable (height or density variable).

4. DISCUSSION

Establishment – measured as regeneration success rate –was found to be best explained by density metrics and variables originated from last return data. While the first return data describes the surface of the canopy, the last returns penetrate deeper into the canopy and thus account for more vertical canopy variation. Last return data are therefore better accounting for light conditions on the ground. This may also be the reason why density metrics are better than height metrics. Since they are greatly affected by the density and structure of the canopy, they also account for light conditions on the ground better than the height variables.

For germination and early establishment of spruce seedlings, soil temperature and humidity are the most important factors (Mork, 1938; Bjor, 1971). Light levels affect both temperature and the distribution of bottom and field layer vegetation, which can be important for water availability. Even though the nearest neighbour trees may have a large influence on light conditions, light levels below the canopy will be affected by trees on a large scale in this mature forest. In fact, the radius of 8.46 m that we used in this study was not very large, as light levels below the canopy are affected by trees or gaps up to at least twice the dominant stand height at northern latitudes (Flemming, 1962; Golser and Hasenauer, 1997). Our radius was set to avoid overlap between adjacent plots, but in further studies different and greater radii should be investigated.

Establishment may be influenced by many stochastic factors, of which weather conditions are the most important, having a strong influence on seed production, germination, and seedling mortality. Also non-stochastic factors like soil conditions, ground vegetation or micro-topography may influence establishment, regardless of stand structure. Our study was conducted in a multi-storied, natural spruce forest. In a managed spruce forest, the relationship between structure and regeneration may not be completely the same. One obvious difference may be the type and frequency of treefall gaps, which enhances regeneration by soil disturbance and woody debris and are important regeneration niches in a natural spruce forest (Kuuluvainen, 1994). Those elements are created mostly by the downfall of (over-) mature trees and related to stand structure. In the managed forest trees are removed at an economic maturity age, and the presence of treefall gaps and downed logs are lower and not related to stand structure in a similar way as in natural forests. Thus, a separate study should be conducted for managed forests.

5. CONCLUSION

Our study was a screening which aimed at identifying laser variables that might explain regeneration success. A full correlation between laser data variables derived from the canopy and regeneration will never be found, as factors not affected by canopy structure also strongly influence regeneration success. However, the study has shown that already existing data derived from laser scanning, for instance during a regular forest inventory, may give us surplus information on regeneration. Our data show that there is a relationship between canopy structure and seedling number, possibly strong enough for prediction of regeneration success in future prediction models.

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