ASSESSMENT OF SUB-CANOPY STRUCTURE IN A COMPLEX CONIFEROUS FOREST

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ABSTRACT:

LiDAR technology emits narrow beams of laser light that are able to exploit gaps in the forest canopy and detect sub-canopy surfaces. In this study, we explore the potential of airborne LiDAR to quantify understorey vegetation cover in a dense and structurally diverse conifer forest on Vancouver Island, British Columbia, Canada. The cover of understorey vegetation, defined below an arbitrary height threshold of 4 m, was recorded in the field both horizontally and vertically at 12 plots for comparison with LiDAR data. Results showed significant relationships between field and LiDAR-based estimates of understorey vegetation cover at both the plot (30 x 30 m area, $r^2 = 0.87$) and sub-plot scale (15 x 15 m areas, $n = 4$ per plot, $r^2 = 0.68$) ($p < 0.05$). In addition, the variability (coefficient of variation) of understorey vegetation cover estimated in the field and with LiDAR data was found to be significantly correlated (r^2=0.88, $p < 0.001$). Overall, this work suggests that small-footprint LiDAR is sensitive to large changes in understorey vegetation cover which can benefit key forestry applications at the landscape scale such as examining stand regeneration success.

1. INTRODUCTION

Information about the forest understorey is critical for both ecological and forest management issues. Understorey vegetation provides food and habitat to a wide range of fauna (Fox & Fox 1984), whilst in multi-aged and mixed species stands, developing an understanding of regeneration success is important for ongoing stand management following a disturbance (Kozlowski 2002). Likewise the spatial distribution and structure of understorey vegetation (*e.g.* quantity, height, and cover) is critical to fire behaviour models which are difficult to parameterise over forested landscapes (Keane et al. 2001). For foresters, accurate and timely information on the understorey can also help in the assessment of nutrient retention and cycling (Yarie 1980), stand regeneration (Lormier et al. 1994), and species diversity (Gentry & Dobson 1987).

Conventionally, the approach to collecting information on the understorey has involved a range of field-based techniques. These generally require detailed, spatially dense field measurements (< 1 ha) (McLaughlin 1978; Scheller & Mladenoff 2002) so that the high spatial variability often present in the understorey can be captured and the ecological processes which occur at fine scales can be understood. For example, the distribution and composition of understorey vegetation has been shown to vary at fine spatial scales due to microtopography (*i.e.* pits and mounds), gaps in the overstorey vegetation, disturbances such as harvesting and nutrient availability (Beatty 1984; Bengtson et al. 2006; Miller et al. 2002). As a result, field-based assessments of the understorey are likely to be an expensive, difficult and time consuming task.

Light Detection And Ranging (LiDAR) however, has been recognised as a tool that might be suitable to quantify sub-canopy vegetation structure over large geographical areas. Earlier studies, for example, have shown that LiDAR can characterise fuel bed roughness (Seielstad & Queen 2003), discriminate understorey discrete LiDAR returns from overstorey returns within a mixed conifer and deciduous two-tiered forest (Riaño et al. 2003), and estimate the Lorey's mean height of suppressed understorey trees in a boreal forest using regression models (Maltamo et al. 2005). Further, Mutlu et al. (2007) used the number of LiDAR hits within 0.5 m vertical bins from 0 to 2 m (2.5 x 2.5 m areas) normalised by the total number of LiDAR hits, to improve the accuracy of a surface wildfire fuel classification, which also involved multispectral passive optical data.

The focus of this work is to determine whether spatial estimates of understorey cover are possible within a conifer forest. To characterise the different types of understorey structure contained within a multi-use conifer forest, a number of sites (12 in total) were examined. The specific objectives were to: (1) assess whether understorey cover can be quantified within 30 x 30 m and 15 x 15 m areas using first return LiDAR data, and (2) determine whether the variability in understorey cover measured in the field was correlated to LiDAR estimates.

2. MATERIALS AND METHODS

2.1. *Field site*

The study area is Clayoquot Sound on Vancouver Island, British Columbia (49^{o} 0' 35" N, 125^{o} 37' 21" W). The area is classified as a Coastal Western Hemlock (CWH) zone, based on the biogeoclimatic ecosystem classification (BEC) system (Meidinger & Pojar 1996). Although the Vancouver Island Range is adjacent to the study area, the topography is subdued and dominated by Pleistocene glacial deposits with an annual precipitation of 3306 mm and mean daily minimum, average and maximum temperatures of 5.4, 9.1, and 12.8^{o}C, respectively (Environment Canada 2006).

Clayoquot Sound is a multi-use forested area and includes both recently harvested Crown land, as well as mature first and second growth forest in Pacific Rim National Park. Western hemlock (*Tsuga heterophylla*) is the dominant or codominant tree species throughout. Western Redcedar (*Thuja plicata*), Amabilis fir (*Abies amabilis*), Yellow-Cedar

(*Chamaecyparis nootkatensis*), Sitka Spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii* var. *mensiesii*), and Red Alder (*Alnus rubra*) also occur within this forest region. Common understorey species include: Salal (*Gaultheria shallon*), Salmonberry (*Rubus spectabilis*), Thimbleberry (*Rubus parviflorus*), Red Huckleberry (*Vaccinium parvifolium*), Evergreen Huckleberry (*Vaccinum ovatum*), Blueberries (*Vaccinium* spp.), and Devil's club (*Oplopanax horridus*). Several of these understorey species are important economically (for the floral industry), provide food for local communities, and include culturally important medicinal plants (Clayoquot Sound Scientific Panel 1995).

2.2 LiDAR characteristics

Airborne LiDAR data were acquired in July 2005 by Terra Remote Sensing (Sidney, British Columbia, Canada) using a TRSI Mark II discrete return sensor attached to a fixed wing platform. The sensor was configured to record first and last returns with a pulse repetition frequency of 50 kHz, platform altitude of 800 m, maximum off-nadir view angle of 23 degrees, wavelength of 1064 nm, and a fixed beam divergence angle of 0.5 mrad. The average pulse spacing equalled one laser pulse return per 1.5 m^2. Ground and non-ground returns were classified using TerraScan (Terrasolid, Finland).

2.2. *Field estimates of understorey cover*

Understorey cover was measured at 12 sites within a series of 2.5 x 2.5 m quadrats (n = 144) which collectively covered an area of 30 x 30 m. At each of the quadrat locations, understorey cover was visually estimated in 4 height intervals: 0.5 to 1, 1 to 2, 2 to 3, and 3 to 4 m above ground surface. A height pole was used as an aid and cover estimates were taken horizontally within 20% intervals.

A single integrated estimate of vertically projected understorey cover (*UC*) for each 2.5 x 2.5 m quadrat was then calculated using Equation 1. Given that:

$$UC = 1 - e^{-GF_{total}\bar{s}} \quad \textbf{(1)}$$

where: *G* refers to the G-function, the projection of leaf area into a given view direction (Ross 1981),

$\bar{s}$ is the mean distance light will travel through understorey material (corresponding to the vertical height intervals used to estimate understorey cover), and

F_{total} is the foliage area index for each understorey sample location.

The calculation of vertically projected cover assumes homogenous volume of vegetation material and will depend on the leaf angles. Given the understorey is composed of mixed species and variable leaf angle distributions, a value between the two more extreme leaf angle distributions (planophile and erectophile) (Ross 1981; Ross & Marshak 1989) of 0.5 was used, which corresponds to a random foliage angle distribution. Since the field measured understorey cover is related to the understorey gap probability (P_{gap}) by the equation:

$$P_{gap,i} = 1 - UC_i \quad \textbf{(2)}$$

where: i = to the sub-quadrat cover measurement obtained at individual sample locations using the modified height pole (*e.g.* i = 1 for understorey cover estimated between 0.5 and 1 m above the ground).

We can also express Eq. 1 in terms of foliage area density for each understorey measurement as follows:

$$F_i = -\ln(P_{gap,i}) / G\bar{s} \quad \textbf{(3)}$$

and subsequently, derive the total foliage area index at each quadrat area by:

$$F_{total} = \bar{s}\sum_{i=1}^{n} F_i \quad \textbf{(4)}$$

Subsequently, understorey cover values were converted into mean estimates at the plot scale (30 x 30 m area) and sub plot scale (15 x 15 m areas) for comparison with LiDAR data.

2.3. *Understorey vegetation cover comparison*

Using coordinates recorded from a differential Geographic Position System (*d*GPS) (horizontal positional errors were approximately 1 to 5 m), LiDAR first return data were extracted for each plot. Returns > 0.5 and ≤ 4.0 m above ground surface were considered to be from understorey vegetation. Understorey cover was calculated at both the plot scale (30 x 30 m area) and sub plot scale (15 x 15 m areas), as the number of understorey returns divided by the total number of returns recorded ≤ 4.0 m. These values were then compared to field-based estimates. Additionally, the variability of understorey cover recorded at each site was computed in both datasets by computing the coefficient of variation (CoV) of the 4 sub-plot cover values derived at each site (15 x 15 m area, n = 4).

3. RESULTS

Strong positive relationships are shown between field and LiDAR-based estimates of understorey cover ($p < 0.001$) (Figure 1). The estimates of understorey cover however, were shown to be better correlated at the plot scale compared to the sub plot scale, which showed a weaker relationship ($p < 0.05$). Note one plot recorded no hits below 0.5 m and was excluded from analysis.

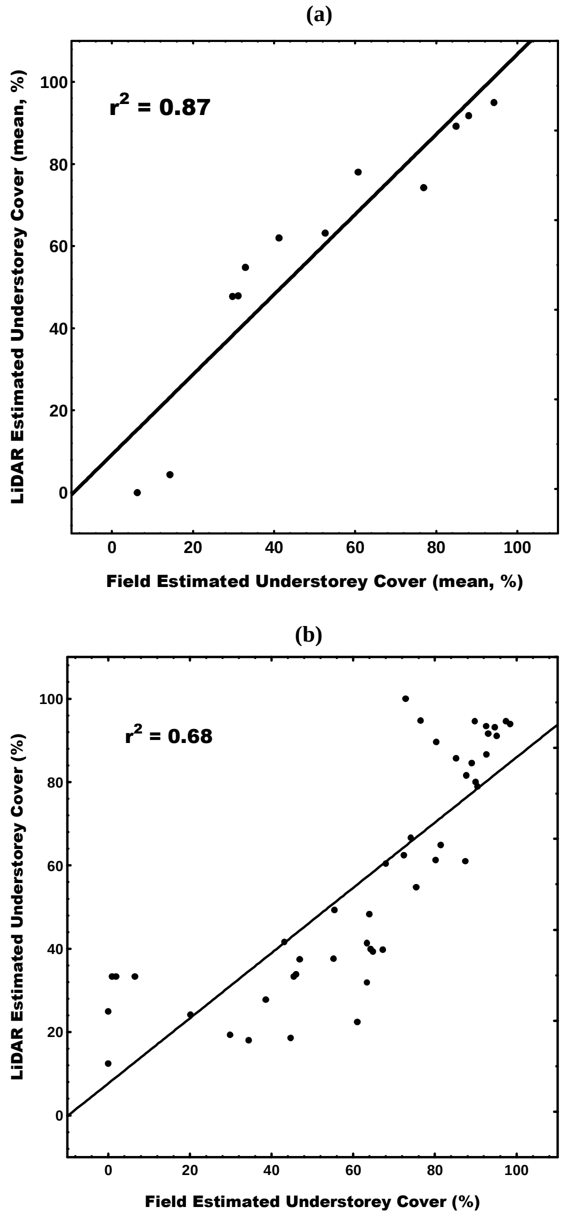

Figure 1. Relationship between field and LiDAR estimates of understorey cover: (a) plot scale (30 x 30 m areas) and (b) sub-plot scale (15 x 15 m areas). *Note*: outliers with an insufficient number of first returns were removed (n < 3).

Analysis of the variability in field and LiDAR estimates of understorey cover, within individual plots, was also shown to be positively correlated ($p < 0.001$) (Figure 2). This suggests that LiDAR is sensitive to changes in understorey cover within 15 x 15 m areas.

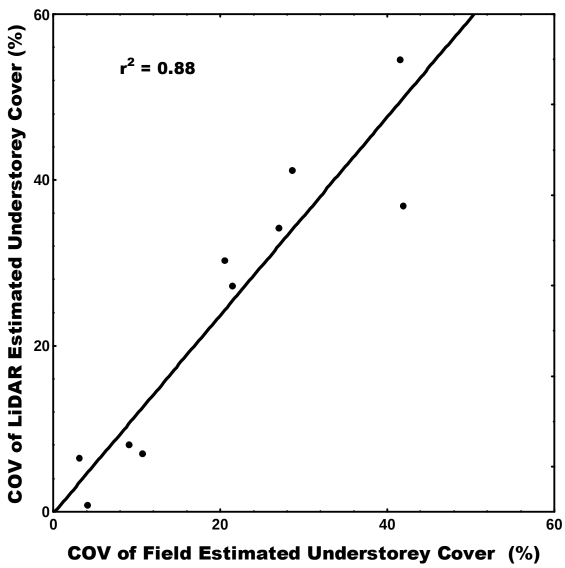

Figure 2. Field and LiDAR estimates of understorey cover variability within plots. *Note*: the CoV for each plot was calculated using four 15 x 15 m estimates of understorey cover per plot. Outliers with an insufficient number of first returns were removed (n < 3).

4. DISCUSSION

The results presented in this paper provide an insight into the capacity of airborne LiDAR to estimate both plot level understorey cover as well as cover at smaller spatial scales. Importantly, this work has shown a strong correlation between field and LiDAR estimates of understorey cover at the plot scale, with plots covering a wide range of cover values from 0 to 100% cover. When each plot was then subdivided into 4, the relationship weakened but remained significant. This suggests the relationships at the sub plot level might have been influenced by the number of LiDAR returns and the spatial registration of field and LiDAR data.

A limitation of this approach is that occlusion through the overstorey and understorey vegetation layers will reduce the number of first returns detected from ground and understorey surfaces. As a consequence, in areas with a dense canopy a larger mapping unit will be needed to capture a sufficient number of returns to derive understorey cover. At one of the 12 plots, for example, understorey cover could not be computed within a 30 x 30 m area as no LiDAR first returns were detected below 0.5 m (above ground surface).

Another important result is the relationship between LiDAR and field predicted understorey cover variation. This relationship is surprisingly strong, providing some confidence that regardless of the overall stand condition, the amount of variation in the LiDAR non-ground hits below 4 m is related to understorey cover variation. Additional work is needed however, to fully explore this relationship (*e.g.* sensitivity to scale).

Further, it should be mentioned that the spatial position of the ground plots becomes increasing important when computing sub plot cover statistics at smaller spatial scales. Since the *d*GPS positional data for this study was recorded under dense forest canopies, which is known to affect the spatial accuracy

(Næsset & Jonmeister 2002), our analysis was restricted to scales that exceeded the horizontal positional errors. The measurement of understorey vegetation characteristics within 5 x 5 m however, may well be the smallest feasible unit to compare with LiDAR observations (assuming similar LiDAR pulse densities of around 1 pulse per m^2).

5. CONCLUSION

We encourage more research into LiDAR's ability to map the understorey and believe that LiDAR can provide a suitable tool for mapping large differences in understorey cover (*e.g.* ~20% intervals), and its spatial pattern, at the landscape scale. Stronger relationships were found at the coarser spatial scale (30 x 30 m), possibly in response to a larger number of understorey hits being available to characterise the understorey.

6. REFERENCES

Beatty, S.W., 1984. Influence of microtopography and canopy species on spatial patterns of forest understorey plants. Ecology, 65(5): 1406-1419.

Bengtson, P., Ursula, F.G. and Bengtsson, G., 2006. Spatial distributions of plants and gross N transformation rates in a forest soil. Journal of Ecology, 94: 754-764.

Clayoquot Sound Scientific Panel, 1995. Report 5: Sustainable Ecosystem Management in Clayoquot Sound, Halfmoon Bay, British Columbia, Canada.

Environment Canada, 2006. Canadian Climate Normals 1971-2000. Tofino A., British Columbia. Downloaded from the World Wide Web on 9 September 2006 from http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html.

Fox, B.J. and Fox, M.D., 1984. Small-mammal recolonisation of open-forest following sand mining. Australian Journal of Ecology, 6: 29-41.

Gentry, A.H. and Dobson, H.C., 1987. Contibution of non-trees to species richness of tropical rainforest. Biotropica, 19: 216-227.

Keane, R.E., Burgan, R. and van Wagtendonk, J., 2001. Mapping wildland fuels for fire management across multiple scales: integrating remote sensing, GIS, and biophysical modelling. International Journal of Wildland Fire, 10: 301-319.

Kozlowski, T.T., 2002. Physiological ecology of natural regeneration of harvested and disturbed forest stands: implications for forest management. Forest Ecology and Management, 158(1-3): 195-221.

Lormier, C.G., Chapman, J.W. and Lambert, W.D., 1994. Tall understorey vegetation as a factor in the poor development of oak seedlings beneath mature stands. Journal of Ecology, 82: 227-237.

Maltamo, M. Packalén P, Yu X, Eerikäinen K, Hyyppä J, and Pitkänen J. 2005. Identifying and quantifying structural characteristics of heterogeneous boreal forests using laser scanner data. Forest Ecology and Management, 216(1-3): 41-50.

McLaughlin, S.P., 1978. Determining the understorey production in southwestern ponderosa pine forests. Bulletin of the Torrey Botanical Club, 105(3): 224-229.

Meidinger, D. and Pojar, J., 1996. Ecosystems of British Columbia. BC Special Report Series No. 6., British Columbia Ministry of Forests, Victoria, Canada.

Miller, T.F., Mladenoff, D.J. and Clayton, M.K., 2002. Old-growth northern hardwood forests: spatial autocorrelation and patterns of understorey vegetation. Ecological Monographs, 72(4): 487-503.

Mutlu, M., Popescu, S. C., Stripling, C., and Spencer, T., 2007. Mapping surface fuel models using lidar and multispectral data fusion for fire behavior. *Remote Sensing of Environment, In Press, Corrected Proof.*

Næsset, E. and Jonmeister, T., 2002. Assessing point accuracy of dGPS under forest canopy before data acquisition, in the field and after postprocessing Scandanavian Journal of Forest Research, 17: 351-358.

Riaño, D., Meier, E., Allgower, B., Chuvieco, E. and Ustin, S.L., 2003. Modelling airborne laser scanner data for the spatial generation of critical forest parameters in fire behaviour modelling. Remote Sensing of the Environment, 86: 117-186.

Ross, J.K., 1981. The radiation regime and architecture of plant stands. Dr W. Junk Publishers, The Hague, Boston, London, 391 pp.

Ross, J.K. and Marshak, A.L., 1989. The influence of leaf orientation and the specular component of leaf reflectance on the canopy bidirectional reflectance. Remote Sensing of Environment, 27: 251-260.

Scheller, R.M. and Mladenoff, D.J., 2002. Understorey species patterns and diversity in old-growth and managed northern hardwood forests. Ecological Applications, 15(5): 1329-1343.

Seielstad, C.A. and Queen, L.P., 2003. Using airborne laser altimetry to determine fuel models for estimating fire behaviour. Journal of Forestry, 101(4): 10-17.

Yarie, J., 1980. The role of understorey vegetation in the nutirent cycle of forested ecosystems in the mountain hemlock biogeoclimatic zone. Ecology, 61(6): 1498-1514.

7. ACKNOWLEDGEMENTS

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