ASSESSING FOREST GAP DYNAMICS AND GROWTH USING MULTI-TEMPORAL LASER-SCANNER DATA

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ABSTRACT:

Research on lidar change detection is at its inception with a few studies to monitor coastal erosion and almost none for forest dynamics. While long-term installations and dendrochronology are cost and time intensive, this study highlights potential use of multi-temporal medium density lidar data for studying forest dynamics in a spatially explicit manner, particularly in identifying new canopy gaps and assessing height growth. It also underlines some of the challenges of co-registering multi-temporal lidar datasets, working with large differences in return densities, and developing methodological approaches to compute growth. Two laser-scanner datasets, acquired in 1998 and 2003 over a 6 km^2 area of the mixed boreal forest in Quebec, Canada, were analysed. After co-registration, an automated method to accurately identify new gaps was developed which showed an overall accuracy of 96% when compared with high resolution images. Mean gap size, gap density and rate of gap openings have been in accordance with the reported statistics for the boreal forests. Forest growth was assessed by comparing various lidar statistics for hardwoods and softwoods in three height classes. The measured growth was in general consistent with expected height growth for the concerned species, however, improvements will be needed to increase the accuracy and reliability of results.

1. INTRODUCTION

During the last decade, it was clearly demonstrated that many forest structure attributes can be measured, or estimated with a high accuracy, using high density scanning laser altimetry data. Diverse studies have shown that height, volume, biomass, and to a lesser extent, crown diameter, stem density, or diameter at breast height estimates can be produced using lidar data (Magnussen and Boudewyn, 1998 Naesset 2002, Lim et al. 2003, Zimble 2003). Though further research efforts are still needed in this area, nonetheless the technology and methods are sufficiently matured to study the changes in forest using multi-temporal lidar datasets. Until recently, standard methods for studying fine scale forest changes were mostly based on space-for-time substitution (Kneeshaw and Bergeron 1998), which is restricted to inferring from current forest conditions, or analysing data collected at long term permanent plots which is labour, time and cost intensive. Studies documenting both spatial and temporal characteristics are rare as necessary field data is difficult to collect.

Research on lidar change detection has only begun with a few studies using topographic change mapping to monitor coastal erosion (http://www.csc.noaa.gov/crs/tcm/, last consulted on July 12th 2004). In forested environments, the high accuracy and density of lidar data would theoretically allow the detection of tree falls, and the estimation of growth. This has been demonstrated in Yu et al. (2004), which is currently the only published study on forest dynamics based on lidar data. Although the time interval between the two lidar surveys was of only two-year, this study could effectively detect harvested trees and assess growth at the individual tree level using very high density, low altitude, Toposys multitemporal lidar data (about 10 returns/m^2). Excepting the short time interval, the conditions of this study were ideal as the lidar instrument used for both surveys was the same, the density was very high and homogeneous, and only one species was studied. Due to the fast technological changes, most future multi-temporal lidar datasets are likely to be generated using different sensors, hence could have different densities, especially for longer time intervals. Indeed, most of the existing lidar data that could compose future multitemporal datasets have a density that is quite lower than what is achievable with a TOPOSYS lidar flown at a low altitude. This paper aims at developing methods for the detection of new gaps resulting from tree falls, and to assess tree growth using heterogeneous, medium density (up to 3 returns/m^2) lidar data acquired over a sector of the mixedwood boreal forest. Although these new techniques could be useful for industrial forest management, our prime interest lies in the development of new knowledge on the dynamics of natural forests. This paper focuses on the development of methods for the co-registration of multi-temporal lidar datasets, manual and automated methods for detecting tree falls and estimating growth.

2. STUDY SITE AND DATA

2.1 Study site

The study site falls within the conservation zone of the *Training and Research Forest of Lake Duparquet* (TRFLD, 79 º 22'W, 48 º 30'N), in the Province of Quebec, Canada. The 6 km^2 sector is characterized by small hills and is essentially covered by lacustrine clay deposits (Brais and Camiré 1992) with elevations comprised between 227 m and 335 m. The mixed vegetation is composed of common boreal species, and dominated by balsam firs (*Abies balsamea L.* [*Mill.*]), paper birch (*Betula papyfifera* [Marsh.]), and trembling aspen (*Populus tremuloides* [Michx]). The age structure found at this site results from a fire driven disturbance regime (Bergeron et al. 2000), and a recent infestation of a defoliating insect (1970-1987, Morin et al. 1993) called the spruce budworm (*Choristoneura fumiferana* [Clem]). Most stands are mature or over mature and reach heights of 20-25 m. The climate is cold temperate with an average annual temperature of 0.8 C and a number of degree days of approximately 2000, while the length of the growing season is on an average 160 days (Environment. Canada 1993)

2.2 Lidar data

The study site was surveyed on June 28th 1998, and again, as part of a larger coverage, on August 14 to 16 2003, thus determining an interval of approximately five growing seasons. The 1998 survey was carried out using an Optech ALTM1020 flown at 700 m above ground level (AGL) operating at a pulse frequency of 4 kHz. Because this lidar could not record both first and last returns in one pass, and had low impulse frequency, two passes for each flight line were done to acquire the first returns, and one for the last returns. The overlap between adjacent swaths was minimal, resulting in some small data gaps in the first returns. The data was registered to ground profiles surveyed with a high grade GPS and tacheometer. All returns were classified as ground and non ground using the REALM software application from Optech Inc. Only the ground-classified last returns were used to generate a bare earth digital terrain model (DTM). In 1998, the provider had also classified the first and last returns into ground and non-ground categories, but had delivered only the non-ground (vegetation) first returns and the ground classified last returns. The latter ones were used to generate a digital surface model (DSM). Note that a true lidar DSM should be created using all first returns. At the time of writing this paper, the full set of first returns was being recovered from the original raw data, but remained unavailable for this study.

	1998	*2003*
Lidar	ALTM1020	ALTM2050
Power	140uJ	200uJ
Flight altitude (m AGL)	700	1,000
Divergence (mrad)	0.3	0.2
Footprint size at nadir (cm)	21	20
Pulse frequency (Hz)	4,000	50,000
Max. scan angle (degrees)	10	15
First return density (hits/m^2)	0.3	3
Ground return density (hits/m^2)	0.03	0.19

Table 1. Specification of the lidar data acquisition

The 2003 survey was done with Optech's ALTM2050 lidar flown at 1,000 m AGL, and recorded the first and last returns for each pulse, with a 50% overlap between adjacent swaths. The data was registered to new ground profiles. The inter-swath geometrical fit was improved using the TerraMatch algorithm by Terrasolid Ltd. (Helsinki). The last returns were classified as ground and non-ground using Terrasolid's Terrascan. The ground-classified last returns were used to build the DTM, while the DSM was created using all first returns. Table 1 presents the key survey and lidar instrument parameters. It shows that the surveys differed in many aspects, but most importantly in terms of density.

2.3 Image data

High resolutions images were used to visualise the forest canopy structure, identify tree species, and verify the appearance of new gaps. An aerial videography survey was carried out on September 27th 1997 using a video camera equipped with a zoom lens connected to a Super VHS video recorder. The plane was flown at 1890 m AGL and acquired image data in the green (520-600 nm), red (630-690 nm), and near infrared (760-900 nm) bands. Frame grabs from the video playback yielded digital 50 cm resolution images covering the 1998 lidar area. A field survey done in 1998 allowed building an interpretation key of tree species. Theoretically, only minimal changes occurred between the acquisition of the September 1997 videographies and the June 1998 lidar data. A panchromatic IKONOS image of 1 m resolution (0.45-0.9µm), acquired on September 5th 2003, and a QuickBird image, in panchromatic (0.61 cm. resolution, 450-900 nm) and a multispectral modes (2.44 m resolution), acquired on June 13th 2004, were also used to give image context to the 2003 lidar dataset. The spectral bands of the QuickBird image used in this study are the same as those of the videographies. The multispectral QuickBird image was pan-sharpened with the panchromatic image by running an arithmetic combination technique in Geomatica v. 9.01 (PCI Geomatics) for better visualization.

2.4 Age-height tables

Due to the unavailability of growth measurements for precisely geopositioned trees in the studied sector, age-height tables, developed by Pothier and Savard (1998) for the most common tree species found in Quebec, were consulted to derive the expected specific height growth values. These tables were developed from field measurements performed in several thousands permanent and temporary 400 m^2 plots by the Forest Inventory Service of the Province of Quebec. For each species, average dominant height at a given age are given, from age 20, with a step of 5 years for four site index and three density classes.

3. METHODS

3.1 Co-registration

Standardization of the heights is obligatory for comparison of the height of the forest canopy at different dates. The first level of standardization consisted of using the same DTM for both years in order to avoid DTM differences causing false canopy height changes. This approach was also used by Yu et al. (2004). To allow the use of the same DTM, the lidar data generated in two different surveys must be perfectly co-registered. Shifts in the *X*, *Y*, or *Z* axes would result in erroneous canopy height change observations. The accuracy of lidar data is known to be very high. Recent studies reported elevation errors below 30 cm (Hodgson et al. 2003) for ground hits. However, a number of factors may affect the positional accuracy of lidar returns, like the quality of the GPS configuration at the time of the survey, mounting errors, INS errors, fluctuation of the scanning mirror speed, reference to ground calibration measurements, etc. Note that, unlike the 2003 dataset, no inter-swath fitting was performed on the 1998 data. We hypothesized that the error level and bias may be different for the two lidar surveys, and hence checked the *XYZ* fit between the two datasets. First returns and ground-classified returns were interpolated using a TIN algorithm to produce respectively a DSM and a DTM in grid format for both years. Planimetric shifts were analysed by visualizing the DTMs and DSMs. The arithmetic difference between DTMs was computed and the resulting image was analysed for trends on sloping terrain. No apparent shift was evidenced in all the analyses, and if one existed it was too negligible to be detected. Therefore, no further numerical analysis for planimetric shift was performed. The DTM difference image had however indicated a possible shift in *Z*. To assess this shift, all the corresponding ground returns of 2003 falling in a 10 cm radius of the 1998 ground returns were compared. The elevation of the 1998 ground returns was on average 22 cm higher than the corresponding 2003 returns. This may be due to errors in the GPS data, or in referencing the lidar data to ground profiles. The discrepancy could also be caused by differences in the ground classification. Comparisons on spots of stable bare ground (rock outcrops) were not conclusive to that regard. The 2003 data was chosen as the reference, and the elevation of all the 1998 returns (first and last) was accordingly adjusted.

3.2 Ground elevation and canopy height models

The density of the ground hits in 2003 was significantly higher than that of the 1998 data. However, there were some small gaps in the 2003 DTM point coverage for which 1998 points existed. We thus merged the 2003 and 1998 ground returns to maximize the overall return density of the DTM. After adjusting the 1998 last returns, preliminary grids of DTMs were created using TIN interpolation of the ground classified returns independently for both years. Wherever the difference in the interpolated grids was higher than 1m, the higher values were replaced with the lower ones under the assumption that the higher ones were caused by reflection of the lidar pulses on low vegetation that were not removed by the ground classification algorithm. The DTM was regenerated using the merged last return dataset and converted to a 50 cm grid. DSM grids of 50 cm pixel were generated by taking the highest point within each pixel and supplementing the missing values (pixels with no returns) with interpolated heights obtained using the inverse distance weighted algorithm. This eliminated a large number of points that penetrated through the crown while otherwise preserving the original value of the DSMs. All interpolations were carried out using ArcGIS v. 8.3 routines. Both the 1998 and 2003 DSMs were transformed into canopy height models (CHMs) by subtracting the corresponding elevations of the merged DTM. Point CHMs (*XYH*, where *H* is canopy height) were created by subtracting the underlying DTM elevation from the *Z* value of individual *XYZ* returns.

3.3 Detecting new gaps

In the study area, it was noted that tree fall may result largely from strong winds during violent thunderstorms, snapping under the weight of snow, and beaver activity (Daniel Kneeshaw, personal communication). Thus, new gaps resulting from tree fall should indicate large elevation differences between the CHMs of 1998 and 2003. We define a new gap as an opening in the canopy caused by the fall of a single or of a small group of trees of a certain height during the study period. To automatically identify the new gaps in a grid environment, a new gap function $G(x,y)$ is defined as a set of all cells that satisfied the following arbitrary criteria:

$$G(x,y) = \begin{cases} 1 & \text{if } CHM98(x,y) \geq 10\,\text{m AND } CHM03(x,y) < 10\,\text{m} \\ 0 & \text{otherwise} \end{cases}$$

where $CHM98(x,y)$ and $CHM03(x,y)$ are respectively the lidar height of the forest cover in 1998 and 2003. A region growing algorithm was then applied to the resulting binary grid to identify individual patches of non null $G(x,y)$ adjacent pixels. Patches having an area less than 5 m^2 were eliminated under the hypothesis that they were due to chance occurrence of spurious low returns. Finally, only patches having a minimum of 3 hits in 1998 were considered for a reasonable representation and meaningful comparison with high density data of 2003. A window of 250m X 290m, were significant changes were appeared was tested for delineating the new gaps. All the accepted non null $G(x,y)$ patches identified in this window were further verified for tree falls by visually comparing the high resolution images of 1997 and 2003-04. To quantify the accuracy of gap identification, a systematic grid of 94 sampling points was overlaid onto the test window and each point was visually inspected on the registered high resolution images for probable gap occurrence. Commission and omission errors are reported in a confusion matrix.

3.4 Assessing growth

The height growth of trees corresponds to the vertical elongation of crown tips over time. Repeated measurements of individual tree height are traditionally used to measure tree growth. In Yu et al., 2004, a method for measuring this elongation was applied which can only be employed if the probability of lidar pulses hitting at or near the tip of any tree is high, i.e. if the return density is very high. Such lidar coverages are however rare, and the cost to cover large forested areas on a regular basis at such a density are presently prohibitive. As the lidar coverages considered in this study are of a lesser density, it was necessary to use all the returns falling on crowns to assess height growth, as many tree tips may be missed. This, however, brings the problem of translating canopy height increase into average tree height increase. Conifer trees grow by elongating their tips vertically, and by elongating existing branches horizontally, while the crowns of the most common hardwood species found in the study area grow like expanding ellipsoids or semi-ellipsoids. In the hardwood and softwood cases, points falling on the crown in 1998 will be slightly higher in 2003 if significant growth occurred, while points that have hit on low surfaces near the crown periphery in 1998 will be much higher as the result of hitting on the crown in 2003 due to lateral growth. Based on age-height tables (Pothier and Savard 1998), it is expected that smaller, and presumably younger, trees grow faster than higher, older ones. The following three experiments were carried out to assess the feasibility and better define the problem of measuring small amount of growth using multitemporal lidar data characterized by different densities.

3.4.1 Manually delineated crowns: Eighteen individual crowns of hardwood trees (trembling aspen) were delineated manually using the CHM grid of 2003. These were discriminated from other species based on the hue of the QuickBird pan-sharpened multispectral image. Manual delineation insured that lidar returns from single crowns could be isolated with certainty. An inner buffer of 0.5m was automatically created from the delineated outline to discard lidar hits falling on the irregular periphery of the crown and to isolate vertical growth. The difference in the maximum and mean heights between the 1998 and 2003 *XYH* points falling within the inner crown (inside of the buffer) were compared to the expected height growth of trembling aspen for the prevailing site index and density found in the study sector using the age-height tables (Pothier and Savard, 1998). The maximum height of the 2003 lidar *XYH* point cloud within each inner crown was used as a proxy for tree height in 2003. The height closest to this one in the age-height table was identified, and the height increase in the last five years was read from the table. The correlation between the observed and expected height increases, as well as between the logarithm of the maximum lidar height and growth, were calculated. The logarithm of tree height was used to linearize the relationships with growth.

3.4.2 Object-oriented crown delineation: As a first attempt to automate the abovementioned procedure, we used image segmentation methods in eCognition v3.0 to extract individual tree crowns on the 2003 grid CHM. Segmentation was done with height as the “theme” using the following parameters: scale=5, homogeneity criterion=0.7, shape=0.3, smoothness=0.5 and compactness=0.5. Subsequently, these segments were classified within eCognition based on the “mean” object feature in height classes 5-10 m (low), 10-15 m (medium), and >15 m (high), and two broad species classes: hardwood and conifers. This delineation was performed twice: once for a hardwood stand, and once for a softwood stand. The vector segments were later buffered inside by 0.5 m and the lidar *XYH* points of both years falling within the inside buffer were analysed as in 3.4.1. Only the polygons which had at least two lidar points were considered for analysis. For each height-species class, the average height changes were calculated for the maxima and mean lidar heights between 1998 and 2003. Again, the results were compared to expected growth values.

3.4.3 Window based: Overall height increases, i.e. those resulting from vertical and lateral growth, were also studied. The maximum, mean, 90^{th} and 95^{th} percentile lidar height differences of all lidar points (Z) falling within 20 x 20 m plots were compared between 1998 and 2003. The use of percentiles is justified by their effectiveness in predicting the height of stands or plots (Magnussen and Boudewyn, 1998, Naesset 2002). Five plots each corresponding to the low, medium, and high classes of hardwoods, and low and medium height classes of conifers were compared to expected values.

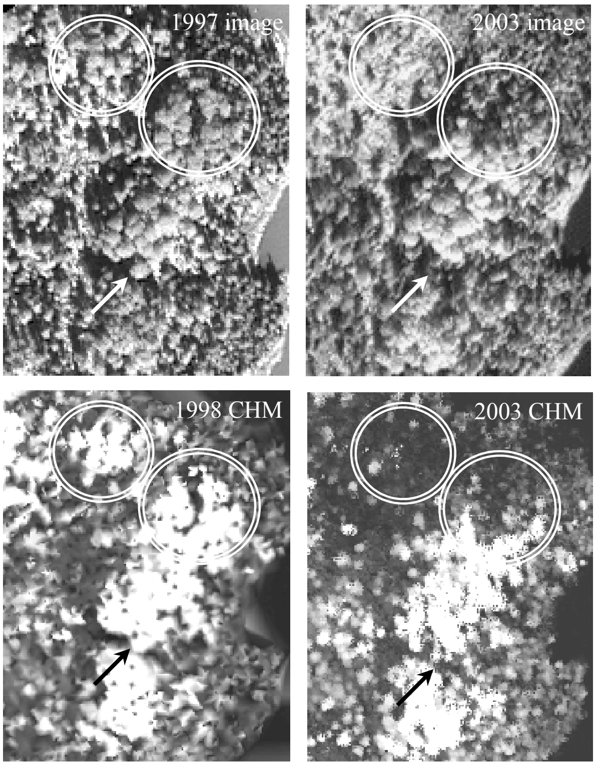

Figure 1. New single-tree (arrow) and multi-tree (circle) gaps between 1998 and 2003 identified on the high resolution images and lidar CHMs.

4. RESULTS AND DISCUSSION

4.1 Detecting new gaps

Examples of the appearance of new single- and multi-tree gaps is illustrated in figure 1. Inside the 6.8 ha study site, 88 new gaps with a minimum size of 0.5 m^2 were identified. The largest gap covered 0.17 ha and the mean gap size was of 79.4 m^2. Gap size distribution is negative exponential with nearly 62% of the gaps being single-tree falls. The total new gap area is 0.71ha, which is about 10.4% of the highly disturbed study site with 2.08% annual rate of new gap opening. Large gaps of size 1,721 m^2, 1,743 m^2 and 798 m^2 were seen within 20-30m of the lake shore in the northern part of the site, perhaps a result of severe wind storms. A large number of gaps were also seen in the neighbourhood of the existing large openings, verifying that new gaps are more likely to occur adjacent to pre-existing gaps. The accuracy of the identification of new gaps was high at 96% when compared visually with the registered images of Ikonos/Quickbird and Videography (Table 2). User’s and producer’s accuracies were very similar, and omission and commission errors of gaps were 2% and 8% respectively.

		High resolution images (reference)			
		NO-GAP	GAP	TOTAL	USER’S ACC.
LIDAR	NO-GAP	56	1	57	98%
	GAP	3	34	37	92%
	TOTAL	59	35	94	
	PROD.’S ACC.	95%	97%		OVERALL 96%

Table 2. New gap error matrix

4.2 Growth assessment

4.2.1 Manually delineated crowns: The statistics relative to the 18 manually delineated crowns of various heights are presented in Table 3. Lidar estimated height growth is rather variable between trees, but the general trend indicates that presumably younger trees have a faster growth rate than older ones, as is expected. The mean difference, and mean absolute difference (deviation), between the maximum lidar height increase and the corresponding age-height table value are respectively 0.42 m, and 1.09 m. These values decrease to –0.08 m and 0.67 m when the two first cases are removed. These two undoubtedly erroneous height growth values (5.42 and 7.42 m) probably result from a poor evaluation of height in 1998 due to the low density of returns. The correlation between the maximum, and mean height of tree crowns in 1998 and 2003, on the one hand, and, on the other hand, the lidar maximum, lidar mean, and expected growth is given in table 4. The highest correlations are seen between $\log H_{max98}$, $\log H_{max98}$, dH_{max}, and dH_{mean}. All correlations are highly significant. Correlations are notably lower for the 2003 height values. The relationship between dH_{max} and dH_{table} is significant at $\alpha = 0.1$ while the one between dH_{max} and dH_{table} is not. A two-sided test revealed that the two correlations are not statistically different. The fact that expected values come from a table in which heights are given for 5 year increments reduces the variance of dH_{table} and may cause the correlation to be lower than if actual field growth measurements had been used. All these results suggest that growth over five years could be measured with lidar. The accuracy however still needs to be assessed thoroughly.

4.2.2. Object-oriented crown delineation: Figure 2 shows an example of the eCognition individual crown segments automatically extracted from the 2003 lidar grid CHM. The resulting objects represented individual crowns in the majority of cases. Conifers corresponding to only the low and medium height classes could be found. In the case of the hardwoods, the expected growth trend is reversed: higher trees appear to grow faster than larger trees (Table 5). Both the maximum and mean height differences have the same behaviour. In the case of the softwoods, the expected trend is observed, and the growth values obtained from lidar are close to those given in the age-height tables. It should be noted that these results were pooled per height class, and not by individual segments.

H_{max03}	dH_{max}	dH_{mean}	dH_{table}
11.89	5.42	4.54	2
14.11	7.49	3.77	2
10.63	1.58	0.73	2
12.23	2.72	0.97	2
12.75	2.9	1.9	2
14.74	2	1.35	2
15.24	0.88	0.94	2
15.79	1.38	1.75	1.7
16.23	1.78	1.13	1.7
14.4	0.37	-0.21	2
15.86	1.11	1.54	1.7
18.99	1.89	2.86	1.3
16.54	0.05	0.06	1.7
24.17	1.6	1.75	0.5
23.62	0.63	0.87	0.6
25.1	1	0.54	0.4
24.88	1	1.1	0.4
25.15	0.09	-2.44	0.4

Table 3. Height changes of individual crowns between 1998 and 2003. H_{max03}: maximum lidar height in 2003, dH_{max}: difference in the maximum lidar heights, dH_{mean}: difference in the mean lidar heights, and dH_{table}: expected difference from the age-height tables.

	dH_{max}	dH_{mean}
$\log H_{max03}$	-0.46 (p=0.053)	-0.39 (p=0.113)
$\log H_{mean03}$	-0.59 (p=0.010)	-0.43 (p=0.074)
$\log H_{max98}$	-0.78 (p=0.000)	-0.62 (p=0.006)
$\log H_{mean98}$	-0.79 (p=0.000)	-0.66 (p=0.003)
dH_{table}	0.41 (p=0.088)	0.37 (p=0.127)

Table 4. Correlation coefficient (and p values) for the logarithm of maximum and mean height in 1998 and 2003 ($\log H_{max03}$, $\log H_{mean03}$, $\log H_{max98}$, $\log H_{mean98}$), maximum and mean height differences, and expected height increase (dH_{table}).

4.2.3. Window based: The differences in maximum, mean, 90[th] and 95[th] between 1998 and 2003 inside 400 m^2 windows are shown in Table 6. For hardwoods, both dH_{max} and dH_{95} behave as expected. Variation in the other difference statistics are rather erratic. Height increases are close to the age-height table values (average deviation of 0.42 m). Trends in the hardwoods are contrary to expectations for difference statistics. Observed growth values are however still close to the expected ones.

5. CONCLUSION

Automated delineation of the new individual gaps has been straightforward, as expected. The detection accuracy has been very high as the changes in the study sector have generated height differences larger than the possible lidar elevation errors. The results are similar and comparable to those reported in Yu et al. (2004) for the harvested trees. Mean gap size, gap density and rate of gap openings have been in accordance with the reported statistics for the boreal forests (Pham et al., 2004). The study suggests that lidar is an excellent tool to map gaps and estimate gap characteristics.

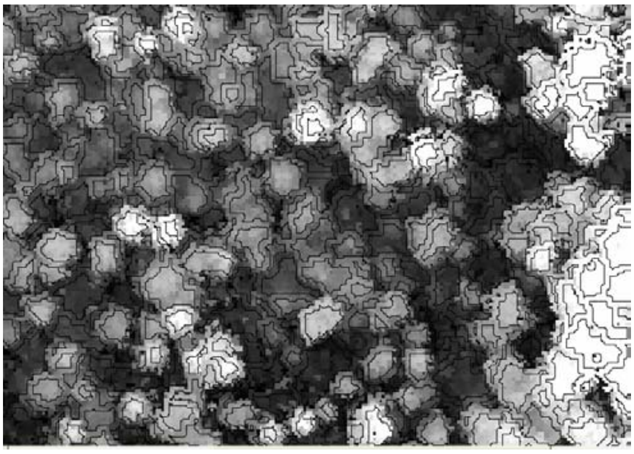

Figure 2. Sub-image of the 2003 lidar grid CHM with overlaid eCognition segments.

	Hardwoods			Softwoods	
	Low	Med	High	Low	Med
H_{max03}	10	15.6	21.3	13	14.5
dH_{max}	0.08	0.38	1.39	1.64	0.78
dH_{mean}	0.3	0.68	1.44	1.09	0.62
dH_{table}	2	1.7	1	1.6	1.4

Table 5. Summary of the object-oriented crowns for low, medium and high trees (see table 3 for symbols).

	Hardwoods			Softwoods	
	Low	Med	High	Low	Med
H_{max03}	16.1	17.2	30.2	11	16.2
dH_{max}	3.36	1.31	0.47	0.13	0.82
dH_{mean}	0.74	0.2	0.69	0.04	0.57
dH_{90}	0.21	0.42	0.35	0.03	0.87
dH_{95}	1.55	0.7	0.41	0.02	0.95
	1.7	1.5	0.1	1.4	1.1

Table 6. Summary of the window based growth analysis statistics, including difference between the heights at the 90[th] and 95[th] percentiles, respectively dH_{90} and dH_{95} (see table 3 and 5 for other symbols).

Growth was evaluated on manually delineated individual crowns, on automatically delineated crowns, and for all the returns inside 400 m^2 windows. Results in the case of the manually delineated crowns show that multi-temporal lidar offers a high potential for estimating growth on an individual tree basis as observed values were in general close to the expected ones, even if the density was rather low in 1998. The automated delineation of crowns on the 2003 lidar CHM were highly satisfactory, however, the trend in average growth by broad height class (low, medium, high trees) were not conclusive. Nonetheless, the general growth rate corresponded well to what is expected within five growing seasons. Finally, average growth computed for $400m^2$ plots behaved as expected for hardwoods, but not for softwoods. All statistics, i.e. mean, maximum, height at the 90^{th} and 95^{th} percentile showed the same trend. In general, results show that multitemporal medium density lidar enables the detection of new gaps with a very high accuracy, and can potentially be used to measure growth on an individual crown, or window basis. A number of issues however need to resolved to improve estimation of growth: a more robust estimation of tree height based on lower density data, unmixing the effects of vertical and lateral growth, and automation of measurements. Future work building on this initial study will compare field measurement of growth to observed lidar values, and will recourse to geometrical tree models to better predict individual heights.

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