B-51. 1. 5 Biomass Estimates for Temperate and Boreal Forest Regions

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ABSTRACT: This paper presents a new remote sensing method using airborne laser altimetry (ALA), which enables expeditious forest survey over extensive areas. The ALA provides vertical canopy profile of ground vegetation at an interval of a few centimeters horizontally along the flight track, and its analysis yields vital statistics characterizing forest stands. In the present study, the ALA was used to survey the stand stocking along a 600 km long transect extending from central Alberta to northern Saskatchewan, Canada. Ground survey was also conducted along the transect for standing stock of 14 sample plots representing typical forest types encountered in the area, i.e. young, mature and senescent even-aged stands of *Pinus banksiana*, *Populus tremuloides*, *Picea glauca* and *P. mariana* all regenerated after fire. The area under the laser-based canopy profile correlated well with stand volume derived from the ground survey ($r = +0.937$). Thus, using the regression of the latter upon the former, stand stocking was estimated along the full length of the transect. The results showed a distinctive transition from the prairie (aspen parkland) to boreal forest at 140-km point north of Edmonton. It also showed the biomass distribution of boreal forest along the transect with a definite peak of maximum timber stocking.

1. INTRODUCTION

What makes today's forest management different from what it was yesterday is global deforestation and global warming. The most effective tool against these two impending threats to the forest of the world is the methodology for speedy yet accurate forest inventory over an extensive area to make quick managerial decisions possible. Precise information on the state of timber resources constitutes the very basis of proper forest management. Timber cruising is therefore important though the ground survey is time-consuming, laborious and even dangerous. Airphotos and satellite imagery can substitute ground survey to a certain extent, but photo interpretation is equally laborious in the former, while cover classification and especially volume estimation is still problematic in the latter.

2. Research Objection

In this paper, we present airborne laser altimetry (ALA) as an example of a new versatile technology for forest inventory. We used the ALA technology in surveying a 600km long transect in Northern Canada in the summer of 1997 with the ultimate aim of using the results as baseline data or control for possible forest stocking/vegetation change expected in not so distant future due to global warming. In the present study, focus was placed on the use of ALA-generated data set to estimate stand stocking along the entire flight course. A comparison between the laser generated vegetation profile and ground survey-generated stand stocking revealed a significant correlation between them. Thus using the regression of the latter upon the former, stand stocking was estimated for the whole 600km transect. The study showed that accurate forest inventory with ALA over an extensive area is very promising.

3. Research Method

3.1 Study site

The laser profiling transect covering a total distance of nearly 600 km (571 km to be exact) began in Edmonton, Alberta extending north to Cluff Lake, Saskatchewan via Wandering River and Fort McMurray (Fig. 1). This area was selected because of the presence of large tracts of boreal forest, ready availability of airborne laser altimetry system and good ground accessibility for ground truthing.

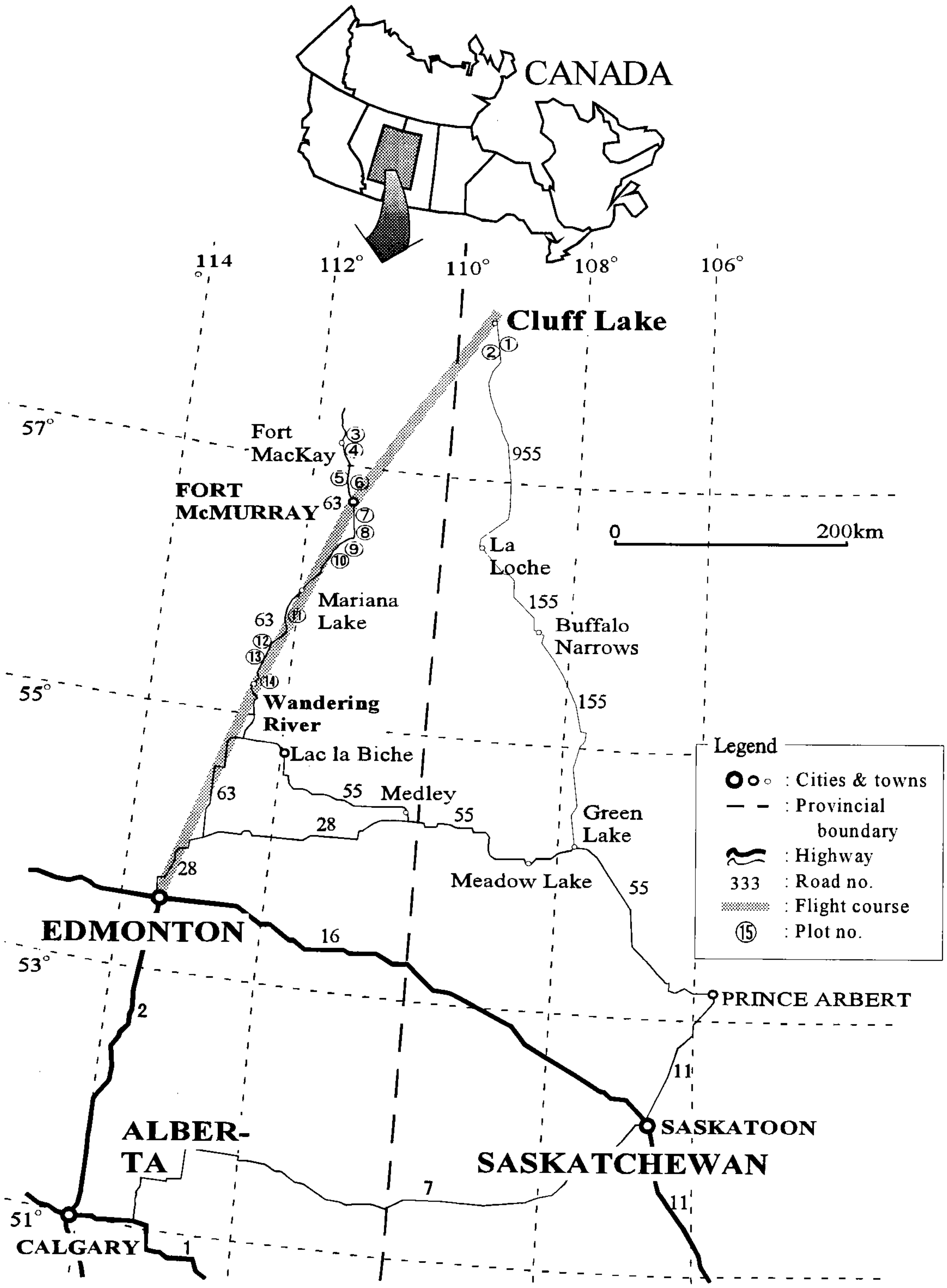

Fig. 1: Study site with laser profiling course and sample plots

The transect covered two major biomes, i.e. prairie and boreal forest, but the former here is more properly called the aspen parkland, which constitute an ecotone between the prairie proper and boreal forest, and is characterized by open grassland-turned farmland alternating with groves of trees (usually aspen). The aspen parkland stretches out north up to Wandering River, thence replaced by the boreal forest.

The boreal forest is characterized by patches of even-aged stands of jack pine (*Pinus banksiana*), aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and black spruce (*Picea mariana*), all regenerated after fire. Seemingly the regenerating species at a given site depends on availability of seeds and soil moisture. Jack pine and black spruce respectively predominate on dry sandy sites and wet boggy sites, while aspen and white spruce regenerate in mesic sites, either simultaneously or the latter following the former, often resulting in a two layered stands with the fast-growing aspen occupying the canopy layer. However, white spruce outlives aspen, and gradually and eventually dominates the stand. Thus in the selection of sample plots on the ground, ten different types of forest stands were distinguished by species and passage of time after fire as in Fig. 2. This classification is rather simplistic, but should suffice for the present aim of choosing representative stands in the area.

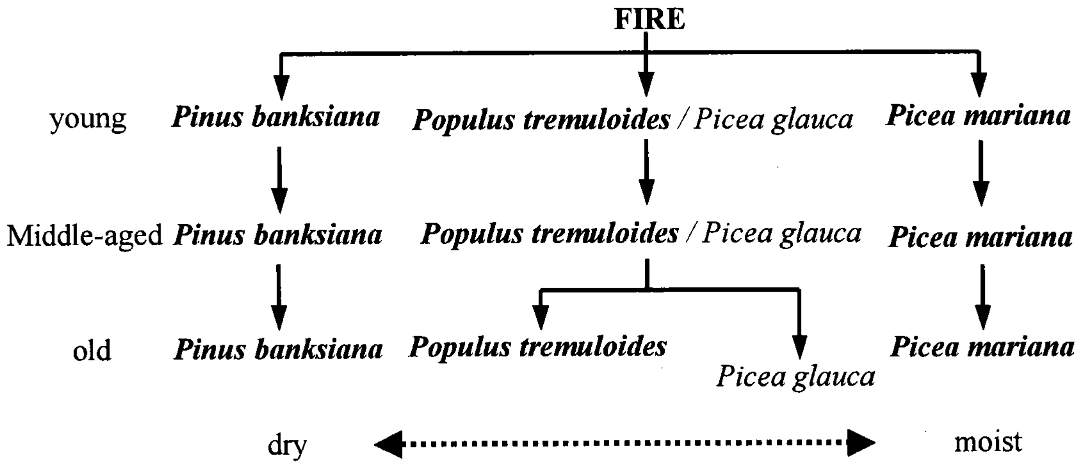

Fig. 2: Types of forest stand distinguished in selection of sample plots

3.2 The airborne laser altimetry system

The components of the airborne laser altimetry (ALA) system are shown in Fig. 3. It consists of an infrared laser altimeter, a differential global positioning system (GPS) and a video camera. The infrared laser altimeter is an instrument which emits laser pulse and measures the clearance between the aircraft and whatever the object reflecting the laser beam from directly below at as high a frequency as 20,000 Hz. This frequency translates to horizontal measurement interval of as close as 1 cm along the flight track. When combined with the aircraft's three-dimensional flight track, monitored and recorded with a differential global positioning system, the continuous series of altimetry data results in surface profile of the ground and then subsequently the vegetation profile as well. Further analysis of the vegetation profile yields vital statistics characterizing forest stands. For example, Fourier analysis of the canopy profile yields power spectrum in which one of the power maxima corresponds with mean crown diameter of trees. It can then be correlated with DBH and stem density, and thus stand volume. With increasing stand height and stem density, both stand stocking and the area under the canopy profile increase, signifying a regression of the latter upon the former.

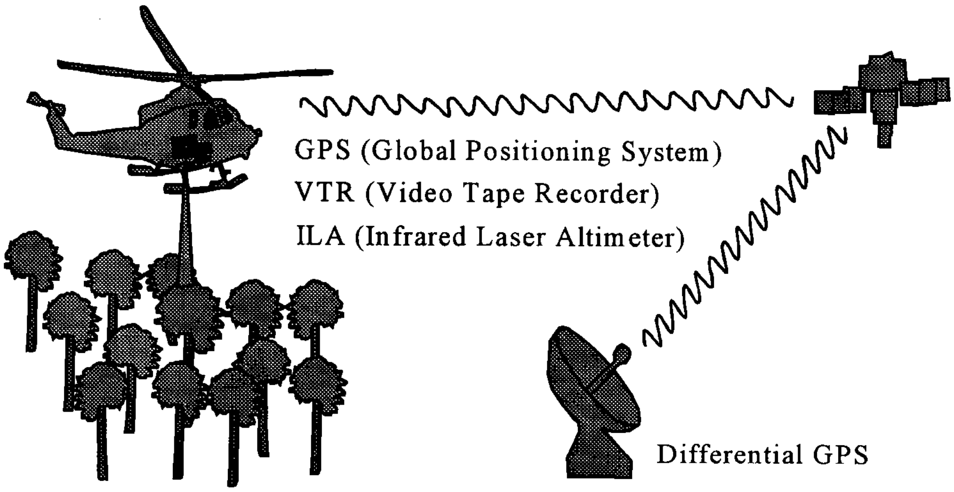

Fig. 3: Airborne Laser Altimetry (ALA) system

In this study, the aircraft was flown at a speed of 140 km/h with a laser pulse emission frequency of 2000 Hz, resulting in a mean horizontal interval of 1.9cm. However due to the share amount of the data that defies even the capacity of electronic recording device, only the minimum, maximum and second maximum clearances between the ground object were taken of every 25 consecutive measurements (about 50 cm).

An ALA-equipped aircraft can cover long distances in a short time. Furthermore, ALA can obtain precise and continuous information on vegetation height, and these numerical altimetry data render themselves to automated mathematical processing with computers. These make ALA a relatively superb tool in timber cruising as compared with other forest surveying methodologies (Table 1).

Tab. 1: General comparison among forest survey methodologies

	Individual Tree Information	Tree Height	Coverage	Data Retrieval	Data Processing	Cover Classification
Ground Survey	◎	△	×	×	△	×
Aerial Photogrametry	○	△	○	○	×	◎
Satelite Imagery	×	×	◎	◎	◎	○
Laser Altimetry	○	◎	○	◎	◎	△

◎ ○ △ ×
superior ◄———► inferior

3.3 Vegetation profile generation

The process of generating the vegetation profile is shown in Fig. 4. By subtracting the laser-measured clearance from the GPS-monitored navigation altitude of the aircraft (a), a surface profile (b) is obtained. It consists partly of vegetation canopy and partly of topographic surface. The continuous topographic surface is obtained by interpolating these patchy pieces of topographic profile (c). Then subtracting the topographic profile from the original surface profile, the vegetation profile (d) is generated, which serves as the basic data for subsequent analysis for more relevant information on trees and forests.

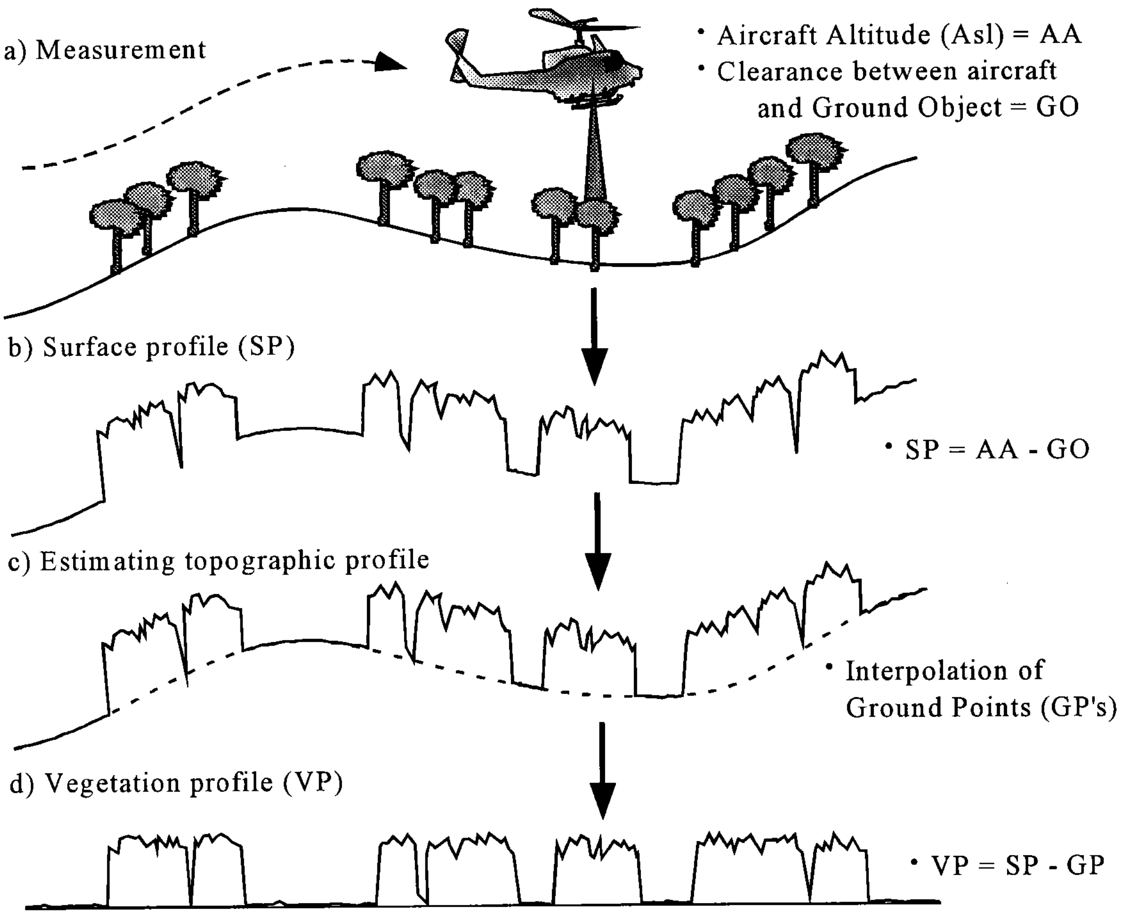

Fig. 4: Vegetation profile derivation process

3.4 Stand stocking estimation

In the present analysis, stand stocking estimation was based on the premise that the area under the canopy profile is proportional to stand volume. Ground survey was conducted to confirm the correlation between the actual stand stocking and the vegetation profile, as well as to establish the regression of the former upon the latter. However, due to some operational difficulties, the ground survey had to precede the laser profiling flight in reality. Thus, instead, the correspondence between them was taken rather loosely by choosing the segment of laser profile that covers the same stretch of stand in which the sample plot was located.

On the ground, a total of 14 forest stands, each representing either one of the 10 type of forests distinguished in Fig. 2, were located along the flight course and surveyed for stand stocking (Fig. 1). The stand stocking was evaluated using the sample plot method or the Bitterlich method or both. The former is expected to provide with accurate estimate of stand volume but is laborious and time consuming, whereas the latter is fast but could be less accurate. Therefore, both the methods were used in nine stands to establish regression between them, which subsequently was applied to correct volume estimates for three stands obtained solely by the Bitterlich methods. For the remaining two stands, stocking was obtained by the sample plot method alone.

In the sample plot method, a square plot with the lengths of the sides approximately equal the mean tree height was used. In each plot the stem diameter at breast height (DBH) was censused, and then was converted to stem volume using a volume equation, which was constructed for each species involved from an aggregate of sample trees consisting of four samples, i.e. one large, two mid-sized and one small stems from each plot surveyed. The stem volume of the sample trees was evaluated by dissecting them into logs. Depending upon the size of tree, stem diameter of the sample trees was measured at 7 to 23 locations along the stem and log volume was evaluated using the Smalian formula except for the apex portion where conic formula was used.

In the Bitterlich method, the stand volume is evaluated as a product of basal area G, stand height H and form factor F. In the field measurement, basal area was measured with a Spiegel Relascope at six to ten locations randomly chosen within the stand, and stand height was represented by the mean height of four to six sample trees of apparently average size. The stand form factor F was obtained from the sample trees felled in the sample plot method. More specifically, stem form factor obtained according to

$$v = fgh$$

for each sample tree was plotted against tree height to determine the parameters a and b of the height-form factor relationship

$$f = ah^b$$

for each species involved. Then these parameters were directly substituted in

$$F = aH^b$$

, which yields stand form factor for any given stand height.

4. Result

4.1 Vegetation profile

The vegetation profile of the entire flight course is shown in Fig. 5. A detailed examination of the profile revealed distinctive patterns representing aspen parkland (Fig. 6), recent burn in boreal forest (Fig. 7) and green boreal forest (Fig. 8). From the profile, the extent of each of these vegetative cover types along the flight course could readily be determined. The aspen parkland extending from Edmonton to Wandering River covered about 23% (140 km) of the entire transect. Thence, it turns into boreal forest, with two stretches of broken profile similar to that of the aspen parkland appearing at 270-310 km and beyond 500-km point from Edmonton. The former is a large stretch of recent burn with sporadic appearance of small groves of forests left unburned, while the latter is a swampy area with scattered appearance of more or less open groves. In both cases, the scattered appearance of small patches of forests makes their profile look like that of the aspen parkland. On the other hand, the green boreal forest is characterized by unbroken profile representing continuous canopy structure.

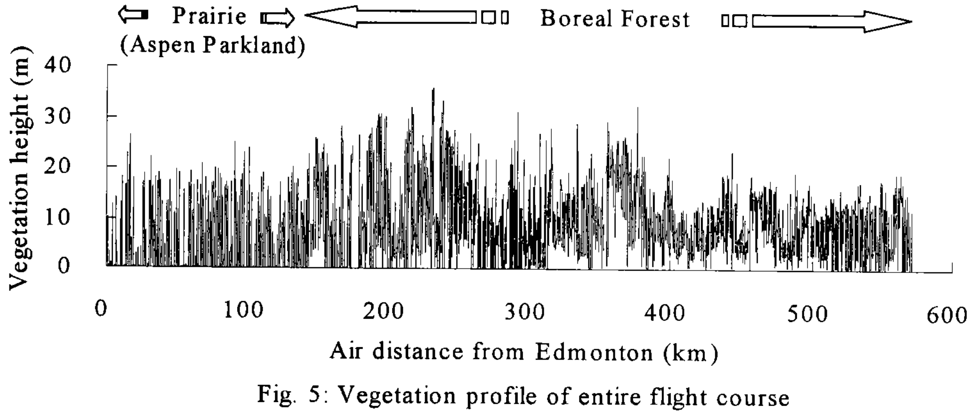

Fig. 5: Vegetation profile of entire flight course

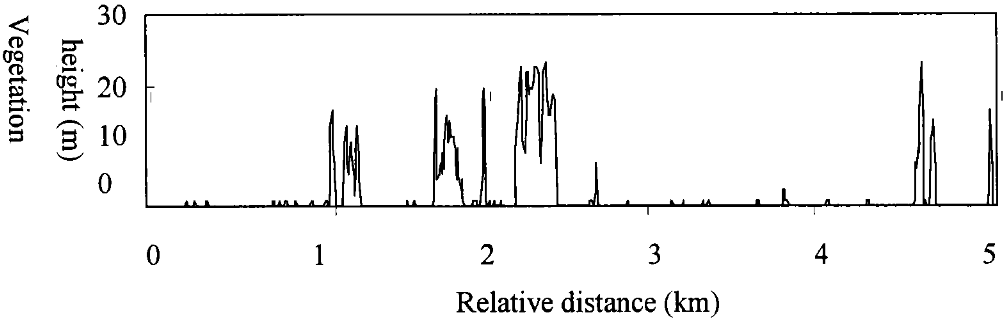

Fig. 6: Typical view (above) and vegetation profile (below) of aspen parkland

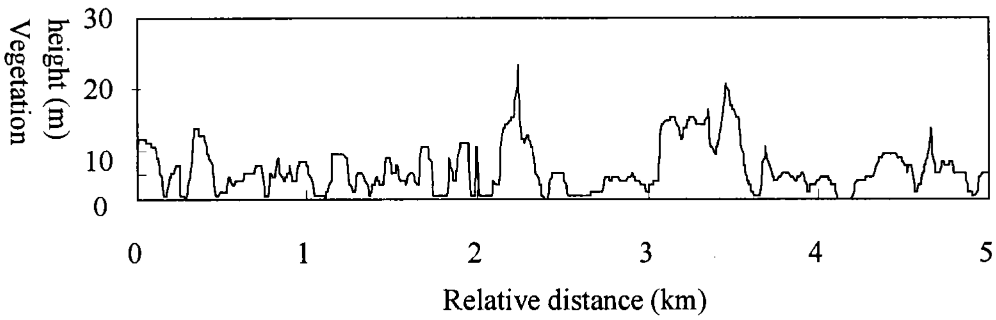

Fig. 7: Typical view (above) and vegetation profile (bolow) of burn

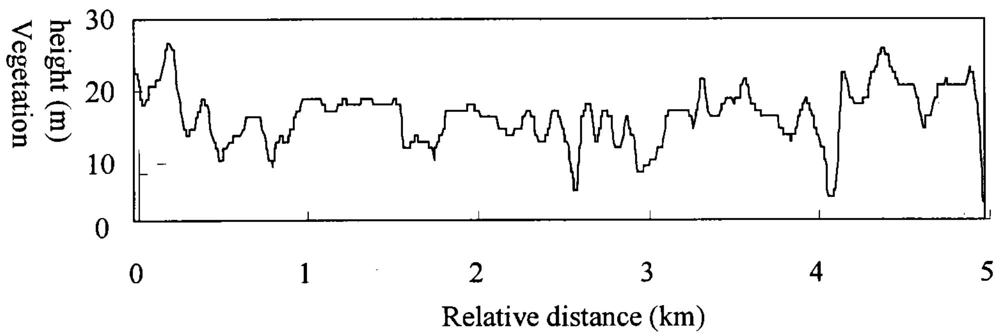

Fig. 8: Typical view (above) and vegetation profile (below) of green bor forest

4.2 Stand stocking

The stand characteristics determined by the ground survey are shown in Table 2. As expected, the stand volume derived from ground survey correlated well with the area under the canopy profile. Accordingly, the stand stocking along the full length of the 600 km long flight track was estimated using the regression of the stand volume upon the area under the vegetation profile shown in Fig. 9. In this figure, unit stand volume V (m^3/ha) is plotted against profile area S per 100 m of flight line. To represent the regression, an equation of the form

$$V = aS^{1.5}$$

, in which the profile area is raised to the power of 1.5 was used to be dimensionally consistent.

Using this regression, the stand stocking all along the full transect was estimated and shown in Fig. 10. In so estimating the stand stocking, the unit profile area S was calculated by integrating the vegetation profile over one kilometer, and then converting it to area per 100 m to suppress the random variation in canopy profile. As a result, the transition from the aspen parkland to the boreal forest appears more distinctively in Fig. 10 than in Fig. 5 of the vegetation profile itself.

Tab. 2: Sample stand characteristics as measured on the ground

Plot No.	Canopy layer	Species *1	Stand age	Survey Method *2 Plot	Bit.	Mean DBH (cm)	Stand Density (trees/ha)	Mean Tree Height (m)	Basal Area *3 (m^2/ha)	Stand Volume *4 (m^3/ha)
1		Pb	Middle	O	O	6.3	2244	8.46	7.88	41.6
2		Pb	Old	O	O	12.5	936	9.64	12.35	81.2
3	upper	Pt	Middle	O	O	10.3	1844	14.15	16.19	98.5
	lower	Pg		O	O	6.9	1721	5.52	8.00	35.1
4		Pb	Middle	O	O	13.2	1161	14.26	17.62	119.3
5		Pm	Middle	O	O	4.5	8843	8.24	21.01	138.7
6		Pg	Old		O			26.62	45.56	565.8
7		Pt	Middle	O	O	11.6	3140	21.67	37.55	379.5
8		Pm	Young	O	O		22752	1.51	1.75	5.3
9		Pt	Old	O	O	7.4	5350	25.20	54.62	690.9
10		Pg	Old	O	O	21.0	1053	24.21	43.34	304.1
11		Pm	Old		O			13.99	41.31	298.5
12		Pb	Young	O		2.0	53191		18.87	65.2
13		Pt	Young	O		2.1	32663		12.96	58.4
14	upper	Pt	Middle		O			23.00	36.00	413.6
	lower	Pg			O			9.89	1.33	7.9

*1 Pb : *Pinus banksiana*, Pt : *Populus tremuloides*, Pg : *Picea glauca*, Pm : *Picea mariana*
*2 Plot : Sample Plot Method, Bit. : Bitterlich Method
*3 Arithmetical sum of individual free basal areas as calculated from DBH whenever the sample plot method was used.
*4 Stand volume is given by canopy layer for plots 3 and 14.

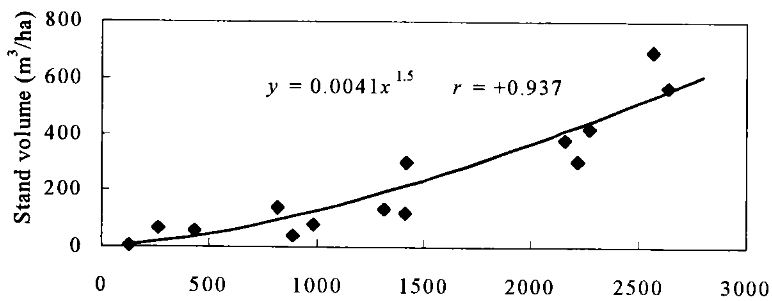

Fig. 9: Correlation between ground survey-generated stand volume and laser-generated canopy profile area

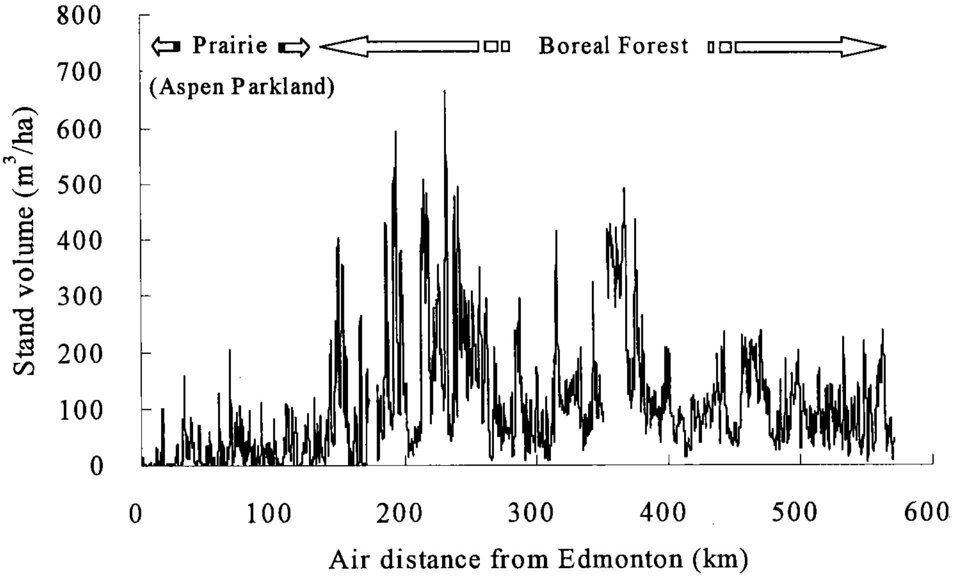

Fig. 10: Estimated stand stocking along flight course

5. CONCLUSION

This study has shown that laser-generated vegetation profile is well correlated with stand stocking and thus, with the use of ALA, stand stocking over extensive forest areas could be obtained faster and with greater accuracy. The present study was only limited to the use of laser-generated vegetative profile area to estimate stand stocking. It would be necessary to extract more stand information from vegetation profile through, for example, Fourier analysis. Another area that needs further work would be the expansion of linear information to two-dimensional information with the use of other remotely sensed data e.g. satellite images, etc.