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ACCURACY ANALYSIS OF PAIRED LARGE-SCALE PHOTO SAMPLE PLOTS

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INTRODUCTION

The remeasurement of a large-scale photo (LSP) sample plot in the field is called a "paired plot". The purpose of the paired measurement is primarily: 1) to check the accuracy of tree species identification and classification on the photos, 2) to evaluate the accuracy of tree height measurements, 3) to develop models to estimate diameter at breast height (DBH) from tree height and crown area and 4) to assess the reliability of volume estimates.

This note is one of a series completed for the NODA project entitled "Enhancing Ontario's Forest Resource Inventory with Stand Structure and Forest Ecosystem Vegetation Types using Large-scale Aerial Photographs". These technical notes summarize the results of studies on the survey of dead standing and fallen trees, the estimation of DBH from LSP tree measurements, the estimation of growth rates using LSP data and a paired comparison between LSP measurements of trees and their field counterpart. Details concerning methods, procedures, results and conclusions are documented in a comprehensive project report (Dendron, 1995).

This technical note concentrates on the accuracy assessment of the LSP methodology, summarizing, specifically, the accuracy of species identification, tree height measurement and volume estimation.

SAMPLE SELECTION

The LSP photos acquired during the project covered a wide range of FRI stand characteristics, including working groups, ages, site index classes and stocking levels. Four common, 80-100 year-old stands in spruce (*Picea* spp.), pine (*Pinus* spp.), white birch (*Betula papyrifera* Marsh.) and poplar (*Populus* spp.) working groups were chosen for the analysis. Twenty-one LSP plots containing about 700 trees in total were used in the study.

DATA COLLECTION

A large-scale photo model is described and illustrated in the main project report (Dendron 1995). The sample plot illustrated in Figure 1 is normally rectangular in shape and about 175 m^2 in size. The exact area of each plot is measured and recorded during the LSP plot measurement process.

Using the tracking photos at a scale of about 1:5 000 and FRI photos and maps, the 21 plots were located in the field. Having located the plots in the field, the 1:1 200 LSP was used to identify live trees, dead standing trees, and dead material on the ground. Trees 7 m and taller and fallen material 5 cm in diameter and larger at the smallest end were numbered and measured on the plot, as shown in Figure 1. The observations included tree species, condition (dead or alive), DBH of all trees, and the total height measurement of selected trees. No tree volume assessments nor other destructive sampling were carried out in this project.

The LSP and field data were entered into data bases and the data sets were merged into a single file for analysis purposes.

ANALYSIS RESULTS

Using the field data as the standard, the LSP interpretation and measurements were analyzed according to a paired comparison design. This included the use of correlation matrices to handle discrete data, such as species codes, and the statistical analysis of differences between the photo and field measurements for each tree. The analysis reveals both systematic errors or trends and random variation from tree to tree.

1. Photo interpretation

The analysis not only assessed how accurately live trees were recognized and classified by the photo interpreter, but also the incidence of missed trees (omissions) and the inclusion of trees on LSP that should not have been because they were outside the plot boundaries, too small, or otherwise imagined (commissions). The confusion between live and dead standing trees was also investigated.

The analysis was carried out using a correlation matrix, sometimes called a confusion chart. Table 1 is such a matrix. It shows frequency of trees correctly identified along the diagonal. Off diagonal entries express incidence of confusion among species of live trees or between live and dead trees. Omissions pertain to trees (live, dead standing, or fallen), which were not identified and numbered on the LSP plot. Commission error refers to trees that were numbered on the LSP when they should not have been, either because they were outside the plot boundaries or below a size threshold.

The four stands referred to earlier—spruce, pine, birch and poplar—were analyzed individually. Table 1, based on an aggregation of the four stands, provides an overall picture of the photo interpretation accuracy. Briefly, it reveals that only three percent of live trees in the data set were omitted, and that no trees were subject to commission error. Of the live trees not subject to omission error, 100 percent were correctly identified. The interpreter thus missed very few borderline live trees, and was extremely accurate in the interpretation of live trees that were not omitted.

Table 1. Correlation matrix showing the relationship between species interpretation on LSP and field observations.

	Photo interpretation from LSP										
Field	S	F	P	L	C	A	B	D	R	Om	Total
S	120	---	---	---	---	---	---	---	---	6	126
F	---	16	---	---	---	---	---	---	---	---	16
P	---	---	126	---	---	---	---	---	---	3	129
L	---	---	---	---	---	---	---	---	---	---	---
C	---	---	---	---	---	---	---	---	---	---	---
A	---	---	---	---	---	30	---	---	---	---	30
B	---	---	---	---	---	---	70	---	---	3	73
D	---	---	---	---	---	---	---	50	3	92	145
R	---	---	---	---	---	---	---	1	69	113	183
Co	---	---	---	---	---	---	---	---	---	---	---
Total	120	16	126	---	---	30	70	51	72	217	702

S to B: Species codes; D: Dead standing; R: Dead fallen Co: Commissions; Om: Omissions

A high proportion of dead standing and fallen trees, however, was omitted (63 percent) and a small amount of confusion between standing and fallen material was evident (3 percent). The confusion arose from the difficulty of deciding when a leaning dead tree is considered to be flat on the ground.

The dead material was missed mainly because of the dense stand canopies that obscured a view of the dead standing trees in the stands and especially fallen material beneath them. In earlier surveys based on LSP (Dendron 1980, 1984), the measurement of wood residues after logging was found to have few omissions and to produce accurate assessments of diameter, length, and the volume of remaining wood residues on clear cut areas. However, on partial cuts with residual standing live trees, omission errors rose sharply. The present study confirms this limitation of the LSP technology.

In this study, the problem was less evident on plots that were made up primarily of hardwood species (photographed with leaves off) and on the plots that contained fewer trees. Three plots with less than 20 trees per plot (average of 34) had no omissions of standing or fallen dead material. To some extent, the omissions were concentrated on the small size classes, but the relationship was not as strong as expected.

2. Tree Height

All trees that were measured, both on the photos and in the field, were paired and their differences found—the field observation being considered the standard. The mean of the differences was used to indicate the degree of systematic error or trends related to size of tree or stand type. The standard deviation of the differences was used to reflect random variation. The mean difference, based on 57 trees, was found to be -0.02 m, an insignificant bias or systematic error.

The standard deviation of the differences (or errors) was found to be 1.03 m. This is about the same level of variation that can be expected from conventional tree height measurements in the field. Thus, the accuracy of the LSP methodology may be higher than the field standard. This could only be proved by a more accurate field procedure such as felling the trees and measuring their length.

3. Volume Assessment

The accuracy of plot estimates of the volume of live trees reflects not only the impact of photo measurement errors, but also the effect of species identification errors, particularly those relating to omissions and the accuracy of models developed to estimate DBH and total or merchantable tree volume. In the last case, the accuracy of the estimation models is greatly influenced by the representativeness of the data sets that are used to develop models of the forest population to which they are applied. Thus, the analysis also investigated the impact of the equations used to estimate DBH from height and crown area in the case of the LSP data, and height from DBH in the case of the field data. To make the analysis completely comparable, both equation types should have been based on the same data set. Unfortunately, time and budgetary constraints made it impossible to assemble a sufficiently large data set to cover both equation types. The height-on-DBH field equations and the LSP DBH equations had to be based on data collected from different stands in northern Ontario.

The results, presented in Table 2, reflect the effect of equation differences by stand type. Although the volume per hectare estimates for all species of live trees by LSP and field survey are satisfactorily close, the results varied significantly among the four stands tested. The aspen and spruce were less than the field estimates; birch and pine where higher. More detailed analysis revealed that most of the differences stemmed from the LSP equations.

Table 2. Results of volume comparison between LSP and field survey. The volume is expressed as gross total cubic volume per hectare.

Stand type	LSP volume (m^3/ha)	Field volume (m^3/ha)	Difference (m^3/ha)
Aspen (*Populus tremuloides* Michx.)	129	204	-75
White birch	302	213	89
Jack pine (*Pinus banksiana* Lamb.)	334	287	47
White spruce (*Picea glauca* [Moench] Voss)	238	259	-21
All species	250	241	9

The pine data was investigated further to discover if the pine stands in the paired comparison test were, in fact, different from the data set used to develop the LSP equations. The differences are shown graphically in Figure 2.

The regional jack pine model was based on data collected outside the test area, from jack pine stands with a range of densities, site index, and ages. The local equation was based on 30 jack pine trees in a single stand of one age class and site type. The models diverge markedly for trees with a DBH larger than 25 cm; at 30 cm DBH, the regional equation will estimate DBH about 15 percent higher than the local equation. When processed through a tree volume equation, the volume differences will be at least 20 percent. This mismatch explains most of the difference in jack pine volume per hectare in Table 2, based on the regional equation. It underlines the importance of selecting trees for equation development such that they accurately represent the stands to which they will later be applied. It also shows the danger of using equations from other geographic areas or stand conditions without first checking for biases or mismatches.

Variations among species equations based on different data sets are further illustrated in Figures 3 to 7, inclusive. The frequency of occurrence and volume of dead standing trees and fallen material was also compared using the 21 paired plots. Also, a field survey based on 135 fixed-area (200 m^2) residue plots in the same four stands provided data to judge the effectiveness of LSP in assessing dead material. The results of the comparison are presented in Tables 3 and 4.

Table 3. Results of stem count and volume comparison of dead standing trees among LSP, paired field, and residue plots. The volume is expressed as gross total cubic volume (m^3) per hectare.

Stand type	Stems per ha			Volume (m^3) per ha		
	LSP	Field	Residue	LSP	Field	Residue
Aspen	128	431	235	9.3	58.1	17.5
Birch	142	232	385	30.5	21.2	19.0
Pine	156	380	357	36.0	37.6	24.9
Spruce	145	504	317	25.3	38.8	18.9
All species	143	412	324	25.3	39.0	10.0

Table 4. Results of stem count and volume comparison of fallen pieces among LSP, paired field, and residue plots. The volume is expressed as gross total cubic volume (m^3) per hectare.

Stand type	Pieces per ha			Volume (m^3) per ha		
	LSP	Field	Residue	LSP	Field	Residue
Aspen	143	591	433	7.7	20.1	19.7
Birch	188	172	295	10.1	9.2	10.7
Pine	84	205	267	3.7	8.3	12.3
Spruce	367	1 083	1009	20.3	43.6	54.6
All species	196	513	501	10.5	20.3	24.3

Referring to the dead standing trees in Table 3, the stems per hectare of the All Species total is significantly greater in the two field-based surveys. However, the volume of All Species by the LSP method is straddled by the two field methods. This implies that most of the volume sampled by LSP is concentrated in fewer trees—the largest dead trees. This means that most of the LSP omissions were small trees, probably of lesser consequence than the larger trees in terms of habitat supply. The LSP volume estimate in the aspen type (actually classified by FRI as aspen when it was predominantly white birch) was the weakest.

In regard to the dead fallen material reported in Table 4, both the number of pieces and volume measured by LSP were below the two field-based counterparts. The two field survey methods produced very similar results both in terms of frequency and volume.

CONCLUSIONS

Twenty-one LSP plots in four FRI stands were remeasured in the field. The stands represented 80–100 year old spruce, pine, poplar, and white birch working groups. The field data were used to assess the accuracy of LSP photo recognition of tree species and condition of plot trees, the accuracy of tree height measurements, and the reliability of total volume estimates.

The interpretation of live trees on the LSP was very reliable. Only three percent were missed, and all those interpreted were correctly identified as to species. However, the dead trees were not interpreted as well. About 63 percent of dead standing or fallen trees were missed, but of the trees not omitted, only three percent were confused between standing and fallen material. The omissions were worse in the denser stands where the crown cover obscured small dead trees in the canopy, and especially dead residue on the ground.

The height measurements were accurate—no systematic errors and with a random variation of about ±1.0 m, two-thirds of the time. This level of variation is about the same as that expected from conventional field procedures. Thus, the accuracy of the LSP measurements is concluded to be as good as or better than can be accomplished in the field on standing trees. This accuracy level is acceptable for any inventory application and should not, in itself, have an impact on the accuracy of DBH or volume estimates.

The overall estimates of the volume of live trees were accurate, though less so for individual stand types (working groups). The variation from one stand working group to another was concluded to result primarily from the use of LSP DBH equations from outside the local area not matching the specific stand densities, site index, age, and structure of the test stands. The mismatch emphasizes the importance of selecting tree data for the development of such models such that they are representative of the stands to which they will be applied. Although not investigated in this study, the same applies to the practice of using height-on-diameter equations and tree volume equations.

The overall estimates of the number of dead standing trees per hectare by LSP was below the two field methods, but the LSP volume estimate was in the middle. The LSP method missed some of the small standing dead trees, but picked up most of the volume in the larger tree classes, probably trees with the most important habitat supply potential. The LSP methodology was less successful with the dead fallen material, mostly because it cannot be seen under fairly dense canopies.

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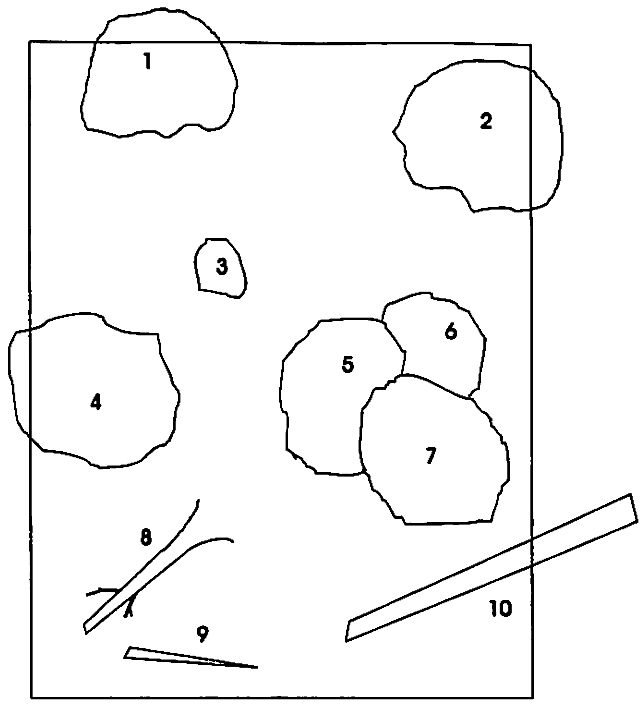

Figure 1. Fixed area photo plot on LSP with numbered live and dead standing and fallen material.

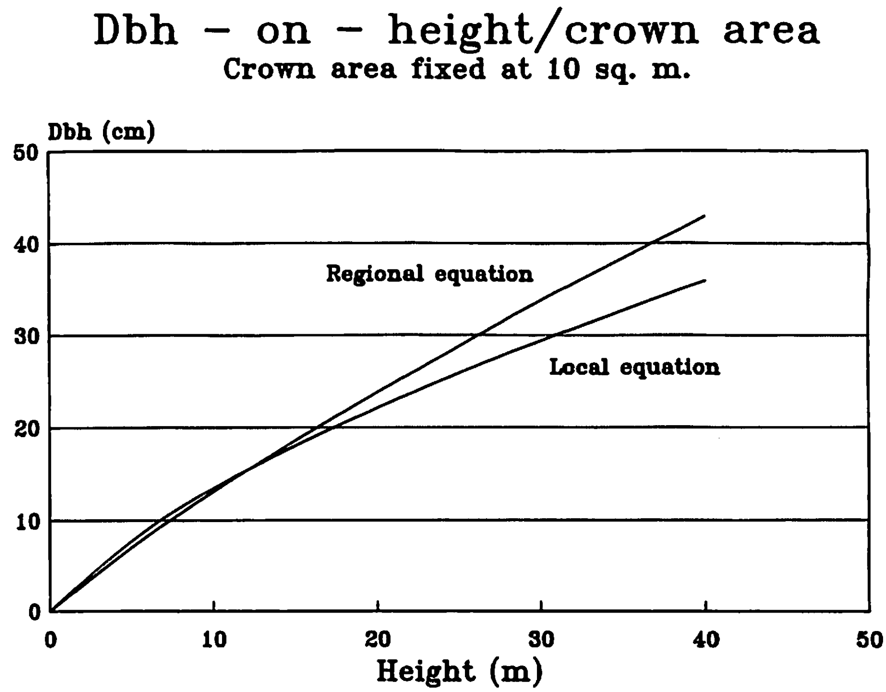

Figure 2. Graphs of DBH on tree height for a fixed crown area of 10 m² for a local and regional model.

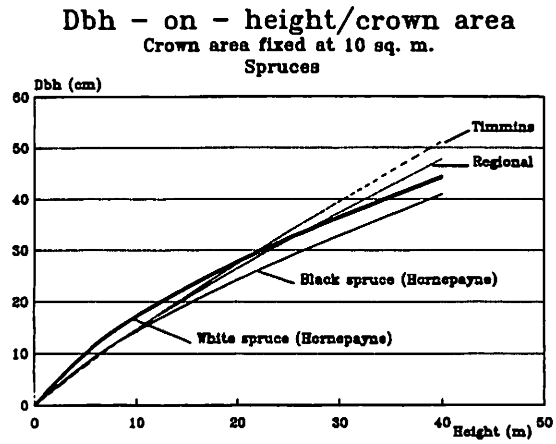

Figure 3. Black spruce and white spruce equations for estimating DBH from photo-measured height and crown area.

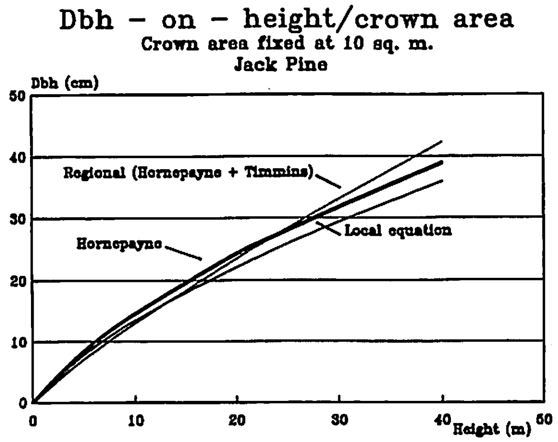

Figure 4. Jack pine equations for estimating DBH from photo-measured tree height and crown area.

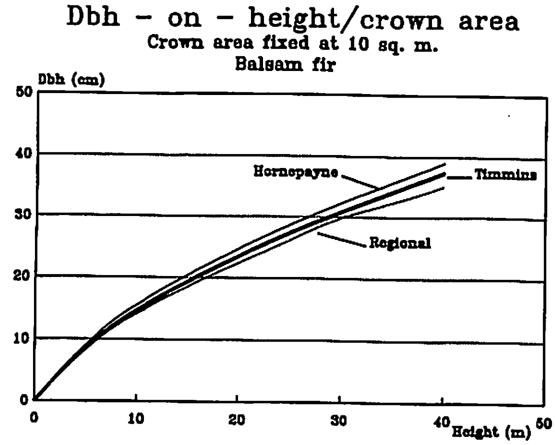

Figure 5. Balsam fir equations for estimating DBH from photo-measured tree height and crown area.

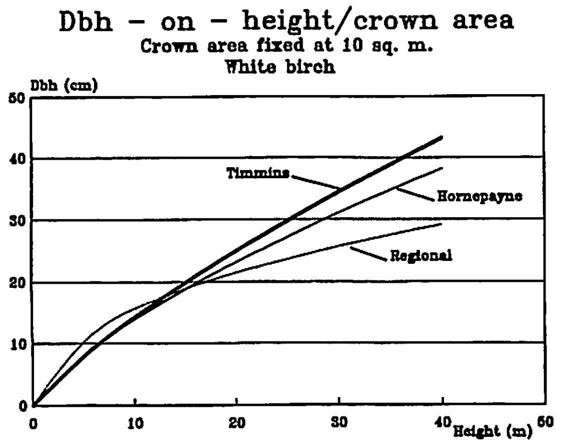

Figure 6. White birch equations for estimating DBH from photo-measured tree height and crown area.

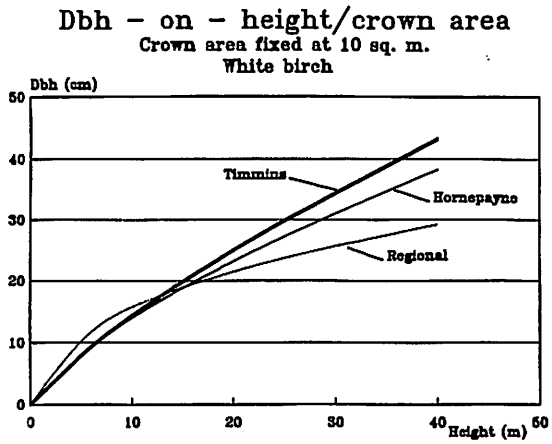

Figure 7. White birch equations for estimating DBH from photo-measured tree height and crown area.