Stem Count Accuracy and Species Determination in Loblolly Pine Plantations Using 35-mm Aerial Photography

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ABSTRACT: Large scale 35-mm aerial photographs of plots located in two mid-rotation age loblolly pine plantations were taken under operational conditions in order to assess the accuracy with which species and number of trees could be determined, and to identify factors affecting that accuracy. Using 4- by 6-inch prints and simple tools and techniques, the total number of loblolly pine was overestimated by 1.4 percent. Few interpretation errors were found to occur in the dominant and codominant crown classes. Trees were omitted from the interpretation far more often than falsely delineated, and for reasons not unique to the 35-mm camera system. Individual trees were correctly placed into one of three species categories: loblolly pine, Virginia pine, and hardwoods, 95 percent of the time, and that accuracy increased to 99.8 percent when only dominant and codominant trees were considered. The evidence suggested that interpretations of canopy-level trees made from 35-mm aerial photographs are reliable for some types of practical applications.

INTRODUCTION

THE SUBSTITUTION of large-scale aerial photography for ground surveys for making detailed measurements in forest stands has been an objective of researchers for many years (Kippen and Sayn-Wittgenstein, 1964). To date, most of the quantitative work has employed 9-inch or 70-mm formats, while 35-mm studies have been mainly qualitative (Meyer *et al.*, 1980; Weih *et al.*, 1984). Despite the advantages of 35-mm systems in terms of cost, availability, and ease of processing, residual concerns over lens quality, lack of lens calibration, and the need for enlargement have cast doubt on their ability to perform in a precise and repeatable manner (Dalman, 1978).

Other investigators have used 35-mm systems for making regeneration counts in young loblolly pine plantations (Smith *et al.*, 1986). To date, however, no quantitative studies have taken place in older pine plantations in the southeastern United States, nor has any systematic analysis of interpretation errors been made. We sought to fill this gap in a limited, but carefully ground-referenced, study focused on the accuracy of tree counts and species determinations in mid-rotation age loblolly pine plantations.

The objectives of this study were

- To evaluate the accuracy of stem counts and species determinations in mid-rotation age loblolly plantations made from large scale 35-mm aerial photographs, and
- To determine the impact forest structure and tree characteristics have upon the photointerpretation accuracy.

MATERIALS AND METHODS

GROUND INFORMATION

One-acre (0.40- ha) sample plots were located in two loblolly pine plantations in August of 1981. Both plantations had been established on cutover sites in the piedmont of Virginia. They exhibited similar site qualities and age, and were selected because they represented extremes in plantation structure. One plot was well- stocked, competition free, and exhibited a uniform tree size and spatial distribution pattern (Figure 1). The second plot was overstocked with excessive amounts of competition and exhibited more variation in tree size and spatial distribution (Figure 1). Although the ranges in age and number of sites examined in this study were limited, the conditions under which more than 1000 tree images were examined were varied, and provided a rigorous test of the interpreters ability to locate and properly identify individual trees in pine plantations. While the number of plots that could be examined was

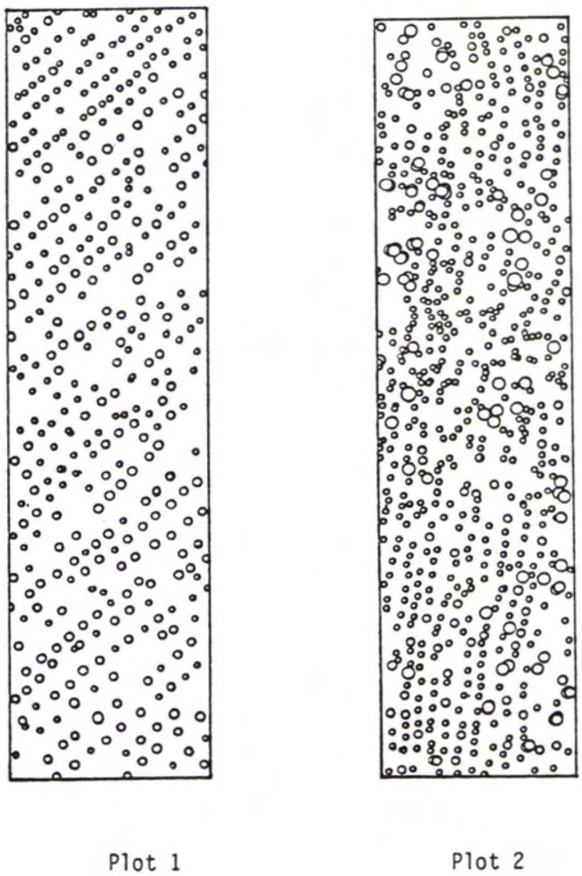

FIG. 1. Spatial distribution and relative diameter of trees on 1-acre sample plots located in loblolly pine plantations in the Virginia piedmont.

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limited because of plot size, a true representation of the spatial and biologic characteristics of each stand was revealed through the use of large plots.

The information collected in the ground survey is summarized in Table 1. Each of the two 0.40-ha sample plots was 31.8 m by 127 m, and was established and measured using the guidelines of the American Pulpwood Association forest models program (Anon., 1969). The location of each tree over 7.6 cm in diameter breast height (dbh) was determined in a plot coordinate system, and a detailed stem map was prepared. The maps served as the base for indentifying photointerpretation errors. Total height, crown class, and species for each stem were also measured or determined. The four crown class categories (dominant, codominant, intermediate, and suppressed) typically used in forestry were recognized (Spurr and Barnes, 1980). During the ground survey, the plots were not altered to facilitate the photointerpretation process.

Aerial Photography

Aerial photography of the two sample plots was taken in October, 1981 when hardwood leaves were in full color. Photo-identifiable targets were placed along the perimeter of each sample plot and in natural openings within the plots to help in their location, and to serve as reference points during the analysis. A typical (Canon) 35-mm single lens reflex camera equipped with a 50-mm lens and autowinder was hand held (but braced) and operated through the belly hole of a DeHavilland Beaver aircraft. A nominal flying height of 137 m above the terrain resulted in a film scale of 1:2750. Natural color, negative ASA 100 (Kodacolor) film was utilized, and yielded high quality 4- by 6-inch prints at a local photography shop. The scale of the final prints averaged 1:600. The use of simple equipment and procedures was aimed at reproducing the operational conditions typically encountered in the southern region.

Photointerpretation and Analysis

The photointerpretation was performed by one individual who was well trained and experienced in photointerpretation and forestry. While no specific training period was deemed necessary, the interpreter did spend several hours familiarizing himself with the photographs. The effect of interpreter on the results reported in this study is not known; however, the interpreter represented the type of personnel that would usually perform this job in a forestry organization.

Following the familiarization process, individual tree crowns were delineated on mylar overlays which were attached to the photos. Viewing was done through an Old Delft Scanning Stereoscope. After the photointerpretation process was completed, the mylar crown maps of the plots were compared to the stem maps prepared from the ground survey. Identifiable trees, openings, and targets were used to match tree locations between the two maps. Three situations occurred in these comparisons: (1) a crown delineated on the mylar had a corresponding stem on the ground (correct interpretation), (2) a crown delineated on the mylar did not have a corresponding stem on the ground (commission error), and (3) no crown was delineated on the photo even though a stem actually existed on the ground (omission error). The number of occurrences of each situation was post-classified for each plot by field- surveyed crown class and species to investigate the effect of stand structure and composition on the results, except for "commission" error trees. Because no stem existed on the ground for these interpreted crowns, the photo- determined crown class and species were used. Further, the locations of ommitted trees were noted on the photointerpretation mylar crown maps.

Subsequent to the previous analysis, each delineated and omitted crown was placed into one of three species categories; loblolly pine, Virginia pine, and hardwood species. Although seven different hardwood species actually occurred in the plots, a combined hardwood category was used. This is consistent with the operational needs of pine plantation managers in the Virginia piedmont. Photointerpreted and ground determined species category were then compared for each stem, and percent accuracy statistics were computed.

Table 1. Summary of the Ground Survey of the Two Sample Plots.

Characteristic	Plot 1	Plot 2
Number of trees	401	702
Basal area (ft²/ac)	127	125
Planting spacing (m)	3 × 2.4	2.4 × 2.4
Age (years)	17	18
Avg. tree diameter (dbh in cm)	19	14
Average tree height (m)	13.7	11.9
Species composition (percent)		
Loblolly pine	97	73
Virginia pine	2	14
Hardwood species	1	13
Crown class distribution (percent)		
Dominant	6	10
Codominant	77	47
Intermediate	13	32
Suppressed	4	11

RESULTS AND DISCUSSION

Stem Counts

Photo-derived and ground-surveyed stem counts for both sample plots in each crown class and species category are compared in Table 2. In general, the relationships between the photo and ground stem counts were similar for the two plots, although important differences were noted. In Plot 1, the stem count from the photographs matched the ground count exactly, while in Plot 2 with its higher stem density and less regular spatial pattern, the total stem count derived from the photo was approximately 8 percent lower than the corresponding ground count. Combined results indicate that the total photo stem count underestimated the ground tally by 5.2 percent. An underestimation was expected because overlapping crowns create confusion for the interpreter, and smaller stems are obscured in an aerial view by taller neighbors in many cases.

Error Analysis

In the past, researchers have concluded their studies by reporting the accuracy of photo-derived stem counts, such as those presented in the previous section; however, such results can be misleading as in Plot 1, for example, where the photo and ground counts were identical, implying no interpretation errors. In fact, 12.4 percent of the interpretation was incorrect (Table 3). To understand the causes and impacts of such errors, and to identify ways to reduce their frequency, a detailed analysis of the errors was performed.

The number of omission and commission errors for the three species categories and four crown classes are presented in Table 3. The results were not the same for the two plots, although some similarities and patterns were found. In Plot 1, which was uniformly stocked and comprised of 97 percent loblolly pine (Table 1), 50 interpretation errors occurred, with just over one-fifth associated with hardwoods or Virginia pines. The photo and ground counts were the same in this plot because the number of omission and commission errors was the same. In Plot 2, with its higher stem density, less uniform tree spacing, and influx of competing species, 209 interpretation errors occurred and approximately one-half were in the hardwood or Virginia pine classes. In Plot 2, the photo-based tree count was low because the omission error rate was approximately twice as large as the commission rate. Evidently, the omission error rate was affected more by the changes in stand characteristics than was the commission error rate.

TABLE 2. COMPARISON OF FIELD-MEASURED AND PHOTO-INTERPRETED NUMBER OF TREES IN EACH PLOT, CATEGORIZED BY FIELD-MEASURED CROWN CLASS AND SPECIES.

Plot	Ground Surveyed Species[2]	Ground Surveyed Crown Class[2] Dominant	Codominant	Intermed.	Suppressed	Totals	Difference (% of Ground)
1	Loblolly	24 (24)[1]	303 (306)	66 (48)	4 (10)	397 (388)	+ 2.3
	Virginia	0 (0)	0 (0)	0 (3)	0 (1)	0 (9)	−100
	Hardwoods	0 (0)	2 (2)	2 (1)	0 (1)	4 (4)	0.0
	Total	24 (24)	305 (308)	68 (52)	4 (17)	401 (401)	0.0
2	Loblolly	66 (66)	256 (257)	147 (139)	45 (48)	514 (510)	+ 0.8
	Virginia	4 (4)	39 (47)	17 (34)	5 (13)	65 (98)	− 33.6
	Hardwoods	2 (2)	18 (22)	37 (50)	9 (20)	66 (94)	− 29.8
	Total	72 (72)	313 (326)	201 (223)	59 (81)	645 (702)	− 8.1
Both	Loblolly	90 (90)	559 (563)	213 (187)	49 (58)	911 (898)	+ 1.4
	Virginia	4 (4)	39 (47)	17 (37)	5 (19)	65 (107)	− 39.3
	Hardwoods	2 (2)	20 (24)	39 (51)	9 (21)	70 (98)	− 28.6
	Total	96 (96)	618 (634)	269 (275)	63 (98)	1046 (1103)	− 5.2
Difference (% of Ground)		0	−2.5	−2.2	−35.7	−5.2	

[1]Photointerpretation total indicated first with the ground survey total in parentheses.
[2]Excepting commission error trees, whose crown class and species were interpreted on the photographs.

TABLE 3. OMISSION AND COMMISSION ERROR TOTALS CATEGORIZED BY PLOT, FIELD-MEASURED SPECIES, AND CROWN CLASS.

Plot	Ground Surveyed Species[5]	Ground Surveyed Crown Class[5] Dominant 0[1]	Dominant C[2]	Codominant 0	Codominant C	Intermed. 0	Intermed. C	Suppressed 0	Suppressed C	Total Error Rate (%) 0[3]	Total Error Rate (%) C[4]
1	Loblolly	0	0	4	1	4	22	7	1	3.9	6.0
	Virginia	0	0	0	0	3	0	6	0	100.0	0.0
	Hardwoods	0	0	0	0	0	1	1	0	25.0	25.0
	Total Error Rate (%)	0	0	1.3	0.3	13.5	33.8	82.3	25.0	6.2	6.2
2	Loblolly	0	0	7	7	24	30	24	21	10.7	11.3
	Virginia	0	0	8	0	18	3	10	2	36.7	7.7
	Hardwoods	0	0	5	0	23	10	14	3	44.6	19.6
	Total Error Rate (%)	0	0	6.1	2.2	29.1	21.4	59.2	44.1	18.9	11.7
Both	Loblolly	0	0	11	8	28	52	31	22	7.7	9.0
	Virginia	0	0	8	0	21	3	16	2	42.0	7.7
	Hardwoods	0	0	5	0	23	11	15	3	43.8	20.0
	Total Error Rate (%)	0	0	3.8	1.3	26.2	24.5	63.2	42.8	14.3	9.6

[1]Omission errors
[2]Commission errors
[3]Number of omission errors divided by the ground tally for that category
[4]Number of commission errors divided by the photo tally for that category
[5]Excepting commission error trees, whose crown class and species were interpreted on the photos

Omission and commission error rates were nearly compensating for loblolly pine; however, hardwoods and Virginia pine tended to be omitted far more often than falsely delineated. Although the hardwood and Virginia pine stems represented less than one-fifth of the total number of stems on the two plots, over 40 percent of the interpretation errors were associated with them. The causes of these errors seemed to arise from the growth patterns of these species. Both tended to occur in dense clumps due to the seed dispersal and seedbed pattern associated with Virginia pine regeneration and coppice reproduction in the hardwoods. Stem congregation caused individual crowns to coalesce into large composite crowns, which hindered the identification of individual stems.

The interpretation error frequency was also related to ground-derived crown class. No interpretation errors were committed with dominant trees in either plot, regardless of species group. Only 32 errors occurred in the codominant crown class. In contrast, 90 percent of the interpretation errors occurreed in the non-canopy classes. The percentage of these errors was similar on both plots, even though their structures and compositions were dissimilar. In short, the results suggest that the portion of the pine plantation of major importance in terms of volume—the dominant and codominant stems—can be reliably interpreted on large scale 35-mm aerial photographs, while we have only limited confidence in our ability to identify intermediate and suppressed trees.

An anomaly which warrants further explanation was found in the results. An underestimate in stem count occurred in nearly every crown class except the intermediate one, which at times was overestimated. This overestimation is entirely associated with large counts in the loblolly pine intermediate category in both plots. Revisiting the plots indicated several reasons for this result. First, ten of the loblolly commission errors in Plot 2 were not errors at all; the photo- delineated crown corresponded to a stem which was smaller than 7.6-cm dbh, the minimum diameter limit of the ground survey. Secondly, many of the commission errors within the intermediate class were caused by long, upturned lateral branches of the dominant and codominant trees which had filled a natural canopy opening, and were mistakenly identified as separate tree crowns. Such branching patterns should be considered in interpreter training programs and possibly in the selection of photo scale.

Species Determination

Pine plantations in the southeastern United States rarely contain only the planted species. Hardwood sprouts and trees from wind-blown seed also populate the stands. Accurate species determinations would allow plantations managers to use aerial photographs to evaluate plantation conditions and assess competition levels. In this study, species identification on the photographs was relatively easy because each of the categories of interest exhibited a somewhat unique spectral signature. The leaf coloration period of autumn permitted easy distinction between the coniferous and deciduous trees, while the separation of loblolly and Virginia pine was based primarily upon texture rather than tone. Virginia pine possessed a fuzzy, "goose-down" appearance, while loblolly pine crowns were full and "billowy."

The accuracies of the species determinations for each plot and crown class are summarized in Table 4. In both plots, loblolly pine had the highest accuracy, followed in decreasing order by the hardwood species and Virginia pine. Species identification accuracy did not show a strong relationship with stand characteristics, as the results were similar for the two sample plots. The accuracy was related to crown class, however. Trees in dominant and codominant positions were accurately categorized, and as the trees became more suppressed, the accuracy of the species identifications consistently declined. While canopy position appeared to be the dominant factor affecting the accuracy of species determinations, the results also suggested some interaction between crown class and species. Within a crown class, loblolly pines were consistently identified more accurately than hardwood species, which were superior to Virginia pines.

Table 4. Percent Accuracy of Species Determinations by Plot, Species, and Crown Class.

Plot	Species	Ground Surveyed Crown Class: Dominant	Codomin.	Intermed.	Sup-pressed	Overall
1	Loblolly	100	100	100	80	99
	Virginia	–[1]	–	0	0	0
	Hardwood	–	100	100	0	75
	Overall	100	100	94	47	97
2	Loblolly	100	99	97	94	98
	Virginia	100	94	56	38	73
	Hardwood	100	100	92	75	94
	Overall	100	98	90	80	94
Both	Loblolly	100	99	98	91	99
	Virginia	100	94	51	26	67
	Hardwood	100	100	92	71	90
	Overall	100	99	91	74	95

[1]None of this type found in the sample plot during the ground survey or photointerpretation.

SUMMARY AND CONCLUSIONS

Large scale 35-mm aerial photographs were taken of two mid-rotation age loblolly pine plantations to investigate their potential for providing stem count and species composition information under operational conditions. In addition to accuracy, the error rate (the number of omission and commission errors relative to the number of trees) associated with each plot, species, and crown class was examined.

We conclude that the utility of large-scale 35-mm aerial photographs depends upon the objectives of the user. If information on dominant and codominant trees is all that is required, aerial photographs similar to those utilized in this study may be appropriate. However, if information on the lower level, non-canopy trees is needed, a ground survey will likely be necessary. The predominant factors affecting the accuracy and reliability of the photo-derived data seem to be biological in nature, rather than related to the format of the photography.

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