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Evaluation of Spruce-Fir Forests Using Small-Format Photographs

35-mm color aerial photographs provide a basis for measuring forest characteristics related to spruce budworm hazard.

Abstract: *Techniques for assessing spruce-fir forest characteristics are important for predicting stand hazard and minimizing fiber losses. This research tested the effectiveness of using large-scale (1:4800), small-format color aerial photographs for evaluating tree condition and identifying host species (balsam fir,* Abies balsamea *(L.) Mill., and white spruce,* Picea glauca *(Moench) Voss.) of the spruce budworm (*Choristoneura fumiferana *(Clemens)). Twenty-four ground sampling units were photographed in July and August 1979. Aerial survey and ground truth information was gathered using crown maps. Contingency tables allowed comparisons of tree condition and species identification from aerial and ground data. Results show that photointerpretation of small-format photographs provided mean aerial estimates of tree condition that fell within one-half of a ranking class of the mean from ground truth data. Balsam fir and spruce were separable with 80 percent frequency and aerial estimates of host species mortality were within 10 percent of ground data. The usefulness of small-format aerial photographs in estimation of forest parameters is addressed.*

Introduction

In the Great Lakes Region spruce-fir stands are intermingled with the stands of other coniferous and broadleaved species. The spruce budworm, *Choristoneura fumiferana* (Clemens), is an important insect in these spruce-fir forests. Effects of attack by epiphytotic populations of spruce budworm can be as variable as distribution of host species, balsam fir, *Abies balsamea* (L.) Mill. and white spruce, *Picea glauca* (Moench) Voss.

Foresters, entomologists, and others have investigated methods for appraisal of spruce budworm impact, including aerial surveys. Variables related to susceptibility to attack and vulnerability to damage have been measurable from aerial photographs and remote sensor data (Waters *et al.*, 1958; Heller and Schmiege, 1962; Aldrich and Heller, 1969; Murtha, 1972; Beaubien, 1975; Ashley *et al.*, 1976). These studies indicate forest characteristics, cost, and timing are important considerations in the success of airborne surveys.

The objective of this research was to test the capabilities of large-scale, small-format color aerial photographs to provide a basis for estimating forest parameters valuable for assessment of spruce budworm hazard. The parameters involve identification of tree condition, including mortality and species.

Methodology

The aerial survey procedure was a modification of the Montana 35-mm aerial photographic system (Meyer and Grumstrup, 1978). A 35-mm camera system (50-mm *f*/1.8 lens, haze filter, and motor drive) was custom mounted on a Cessna 150 or 182 aircraft (Figures 1 and 2).

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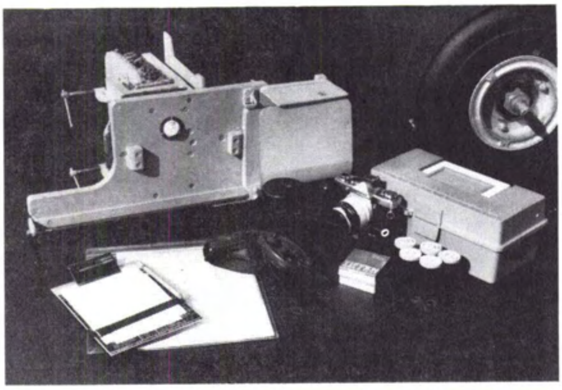

FIG. 1. The aerial photography equipment.

In the spring of 1979, four spruce-fir stands were selected for study in the Ottawa National forest in Michigan's Upper Peninsula. Six ground sampling units (GSU) were randomly located within each stand. A 0.08 hectare (ha) circular plot served as the GSU. Each GSU was marked with white butcher paper or a red helium-filled balloon to aid the pilot, photographer, and photointerpreter in locating respective GSU. An 8 by 8 metre (m) cross of 45 centimetre (cm) wide butcher paper located at plot center was the most practical positioning of markers. In very dense stands, 8-m long T-markers pointing to plot center or red helium balloons suspended near the top of the canopy were also placed in the nearest opening to aid in GSU location. In all cases, the location of auxiliary markers was identified with ground measurements of azimuth and distance from plot center.

Film, flight log, and pre-flight preparations followed Meyer and Grumstrup (1978). Photographs of all twenty-four GSU were taken at approximately 240 m above ground level (agl) in late July or August 1979, resulting in photos with a scale of roughly 1:4800. All flights were restricted to mid-morning (9 A.M. to 11 A.M.) and mid-afternoon (2 P.M. to 4 P.M.). Ektachrome ASA 200 film was used to obtain color positives with overlap for stereoviewing.

After a day of training, three photointerpreters, viewing in stereo, identified trees on the aerial photographs as spruce, balsam fir, or other conifers and hardwoods. Viewing was accomplished using a Bausch and Lomb 240 stereoscope with 10× magnification mounted over a Richards light table. All detectable spruce and fir trees were given a tree condition rank (TCR) according to a quantitative classification system summarized in Table 1. During the interpretation process crown maps (Figure 3) were drawn from photos of each GSU for classification and eventual comparison purposes.

Ground truth information was gathered within two weeks of photography. Copies of the original crown maps and classification scheme were employed in the ground surveys. Species were identified, and spruce and balsam fir trees (> 11.6 cm d.b.h.) in each GSU were evaluated for tree condition. White and black spruce, *Picea mariana* (Mill.) B.S.P., were tallied together throughout the study and grouped as spruce.

Data were presented in contingency tables for calculation of agreement between aerial and ground survey approaches. Stratified by stand and photointerpreter, each contingency table presented a tree by tree comparison of aerial and ground survey data. The contingency table allowed computation of TCR agreement, species agreement, and percent mortality, as well as determinations of photo tree count and errors in classification. Tables 2 and 3 show contingency tables generated from computer stored data files for photointerpreter 2, stand 3.

RESULTS

Table 4 summarizes results of aerial and ground survey comparisons from four spruce-fir stands in Michigan's Upper Peninsula. Stand averages are the mean results of three photointerpreters who identified and ranked damaged trees from Ektachrome slides and in the field.

The sum of spruce and fir trees tallied within six GSU per stand during the ground survey established the tree count in entire ground sample.

FIG. 2. Camera system and mount in position on a Cessna 182.

TABLE 1. QUANTITATIVE CLASSIFICATION SYSTEM USED DURING PHOTOINTERPRETATION AND GROUND SURVEYS TO RANK TREE CONDITION (TCR) OF SAMPLED FIR AND SPRUCE

(1) No defoliation-no observable feeding damage, 0–20 percent of total foliage missing
(2) Light to moderate defoliation, 21–50 percent defoliation of total foliage
(3) Heavy defoliation, 51 percent or greater defoliation with no observable top-kill
(4) Severe defoliation, 51 percent or greater defoliation with obvious top-kill
(5) Mortality, dead trees

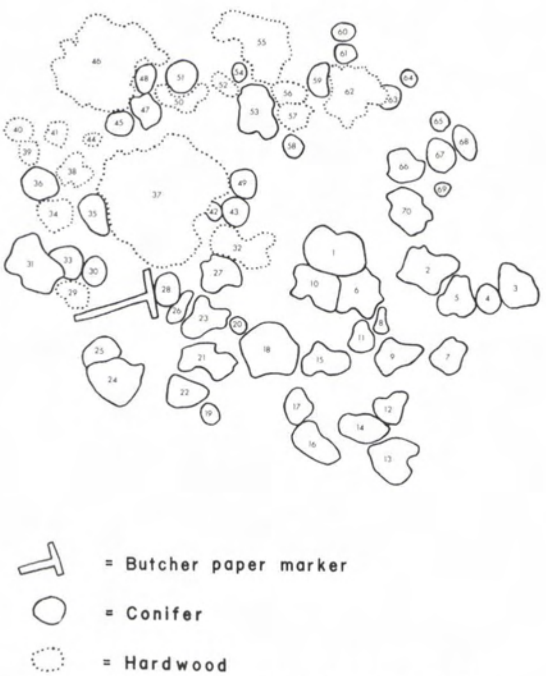

FIG. 3. Crown map of plot 3 in stand 4.

Tree counts ranged from 170 trees (stand 1) to 308 trees (stand 3). Photo tree count of spruce and fir per stand was easily determined for each of three photointerpreters, and subsequently recorded as a percentage (percent detection) of the total located during ground inspection. Percent detection varied by less than 10 percent among photointerpreters in any particular stand. Stand averages ranged from 58 percent in stand 1 to 77 percent in stand 3 (Table 4).

TABLE 2. CONTINGENCY TABLE[1] FOR TREE CONDITION RANK DATA FOR PHOTOINTERPRETER 2, STAND 3. THE TABLE ACCENTUATES DATA PRESENTATION, SURVEY AGREEMENT, AND MORTALITY CALCULATION.

Aerial Tree Condition Rank	Ground Tree Condition Rank					
	1	2	3	4	5	Total
1	0	0	0	0	0	0
2	0	111	26	1	3	141
3	0	10	41	1	5	57
4	0	0	14	0	3	17
5	0	0	9	1	16	26
Total	0	121	90	3	27	241

Photo Tree Count = 241
Tree Condition Rank Agreement
$= (0 + 111 + 41 + 0 + 16)/241 = 0.70$
Percent Mortality (Aerial) = 26/241 = 0.11
Percent Mortality (Ground) = 27/241 = 0.11

[1] The diagonal presents agreement between ranking of ground and aerial tree condition.

TABLE 3. CONTINGENCY TABLE FOR EVALUATION OF SPECIES IDENTIFICATION, PHOTOINTERPRETER 2, STAND 3

Aerial Interpretation	Ground Truth		
	Balsam fir	Spruce	Total
Balsam fir	204	6	210
Spruce	24	8	32
Total	228	14	242

Species Agreement = (204 + 8)/242 = 0.88

TCR agreement exhibited the greatest degree of variation of any parameter among photointerpreters in all four stands. Stand 1 (Table 4) showed the least TCR agreement between survey methods. Fluctuation of overall TCR agreement fell between 53 and 65 percent, with combined four stand TCR agreement equal to 61 percent (Table 6).

Species identification was evaluated as the percentage of agreement between aerial and ground surveys (Table 3). This analysis included only spruce and fir because preliminary tests indicated these trees could be separated from other coniferous and broadleaved species with greater than 95 percent accuracy. With exception of stand 1, species agreement ranged between 73 and 89 percent (Table 4). Species agreement for stand 1 averaged 53 percent.

An average stand TCR was calculated for trees detected in the aerial survey (average ATCR), from matching ground survey data of those trees detected during photointerpretation (average GTCR), and for all trees tallied during the ground survey (average GTCR in entire ground sample). In Table 4 these stand TCR values are expressed as a mean, plus or minus one standard deviation. Throughout the study, mean TCR based on photointerpretation of stand trees was within one-half of a ranking class of the mean value assigned to the same sample by ground inspection. Average stand TCR compiled by the three photointerpreters was within identical limits of the mean rank for the entire ground sample in each stand.

Percent mortality was calculated from the contingency tables (Table 2). Expressed as a portion of the six plot sample per stand, percent mortality was determined for aerial and ground survey data, including the entire ground sample data set (Table 4). In general, aerial estimates of tree mortality were within 10 percent of ground truth values.

Individual photointerpreters were similar in over- or underestimating tree mortality within any particular stand, though inconsistency was associated with error of estimation between stands. In stands 1, 3, and 4, aerial tree mortality estimates were lower than that found by ground determination (Table 4). Conversely, photointerpretation of

TABLE 4. RESULTS OF AERIAL ASSESSMENT SURVEY IN FOUR SPRUCE-FIR STANDS. FIGURES EMPHASIZE THE COMBINED EFFORTS OF THREE PHOTOINTERPRETERS TO IDENTIFY AND RANK DAMAGED SPRUCE AND FIR TREES FROM EKTACHROME SLIDES. TCR = TREE CONDITION RANK, ATCR AND GTCR = AERIAL AND GROUND TREE CONDITION RANK, RESPECTIVELY. ENTIRE GROUND SAMPLE = 6 PLOTS/STAND.

	Stand			
	1	2	3	4
Tree Count in Entire Ground Sample	170	304	308	260
Photo Tree Count	98	202	238	167
Percent Detection	58	66	77	64
TCR Agreement (%)	53	58	65	61
Species Agreement (%)	53	79	89	73
Average ATCR ($\pm 1\sigma$)	3.0 ± 1.2	2.8 ± 1.1	2.6 ± 0.9	3.1 ± 1.2
Average GTCR ($\pm 1\sigma$)	3.3 ± 1.3	2.7 ± 0.9	2.7 ± 1.0	3.2 ± 1.2
Average GTCR in Entire Ground Sample ($\pm 1\sigma$)	3.2 ± 1.2	2.8 ± 1.0	2.9 ± 1.0	3.2 ± 1.2
Percent Mortality (Aerial)	20	16	9	23
Percent Mortality (Ground)	30	9	11	24
Percent Mortality in Entire Ground Sample	27	13	15	24

stand 2 resulted in tree mortality estimates consistently higher than ground truth values.

For photointerpreter comparisons, Table 5 presents a subsample of survey results for stand 1 to 4. Each subsample consists of a population of trees within the entire ground sample detected by all three photointerpreters. Photo tree count and associated percent detection consistently dropped, while average ATCR and GTCR remained relatively unchanged. TCR agreement, species agreement, and percent mortality showed slight increase in precision and accuracy of estimation within subsample data sets.

In contingency tables, counts along the diagonal represent agreement between aerial and ground classification (Table 2). Specific errors can be identified and trends evaluated from neighboring cells of the diagonal. Table 6 illustrates TCR data from subsample contingency tables, presenting four stands and three photointerpreters combined. The common error involved distinguishing a moderately damaged tree (Rank 2) from a tree with heavy defoliation (Rank 3). For example, a "3" was incorrectly classified as a "2" with 73 percent frequency. Another source of error involved discrimination of heavy defoliated trees (Rank 3) and dead trees (Rank 5). However, it was just as common to classify a "3" as a "5" as the reverse situation. Frequency of occurrence of the remaining sources of error was below 30 percent of the total number of errors amassed. Further, misclassification resulting from these error types remained relatively consistent.

Basal area data from the four study stands is presented in Table 7. Data are displayed as a ratio of relative proportions of host species to other tree types. Measured in square metres per hectare, balsam fir and spruce basal area was compared to other softwood and hardwood species basal area. Stands 2 and 3 exhibited the largest spruce and fir composition in relation to other species. Conversely, stand 1 showed only a 2:1 ratio of spruce and fir to all other species, and in stand 4 composition of hosts relative to other species approached one.

DISCUSSION

Combined field experience and analysis of aerial and ground survey measurements indicate that four factors played a significant role in the outcome of this project. These factors include: (1) standard methods of classification, (2) forest composition, (3) advantages and disadvantages of small format photography, and (4) timing of photography.

STANDARD METHODS OF CLASSIFICATION

Forest type classification is dependent on tone or color differences, crown shape, and recognition of the sampling site. Crown structure and site assimilation are important features for separating balsam fir from spruce, while detectable differences in tone or color are slight. With the exception of stand 1, species identification success measured about 80 percent. Poor photointerpretation results from stand 1 were attributed to overexposed photos which washed out identifying characteristics. Properly exposed photographs of stands 2, 3, and 4 resulted in improved separation of spruce and fir.

Classification of insect defoliation commonly involves subjective judgments of the amount or percentage of foliage removed from a particular

TABLE 5. SUBSAMPLE OF SURVEY RESULTS FOR FOUR STANDS, EMPHASIZING PHOTOINTERPRETER COMPARISON. THE SUBSAMPLE CONSISTS OF AN EXTRACTION OF THOSE TREES WITHIN THE ENTIRE GROUND SAMPLE WHICH ALL THREE PHOTOINTERPRETERS DETECTED.

		Photointerpreter		
	Stand 1	1	2	3
Common Photo Tree Count	88			
Percent Detection	52			
TCR Agreement (%)		50	61	50
Species Agreement (%)		52	55	51
Average ATCR ($\pm 1\sigma$)		2.9 ± 1.2	3.1 ± 1.2	3.0 ± 1.2
Average GTCR ($\pm 1\sigma$)	3.3 ± 1.3			
Percent Mortality (Aerial)		19	22	21
Percent Mortality (Ground)	31			
		Photointerpreter		
	Stand 2	1	2	3
Common Photo Tree Count	192			
Percent Detection	63			
TCR Agreement (%)		56	63	55
Species Agreement (%)		80	83	78
Average ATCR ($\pm 1\sigma$)		2.7 ± 1.1	2.7 ± 1.0	2.9 ± 1.1
Average GTCR ($\pm 1\sigma$)	2.7 ± 0.9			
Percent Mortality (Aerial)		16	12	19
Percent Mortality (Ground)	8			
		Photointerpreter		
	Stand 3	1	2	3
Common Photo Tree Count	226			
Percent Detection	74			
TCR Agreement (%)		58	70	70
Species Agreement (%)		88	88	91
Average ATCR ($\pm 1\sigma$)		2.5 ± 1.0	2.7 ± 1.0	2.4 ± 0.7
Average GTCR ($\pm 1\sigma$)	2.7 ± 0.9			
Percent Mortality (Aerial)		10	11	4
Percent Mortality (Ground)	11			
		Photointerpreter		
	Stand 4	1	2	3
Common Photo Tree Count	155			
Percent Detection	60			
TCR Agreement (%)		61	70	54
Species Agreement (%)		74	77	72
Average ATCR ($\pm 1\sigma$)		3.2 ± 1.3	3.2 ± 1.2	2.9 ± 1.1
Aveage GTCR ($\pm 1\sigma$)	3.3 ± 1.2			
Percent Mortality (Aerial)		26	26	15
Percent Mortality (Ground)	25			

tree or forested area. To enhance this process, the photointerpreters had related experience and on-the-ground knowledge of forest resource inventory. Having participated in an impact study of spruce budworm in Michigan's Upper Peninsula (Mog and Witter, 1979), all three photointerpreters were familiar with the biology of spruce-fir stands, budworm impact, and tree condition classification systems. In addition, photointerpreters were adequately experienced with aerial photos and could recognize homogeneous or contrasting features, and variations in color, tone, texture, size, and patterns.

However, there exists no standard method of estimating defoliation on the ground or from the air other than individual experience (Talerico *et al.*, 1978). As seen in Table 5, differences in estimates among individuals vary from time to time and can be large. Overall success of photointerpreters to match ground survey tree condition

TABLE 6. CLASSIFICATION RESULTS OF TREE CONDITION RANKING FOR 24 GROUND SAMPLING UNITS (FOUR STANDS COMBINED)

Ground Truth Data		Aerial Photointerpretation				
		Ranking Class				
Ranking Class	Number Observed	1	2	3	4	5
1	0	0	0	0	0	0
2	900	0	758	108	14	20
3	651	0	288	243	42	78
4	114	0	27	45	23	19
5	318	0	33	75	27	183
Total	1983	0	1106	471	106	300

Project TCR Agreement
$= (0 + 758 + 243 + 23 + 183)/1983 = 0.61$

classification (TCR agreement) was 61 percent (Table 6). In light of potential variation among individuals in estimating defoliation, both during ground surveys and on photographs, it is difficult to evaluate the strength or weakness of this percentage. From examination of sources of error it is obvious that discriminating moderately damaged trees (Rank 2) from heavily defoliated trees (Rank 3) can be a difficult judgment. Shadowing, ground vegetation, and mosses can influence photointerpreters' decision process in classifying tree condition from aerial photographs. It is speculated that discrimination of no damage (Rank 1) and moderate damage (Rank 2) would have resulted in similar difficulties, if photointerpreters had not received ground experience and benefited from knowledge of area-wide impacts.

Aerial estimates of tree mortality fluctuated in respect to ground survey data, and this can be related to the difficulty photointerpreters had distinguishing heavily defoliated trees (Rank 3) from dead trees (Rank 5). Balsam fir often retains some green foliage, and epiphytic green moss and lichen cover on branches after the tree is considered dead. Under either circumstance, reflectance of a dead tree can simulate that of a heavily defoliated tree. This confusing appearance on photographs of numerous dead trees resulted in aerial mortality estimates above and below actual ground truth data.

TABLE 7. BASAL AREA RATIO TABLE. RATIOS REPRESENT RELATIVE PROPORTION OF RESPECTIVE FOREST TYPES WITHIN EACH STAND, MEASURED IN SQUARE METERS PER HECTARE.

			Stand			
			1	2	3	4
Balsam fir Spruce	:	Hardwood and other Softwood species	2.0:1	3.2:1	2.6:1	1.5:1

Comparisons of average tree condition rank from respective surveys in each stand were encouraging. Regardless of percent detection, TCR agreement, or aerial mortality estimates, photointerpretation consistently provided estimates of average stand tree condition within one-half of a ranking class of ground inspection averages. These highly accurate aerial estimates of tree condition can provide timely stand impact assessment information desperately needed by forest managers.

FOREST COMPOSITION

Heterogeneity of the spruce-fir type in Michigan's Upper Peninsula influenced project design through selection of aerial survey technique, photographic scale, sampling design, and statistical analyses. Data analysis was assembled by stand to investigate relationships between aerial survey results and species composition.

From the onset, detection of individual crowns was deemed necessary to assess tree condition and identify species. However, photointerpreters detected only a portion of the actual number of spruce and fir tallied during ground inspection. In many cases, omission errors were caused when smaller trees were obscured by overstory shadowing cast while photographing at lower sun angles. In addition, several hardwood species that cohabit spruce-fir stands often form an overstory obstruction causing errors of omission and commission. Some spruce and fir trees were completely covered while partial obstruction of others limited viewing of critical distinguishing characteristics. Basal area data (Table 7) and photointerpretation results indicate that stands of different forest type lead to varying degrees of precision and accuracy. In general, study areas with greater volume of hardwood and other softwood species lead to a smaller percentage of host tree detection. This is accompanied by a lower agreement of tree condition and species identification between aerial estimates and ground truth data.

ADVANTAGES AND DISADVANTAGES OF SMALL-FORMAT PHOTOGRAPHY

Advantages of 35-mm photography include costs, ease of handling, versatility, and the establishment of a historical ground condition record. Equipment purchase and film processing costs were considerably less than large format systems. Use of Ektachrome slide film and E-6 developing kits allowed for rapid processing following each flight. 35-mm size transparencies were also useful as they required little storage space and could be viewed with Bausch & Lomb stereoscopic equipment.

The portable camera mount is used without aircraft modification, positioned on the left side of high winged airplanes. The mount is adaptable to several varieties of aircraft, and this versatility enables the user to rapidly acquire photographs without the responsibilities of aircraft ownership.

Aerial photographs obtained in 1979 established a historical record of the sampled spruce-fir stands. This allows rapidly changing conditions such as insect distribution and tree condition status to be documented. Future seasonal and temporal photographs have the potential to monitor long-term change in spruce budworm infestation and defoliation intensity for purposes of pest management.

There are some limitations associated with small-format photography. Atmospheric convection, topographic relief, and light aircraft altimeter precision resulted in photographic scales that exhibited some degree of variation. Few photographs included indentifiable ground features from which to determine accurate photo scale. Unobstructed views of plot markers did exist, but could not be used on a consistent basis for scale determination. Hardwood overstory, crown shadows, and relief displacement often masked portions of the markers.

TIMING OF PHOTOGRAPHY

Seasonal and daily timing of flight work is an important consideration for assessing spruce-fir stands infested with spruce budworm. Previous studies (Ashley *et al.*, 1976) indicate that midsummer photographs, flown when clipped needles retained in budworm's webbing were at the height of browning, are best for evaluating current defoliation. Overall tree condition and past feeding showed up greater on fall photographs after damaged needles had fallen from webbings.

To quantify past and current damage concurrently, we chose to obtain photographs in late summer (29 July to 28 August). To allow time for data processing, management decisions, and initiation of potential salvage operations, it is important to assess spruce-fir stands' absolute condition as soon as possible after the current year's defoliation has occurred.

Flights were scheduled to avoid maximum midday atmospheric convection and its effects on small aircraft at low flying altitudes. Mid-morning and afternoon flights were selected as atmospheric stability was considered a necessity, even at the expense of some image contrast and reduction in tree shadows associated with high sun angle photographs.

Conclusion

This investigation determined the precision and accuracy of estimates of forest parameters obtained using small-format aerial photographs. Working with photographs at a scale of 1:4800, it is possible to conclude:

- Small-format aerial photographs, using Ektachrome slide film and E-6 developing kits, are a viable medium for identifying spruce-fir forest characteristics of tree condition and spruce budworm host species;
- Balsam fir and spruce were separable with 80 percent frequency on quality photographs;
- Mean aerial stand tree condition estimates always fell within one-half of a ranking class of the mean from ground truth data;
- Aerial estimates of host species mortality were within 10 percent of ground truth data; and
- Spruce-fir stands with greater volume of hardwood and other softwood species lead to a greater number of omission and commission errors in aerial estimates of forest parameters than do spruce-fir stands with less hardwood and other softwood component.

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International Symposium
Land Information at the Local Level

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This Symposium, sponsored by the Land Information Institute (LII), the Institute for Modernization of Land Data Systems (MOLDS), and the University of Maine at Orono (UMO), and cosponsored by some seven national and international professional organizations, including the American Society of Photogrammetry, will assemble experts from the United States and abroad who are active in land information management. Technical, political, economic, legal, and institutional elements will be considered in a balanced and unified manner with emphasis on problems at the local level. How institutional arrangements affect the collection, dissemination, and maintenance of land information will be discussed. Other sessions will deal with land related issues and the need for land information systems. Topics on management of spatial data, electronic communication and distributed data base management, digital mapping, and geodetic satellite techniques which use the Global Positioning System will comprise the sessions on technology. There will be a special session on International Perspectives where experts from Europe will present their experience with land information at the local level.

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