PEER-REVIEWED ARTICLE

The Alaska Four-Phase Forest Inventory Sampling Design Using Remote Sensing and Ground Sampling

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Abstract

A four-phase sampling method using Landsat, high-altitude color infrared photography, low-altitude color infrared photography, and ground samples was tested in interior and coastal Alaska from 1982 through 1986. Ratio and regression estimators were applied using variables at the remote sensing phases as covariates related to variables of interest measured on the ground. The four-phase sampling strategy yielded more efficient estimators in coastal Alaska's more heavily timbered area than in interior Alaska's highly heterogeneous vegetation complexes. Advantages and disadvantages associated with each of the phases of the study are presented, as well as a general evaluation of the entire system.

Introduction

Inventorying and monitoring Alaska's vegetation requires major effort. Alaska has 151 million hectares of land, inland lakes, and rivers within its borders. Over 80 percent of this area (121 million hectares) is estimated to be forest and rangeland (USDA Forest Service, 1989; Waddell and Oswald, 1989). Ecosystems vary greatly over the state, ranging from maritime temperate conifer forests in southeast Alaska, where timberland can carry more than 1,500 cubic metres of wood volume per hectare, to tundra at the northern extreme.

The Forest Service is responsible for inventorying the timber resource of Alaska. The first timber inventory in southeast Alaska, beginning in the early 1950s, used 1:40,000-scale vertical black-and-white photography. These photos were acquired by the military and were flown simultaneously with larger scale oblique black-and-white photography (Anderson, 1956). The timber inventory of interior Alaska began in 1960, with 1:5,000-scale black-and-white infrared photo strips flown at 40-kilometre intervals (Haack, 1962). These photo strips formed the frame for sampling forest vegetation across interior Alaska. One of the very early inventories incorporated aerial stand-volume-table measurements in an extensive timber inventory (Allison and Breadon, 1960; Haack, 1963). Results of these inventories were reported by Hutchison (1967).

Between 1965 and 1978, timber and vegetation were generally inventoried with medium-scale black-and-white panchromatic photography, using a stratified two-phase sampling design (Bickford, 1952). In 1977, with the acquisition of statewide small-scale photography (U-2 and RB-57 flown), color infrared photography was used for stratification in double sampling for stratification with good success (Hegg, 1984). Since the mid-1970s, satellite-borne sensors have shown considerable promise for use in vegetation inventories (Kuusela and Poso, 1975; Heller, 1975; NASA, 1976; Hoffer *et al.*, 1979; Walker *et al.*, 1982; USDA Forest Service, 1983b; Hame and Tomppo, 1987). Such a sampling approach commonly used Landsat MSS for stratification into classes such as forest, barren, water, etc.

The objective of this study was to develop and test a sampling strategy that predicts the area, volume, and net growth of Alaska forests from regression or ratio estimators using ground information as truth (y) and remote sensing information as covariates (x). The Forest Inventory and Analysis units require a 3 percent allowable estimation error per 404,685.64 ha (million acres) of timberland and 10 percent allowable error per 28,317,000 m^3 (billion cubic feet) of growing stock.

Methods

A New Four-Phase Design

In the early 1980s, the Forest Inventory and Analysis project in Anchorage began testing a new four-phase multiresource inventory system. The project used Landsat MSS (LS) imagery, high-altitude (1:60,000-scale) color infrared photography (HAP), low-altitude (1:3,000-scale) color infrared photography (LAP), and ground plots. This system also used recent enhancements in remote sensing (i.e., newly developed aerial stand-volume tables) to gather data and information about Alaska's inaccessible timber and nontimber vegetation.

The new system was named the "Alaska Integrated Resource Inventory System" (AIRIS) (LaBau and Schreuder, 1983). The sampling design evaluated information collected on circular sample plots of 8 hectares systematically located on (1) a 5-kilometre grid on Landsat imagery, (2) a 10-kilometre grid for high-altitude color infrared photography, (3) a 20-kilometre grid for low-altitude color infrared photography,

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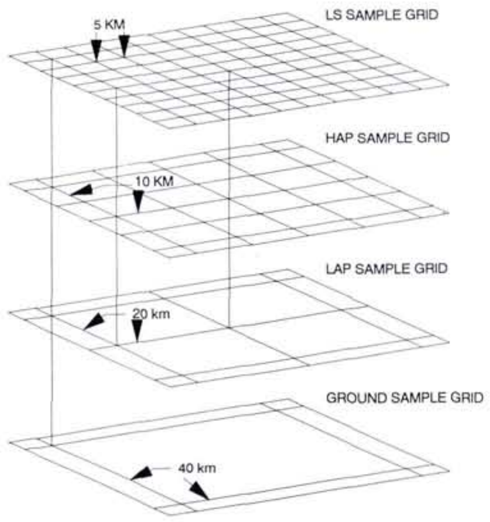

Figure 1. AIRIS four-phase sample grid intervals

and (4) a 40-kilometre grid on ground plots (see Figure 1).[1] Plot centers for all four phases were at the grid intersections. The type of information collected is shown in Table 1. Viereck and Dyrness (1980) developed the vegetation classification system and it was modified for remote-sensing applications (USDA Forest Service, 1983a).

TABLE 1. SUMMARY OF INFORMATION MEASURED OR OBSERVED AT EACH OF THE FOUR PHASES IN AIRIS.

Phase	List of information measured or observed
Landsat	Percent of 8 hectare plot in various classification groups (level 1 and 2)
High altitude photography	Percent of 8 hectare plot in various classification groups (level 3) Elevation Universal transverse mercator Description of classification group edge Distances to various physiographic features (water, roads, cities, etc.)
Low altitude photography	Percent of 8 hectare plot in various classification groups (level 4) Foliar cover of classification groups Stand size class of classification group Understory component of classification group Crown diameter of trees Heights of trees and shrubs from stereo photos (parallax measurement) Ground land use
Ground plots	The standard set of forest inventory variables, including tree species, diameter, heights, damage classes, understory vegetation description, wildlife habitat features, fuel loading summary, soils description, etc.

In order to assess the applicability of the four-phase inventory design to a variety of vegetation conditions, it was tested in two very different vegetative ecosystems of Alaska. The two areas selected were the Tanana River basin and southeast coastal Alaska. The Tanana River basin has a boreal forest ecosystem, located between 62 degrees, 50 minutes and 65 degrees, 50 minutes north latitude in interior Alaska. The southeast coastal Alaska area has a temperate rain-forest ecosystem, located between 55 degrees and 60 degrees north latitude.

The first part of this study was conducted in the 13.47-million-hectare Tanana River basin during the summers of 1982 and 1983 to evaluate AIRIS on a wide range of interior Alaska classification groups. Next, AIRIS was used in the 11.2-million-hectare southeast Alaska coastal area during the summers of 1985 and 1986. In southeast Alaska, the large-scale nominal photo scale was changed from 1:3,000 to 1: 7,000 to lessen the hazard for low-flying photo aircraft in rough terrain.

We recognized that satellite-based remote-sensing systems like Landsat MSS were being improved and replaced. Landsat's Thematic Mapper (TM) (Hame, 1987; Naugel *et al.*, 1986) reportedly gave better results than MSS. The French Spot System (Begni *et al.*, 1986) seemed to improve classification accuracy greatly for small areas. But by the mid-1980s, the TM system and data set were not developed enough for our extensive Alaska inventory system. SPOT had not yet been launched.

Also, existing computer hardware in the 1980s did not have the processing capability to accomodate the enormous database associated with higher resolution imagery. For very large areas, such as the Tanana River basin or southeast Alaska, we had to manipulate the MSS data in pieces to handle the large amount of data.

The Landsat MSS data were georectified to 1:63,360-scale 15-minute USGS map sheets which are standard for Alaska. The approximate number of ground control points per image was 50. A third-order polynomial equation was used in the coordinate transformation. The imagery was classified using the modified cluster block approach described by Fleming *et al.* (1975). Using this approach, cluster statistics were calculated for a mosaic of recognizable sub-scenes. The cluster statistics were calculated using an isodata clustering algorithm in an "unsupervised" mode. After the training statistics were defined, a maximum-likelihood classifier was used to classify the sub-scene mosaic. The cluster classes were labeled and the cluster statistics were modified using ground reference information, terrain data, and other ancillary information. The modified statistics were used to classify an entire scene. The modified statistics were further refined to produce the first-phase data set. Aerial photos were then used for general verification.

The 14-scene Tanana MSS data set was geocoded to three Universal Transverse Mercator (UTM) zones. The 12-scene southeast Alaska MSS data set was divided into seven subsets covering three UTM zones. Landsat MSS and HAP photography were purchased. Low-altitude aerial photos were acquired at 20-kilometre intervals with a combination of a radio-based navigation system (OMEGA and LORAN) in interior Alaska and visual controls in southeast Alaska. Visual controls were more satisfactory in overflying and photographing plot locations. Aerial stand-volume-table algorithms were developed

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[1] Strictly speaking, the design used is four-phase sampling with subsampling because the ground plots are subsampled for many of the variables of interest. But this within-plot variability plays a minor role in estimation, so we ignored it.

TABLE 2. ESTIMATED PERCENTAGES FOR SELECTED CLASSIFICATION GROUPS IN EACH OF THE FOUR PHASES.

	Tanana River Basin				Southeast Coastal Alaska			
Classification group	Ground	LAP	HAP	Landsat	Ground	LAP	HAP	Landsat
Needleleaf	41.2	39.0	31.1	34.0	48.8	49.1	47.3	46.8
Broadleaf	23.8	33.4	36.2	21.9	14.8	13.9	16.4	10.8
Mix Vegetation	12.4	6.6	15.9	16.3	.4	1.0	.1	0.0
Herbaceous	5.8	5.1	4.2	10.3	2.9	1.8	.8	7.6
Barren	14.8	13.2	11.4	15.9	31.4	31.5	32.9	31.9
Water	1.8	2.7	1.8	1.6	1.7	2.6	2.4	2.9
Number of plots	87	325	1291	5448	87	226	919	3708

for use in estimating volumes from the large-scale photos (Mead and Setzer, 1984; Setzer and Mead, 1986). The selected ground sample plots were visited and measured for the variables of interest.

Estimation Theory

Regression and ratio estimators for four-phase sampling were derived (Li *et al.*, 1984; Schreuder, 1981). This scheme uses covariate information from the three remote-sensing phases and correlates it with relevant ground information. The information from the three phases is then combined with the ground information by using three double sampling with ratio or regression estimators. The three estimates of the same parameter are pooled by combining them with appropriate weights w_i ($i = 1, 2, 3$). Li *et al.* (1984) compared weights based on the estimated variance-covariance matrix and the estimated variances. The more complex estimator based on the estimated variance-covariance matrix was more efficient, but the simpler estimator is preferred when computational simplicity is desirable.

Within the regression framework are three regressions for the LAP, HAP, and LS phases. Each is combined with the ground-based information

$$y_i = a_{\mathrm{LAP}} + b_{\mathrm{LAP}} \quad x_{\mathrm{LAP}_i},$$

$$y_i = a_{\mathrm{HAP}} + b_{\mathrm{HAP}} \quad x_{\mathrm{HAP}}\mathrm{i},$$

and

$$y_i = a_{\mathrm{LS}} + b_{\mathrm{LS}} \quad x_{\mathrm{LS}}\mathrm{i},$$

where y_i is the value for the variable of interest on plot i; $x_{\mathrm{LAP}i}$, $x_{\mathrm{HAP}i}$, and $x_{\mathrm{LS}i}$ are the corresponding covariate values on plot i; and a and b are estimated regression coefficients. The regressions are then used to yield estimates

$$\hat{Y}_1 = Na_{\mathrm{LAP}} + b_{\mathrm{LAP}} \quad x_{\mathrm{LAP}},$$

$$\hat{Y}_2 = Na_{\mathrm{HAP}} + b_{\mathrm{HAP}} \quad x_{\mathrm{HAP}},$$

and

$$\hat{Y}_3 = Na_{\mathrm{LS}} + b_{\mathrm{LS}} \ x_{\mathrm{LS}},$$

where N is population size and x_{LAP}, x_{HAP}, and x_{LS} are the large sample estimates for the covariates from LAP, HAP, and LS, respectively. These estimates are then combined with weights w_1, w_2, and w_3, as discussed earlier, into an overall estimate:

$$\hat{Y} = w_1\hat{Y}_1 + w_2\hat{Y}_2 + w_3\hat{Y}_3.$$

We used the inverses of the sample variances as weights, so the variance estimator (Li *et al.*, 1984) is

$$v(\hat{Y}) = \frac{1}{w}\left[1 + \frac{4}{w_2}\sum_{i=1}^{3} w_i\,(w - w_i)\;/\;(n_i - 2)\right],$$

where

$$w = \sum_{i=1}^{3} w_i.$$

Selecting Good Covariates

Deciding on usable covariates for this study was one of the most difficult, and initially misunderstood, aspects of the study. We wanted to use regression estimators that assumed good relations between the covariates and variables of interest, but such good relations often do not exist. We found it difficult to measure covariates that were highly correlated with variables of interest assessed on the ground. It was most difficult with Landsat. Some vegetation types, with both low- and high-altitude photography, were also difficult to assess. A worst-case example is timberland because classifying timberland is even subjective on the ground, particularly for marginal sites.

Another problem with covariates was that some data variables were "forced" into discrete rather than continuous values. Variables such as classifications of forest types, cover class, and stand-size class produced many percentage values that were 100 at one phase and 0 at another. It only took a few such occurrences to result in poor correlations.

Results and Discussion

The four-phase sampling design was used in two very different parts of Alaska. We will discuss each sampling phase independently and then summarize the utility of the entire design.

Table 2 indicates the accuracy of AIRIS remote-sensing estimates of what was found on the ground. The table gives estimated percentages of classification groups observed at each of the four phases. A comparison between estimates shows that, in both survey units, proportion of classification groups in all phases of remote-sensing agreed quite closely with the ground proportion for the barren and water classes. There is a fairly consistent trend in estimating needleleaf vegetation in southeast Alaska. In the Tanana River unit, however, the proportions estimated for needleleaf on HAP and LS were 25 and 17 percent below the ground estimates. We presume this occurred because open conifer forest lands were classed as mixed or other non-needleleaf vegetation.

Estimates of proportions for the southeast coastal Alaska phases were generally closer between ground and remote-sensing phases than were estimates for the Tanana River basin. This was probably because the vegetation in southeast

Table 3. R^2 Values by Sample Phase and Classification Group with Ground Estimates.

Classification group	Tanana River Basin			Southeast Coastal Alaska		
	LAP	HAP	Landsat	LAP	HAP	Landsat
Needleleaf	0.78	0.54	0.17	0.98	0.80	0.56
Broadleaf	0.57	0.48	0.05	0.55	0.41	0.18
Mixed Vegetation	0.67	0.10	0.00	0.09	—	—
Herbaceous	0.62	0.24	0.00	0.02	0.00	0.34
Barren	0.99	0.97	0.78	0.89	0.93	0.85
Water	0.96	0.81	0.03	0.94	0.92	0.80

Alaska is more homogeneous and, therefore, gives better consistency in estimates from the remote-sensing phases. The correlations of remote-sensing information with ground measurements by classification group (Table 3) were generally good for the class called "barren" for all remote-sensing phases. The correlations for the water class were generally good, except in the Tanana River basin for Landsat.

Generally, correlations for Landsat vegetation estimates were low, except for needleleaf forests in southeast Alaska (0.56). Low R^2 values for both mixed and herbaceous vegetation in southeast Alaska are probably due to low sampling intensities. This can result in an unsatisfactory range of values for the variables. Low correlation of HAP with ground information in the Tanana River basin can be attributed to the inability to photointerpret particular vegetation characteristics observed on the ground. Highly heterogeneous vegetation patterns, often the result of fire and permafrost, can cause some of this confusion.

Some of the most disappointing correlations of estimates by general land class (Table 4) came when we tried to predict the timberland acreage, which is a basic statistic required in forest inventory and analysis reports. The correlations between LAP and HAP with ground values in southeast Alaska were more acceptable. We attribute this to the higher prevalance of timber in southeast Alaska than in interior Alaska. Area, forest volume (m^3), growth (m^3), and associated standard errors were estimated. All tables of estimates and standard errors are presented by six forest type categories (black spruce, white spruce, balsam poplar, aspen, paper birch, and nonforest) and by three land-use classes (timberland, other forest, and nonforest) for the Tanana River basin. Table 5 summarizes estimates of area and standard errors by forest type and ground-checked land use. (Such standard errors, expressed as a percentage of the estimated totals, can be misleading if the estimated totals or sample sizes are small. It also should be noted that, for Tables 5, 6, and 7, row and column totals may not reflect the exact sum of values in the rows and columns. This is because our regression sampling computes estimates for each cell.)

The only comparable inventory estimates were made in the early 1960s (Hutchison, 1967). Total area, only 2 percent different, was comparable: 13.73 million ha ((33.899 million acres) in the 1967 report and 13.99 million ha (34.56 million acres) in the AIRIS report. Estimates of total forest land were only 3.9 percent different: 8.39 million ha ((20.73 million acres) in the 1967 report and 8.73 million ha (21.57 million acres) in the AIRIS report.

Major differences existed, however, in the estimate of timberland which is defined as forest producing, or capable of producing, 1.40 m^3 per ha (20 cubic feet per acre) per year. The 1967 report showed 1.95 million ha (4.83 million acres) of timberland, but the AIRIS report showed only 0.59 million ha (1.47 million acres); the earlier estimate was thus 3.2 times as large as the AIRIS estimate. Some of this difference was the result of different approaches to evaluating productivity of the sites. There may also have been a slight difference in definitions used. But the AIRIS estimates appeared to have underestimated timberland, based on a recent inventory of a portion of the Tanana River basin. The more recent inventory (van Hees, 1984) provided an estimate of 0.89 million ha (2.19 million acres) of timberland from the 5.50 million ha (13.6 million) acres of the most productive portion of the Tanana River basin. This inventory, completed in 1975, showed 291,384 ha (720,000 acres), 49 percent higher than the AIRIS estimate.

AIRIS did not sample rare riparian balsam poplar acreage on timberland because of the small ground-sample size. Standard errors were not unreasonably high, given the relatively small sample size associated with various cells in the table. The nonforest sampling error was small because of the many plots that fell in that class.

Estimates of volume (m^3) and standard errors (Table 6) were generally reasonable. The large amount of volume in the white spruce-other forest class was a surprise. Almost 52 times as much volume was in noncommercial white spruce stands as in white spruce timberland (Table 6). Over twice as much noncommercial volume is in white spruce as in black spruce. These comparisons have not been made at this scale before, so further study is needed before general conclusions can be attempted.

The standard errors of the estimates (in m^3) looked reasonable upon comparing the standard error estimates for area (Table 5) and considering the very small ground sample size. The reason for the large standard error associated with nonforest land is that little volume exists there, and the volume present has a high degree of variability.

Growth rates of 2.7 percent for timberland (Table 7) were slightly higher than expected, but, because of the low

Table 4. R^2 Values by Sample Phase and General Land Class with Ground Estimates.

General land class	Tanana River Basin			Southeast Coastal Alaska		
	LAP	HAP	Landsat	LAP	HAP	Landsat
Timberland	0.387	0.268	0.400	0.522	0.722	0.350
Softwoods	0.690	0.229	0.204	0.914	0.759	0.529
Hardwoods	0.345	0.516	0.079	0.966*	0.___**	0.005
Mixed vegetation	0.677	0.105	0.001	0.962	0.856	0.588
Nonforest	0.908	0.803	0.478	0.966	0.857	0.588

* High correlations have to be treated with caution because 84 plots with LAP data were zeros and 2 plots with LAP data were 100 percent.

** Values cannot be computed because all the HAP values are zeros.

intensity of the forest land sample, no dead trees were sampled so the net growth had no mortality factored in. Thus, the figures in these tables are higher than the normal net-growth summaries, which have mortality removed. Growth rates in the first inventory of interior Alaska were about 1.5 percent after the effects of mortality were removed (Hutchison, 1967).

Aspen had the best growth rate. The growth rate of balsam poplar was surprisingly small compared to other growth rates. The total growth estimates for paper birch, which were about half of the other growth rates, is of interest and needs further study. The standard error estimates (Table 7) were consistent with those found in the volume estimates (Table 6), with the possible exception of the difference in total volume for paper birch.

Assessment of the Sampling Design

A major advantage of the Landsat phase is that frequent and complete coverage of the population was generally available, although we spent much time assembling the needed information. The area can be mapped using the Landsat MSS data so that historical information on the area of interest is available. Potential complexities in implementing any sampling design can be considered early on by studying this map and the mapped database can be related to the inventory information.

One big disadvantage of using Landsat MSS data in this regression framework was the complexity of the process, which included screening imagery needed to select the total set of available scenes; deciding whether available scenes are useful; training personnel to handle and interpret Landsat data; registering the scenes; deciding on what ancillary data might be useful in interpreting Landsat data; evaluating the results for logical integrity; classifying the entire scene and all 8-hectare plots; matching up the Landsat locations with those for the three other phases; and acquiring priority use of a large computer. Classifying vegetation for rough terrain, such as in coastal Alaska, also presented problems.

One of the greatest handicaps in this study was the limited availability of a large, dedicated computer. The amount of data available on the Landsat tapes was so enormous that the computing power available was limiting and caused considerable delay. The Tanana River basin unit, for instance, touched on 24 three-degree USGS topographic quadrangles. Computing power has recently increased dramatically. The analysis phase of the Landsat MSS data took one person-year for the Tanana unit and three-fourths of a person-year for the southeast unit. Landsat MSS data would likely be more useful in a stratification rather than a regression framework.

TABLE 5. AREA AND STANDARD ERROR OF ESTIMATE IN PERCENT (IN PARENTHESIS) BY FOREST TYPE AND GROUND LAND-USE CLASS, TANANA RIVER BASIN, AIRIS STRATIFIED FOUR-PHASE SAMPLE, BEST ESTIMATOR.

Forest Type	Timberland	Other Forest	Nonforest	Total area
	Estimated acreages (ha)			
Black Spruce	88,035 (81.1)	4,346,070 (11.9)	0	4,572,869 (8.2)
White Spruce	63,242 (60.5)	1,954,930 (22.4)	0	1,759,591 (23.0)
Balsam Popular	0	160,666 (86.9)	0	96,406 (40.2)
Aspen	187,975 (76.3)	359,175 (63.3)	0	506,366 (40.9)
Paper Birch	245,890 (45.8)	787,852 (33.9)	0	934,464 (29.1)
Nonforest	0	0	5,368,412 (5.4)	5,665,289 (3.4)
Total all classes	595,554 (27.5)	8,133;259 (4.4)	5,388,006 (5.4)	13,986,435 (0)

TABLE 6. NET VOLUME (M^3) AND STANDARD ERROR IN PERCENT (IN PARENTHESIS) BY FOREST TYPE AND GROUND LAND-USE CLASS, TANANA RIVER BASIN, AIRIS STRATIFIED FOUR-PHASE SAMPLE, BEST ESTIMATOR ADJUSTED[1].

Forest Type	Timberland	Other Forest	Nonforest	Total volume
	Estimated net volume (m^3)			
Black Spruce	1,068,229 (99.8)	27,137,016 (35.0)	0	28,205,240 (33.8)
White Spruce	1,107,326 (75.6)	57,465,364 (32.1)	0	55,287,645 (31.2)
Balsam Poplar	0	2,883,487 (99.9)	0	2,883,487 (99.9)
Aspen	11,414,806 (68.5)	13,626,925 (95.7)	0	25,041,729 (60.7)
Birch	4,795,274 (46.5)	14,544,576 (34.0)	0	28,703,019 (19.7)
Nonforest	0	0	661,390 (58.6)	661,390 (58.6)
Total all classes	22,534,535 (44.4)	109,344,159 (19.9)	661,390 (58.6)	140,029,698 (15.6)

[1] See Li and Schreuder (1985).

TABLE 7. NET GROWTH (M^3) AND STANDARD ERROR OF ESTIMATION IN PERCENT (IN PARENTHESIS) BY FOREST TYPE AND GROUND LAND-USE CLASS, TANANA RIVER BASIN, AIRIS STRATIFIED FOUR-PHASE SAMPLE, BEST ESTIMATE, ADJUSTED[1].

	Timberland	Other Forest	Nonforest	Total volume
	Estimated net growth (m^3)			
Black Spruce	18,951 (99.8)	1,888,525 (39.7)	0	1,907,477 (39.3)
White Spruce	67,742 (71.6)	3,120,620 (35.1)	0	2,998,270 (32.8)
Balsam Poplar	0	122,685 (99.9)	0	1,282,985 (99.9)
Aspen	955,136 (68.6)	1,634,256 (97.9)	0	2,589,392 (66.8)
Birch	384,957 (47.7)	782,116 (43.4)	0	1,176,458 (37.6)
Nonforest	0	0	14,414 (57.2)	14,414 (57.2)
Total all classes	1,773,369 (46.0)	7,548,202 (25.8)	14,414 (57.2)	9,336,852 (21.5)

[1] See Li and Schreuder (1985).

High-altitude photography (HAP) has the advantages of nearly total, usable coverage, is relatively inexpensive, and is likely to be cost-effective in estimating certain variables. People can be easily trained to use it, and a larger pool of trained people is available for HAP than for LS analysis. High-altitude photography may be older and more out of date than Landsat MSS. Contracting for new coverage requires cooperation from other agencies because costs are so high for photo acquisition. Often, only third generation transparancies are available. Shadow problems occur, especially at high latitudes and in steep terrain. Low resolution presents problems in classifying timberland when compared to low altitude photography. Quality control of the photographs must be stringent. In this study interpretation was inconsistent, often because photos varied in color balance, saturation, and exposure. Registration to match the ground sample was time-consuming, expensive, and challenging. Photo manipulation for interpretation was cumbersome. Scale rectification over rough terrain was also a problem. In summary, HAP has the advantage of being readily available for large-area coverage. The principal disadvantages are that new coverage is difficult and expensive to obtain. Automatic registration with respective ground plots is difficult.

Low-altitude photography has the advantages of high resolution and it can be used with available aerial stand-volume tables. It provides good area control for the sampling process and probably gives the best area measurements for certain vegetation cover and land-use classes. Polygon data, including vegetation edges, are available for edge analysis studies. In this study, coverage was almost cloud-free when it was acquired. Coverage was recent, was first generation, and served as a detailed permanent record of the ground plots.

Low-altitude photography also had disadvantages. Acquisition was unpredictable and was more expensive than expected because of inclement weather. Coverage was limited. Photo manipulation for interpretation was cumbersome, and shadow was often a nuisance on the color infrared photography. Photo plots were difficult to locate on the ground in highly homogeneous areas because the stereo model area was too small to register distinct land or vegetation features between photo and ground. Fortunately, this problem was uncommon. Even with global-navigation-system guidance, capturing the precise photo image over the desired grid location was often impossible.

In summary, the key advantages of low altitude photography were high resolution that results in reliable aerial volume tables, certain area variables that result in accurate measurements, and photos that result in a good permanent record for obtaining detailed information. The main disadvantages were that acquisition was difficult and needed to be planned several years in advance to ensure adequate coverage.

Advantages of the 8-hectare ground plots are that a broad spectrum of multiresource data can be obtained from such plots, definitive information on boundaries and riparian habitat can be collected, and previously unavailable data can be obtained through juxtaposition of different land or vegetation classes. This phase generally represented the best available determination of what is actually there.

The main disadvantage of the 8-hectare ground plot design was that measuring the ground plot with its cluster of 19 points was time consuming and labor intensive. Tough decisions were required to limit information collected because of the tendency to sample everything of interest.

In summary, the sampling of the large ground plot yielded pertinent and accurate data. Small, disturbed plots complicated the efficient collection of data. There were major logistical problems, in terms of transportation support and the difficultly of traversing terrain, particularly in coastal Alaska.

Clouds in the imagery resulted in missing data for all phases of remote sensing. Bias may have entered in forest and nonforest differentiations because clouds tended to accumulate in mountainous and nonforest areas. Because of missing remote-sensing data, we eliminated sets of plots where one layer was missing. This reduced the useful data set and increased sampling error.

Conclusions

Results with this sampling strategy were disappointing; R^2 values were less satisfactory than expected and some of the larger values are misleading because of small sample sizes and/or extreme values (Tables 3 and 4). We had a small sample size because the planning stage emphasized multiresource data. Therefore, only a small number of timber plots were selected. Increased sampling intensity, through stratified allocation of plots to forested land rather than nonforested lands, would have given better results for estimating timber.

Classifying subjective variables such as "timberland" was difficult even on the ground, particularly for younger and marginal sites. Clearly, this classification was even more difficult on Landsat and high-altitude photography. Thus, the design was successful only for some of the more homogeneous classification groups. They were more prevalent in coastal Alaska. A site could easily be classified completely as timberland at one phase and noncommercial forest in another. Such 100 to 0 percent classifications are, of course, not conducive to good covariate relations.

Besides the somewhat disappointing correlations and problems with sample allocation, other key problems were as follows:

- Acquisition and registration of the total set of Landsat scenes was difficult and time consuming;
- Computer identification of forest land in conifer forest with 10 to 40 percent crown cover was often classified as hardwood forest or shrubland on remotely sensed imagery (instead of conifer, as classified on the ground plots);
- A very large-capacity computer was needed but not available for Landsat classification;
- Low-altitude color infrared photo coverage proved very difficult to acquire because of weather problems; and
- Study plans failed to predict how much labor would be needed for activities such as satellite data classification and aerial stand volume table measurements.

Basically, the sampling strategy may be a good one but it was several years ahead of current support technology. It resulted in greater inefficiencies and higher costs than might be expected today with the latest developments of remote-sensing and computer support systems. The change from multiresource objectives to more timber-oriented objectives also hurt. This also explains why this design was more useful for timbered areas like southeast Alaska than for diverse ecosystems like interior Alaska. The design used offers flexibility. Two-phase or three-phase sampling for regression with or without stratification should be further investigated in the future as computer and remote-sensing technology improve.

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