A Comparison of Optical Bar, High-Altitude, and Black-and-White Photography in Land Classification

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ABSTRACT: For large-area forest surveys, 1981-84 color infrared national high-altitude program (NHAP) and 1983 optical bar color (OBC) infrared photography resulted in equally precise estimates of land-use/land-cover area. Both were only slightly more precise than 1970 black-and-white photography. OBC was the least cost effective because optical bar imagery is usually flown specifically for a survey, whereas NHAP and older black-and-white photography are readily available. Optical bar photography can be used effectively up to 35 degrees from nadir.

INTRODUCTION

AERIAL PHOTOGRAPHY has been used in forest surveys. Aerial photos provide much information about resources, particularly the location and area of land-use/land-cover classes. An airplane can cover a large area much faster and more economically than field crews. Aerial photographs also provide a frame from which to sample plots for ground observation. In small- to medium-scale or intensive surveys, a stratified sampling procedure is often used in which the entire forest area is delineated into strata, such as forest types. Plots are then selected randomly within each stratum for ground observation. In large-area or extensive surveys, a double sampling for stratification procedure is often used. Rather than stratifying all forest land, a large number of sample points are randomly or systematically selected for classification on the photos. Thus, stratum sizes are extimated rather than known. Plots are then selected randomly within each stratum for ground observation.

OBJECTIVES

The three most inexpensive and readily available types of imagery were compared for their accuracy, precision, and cost effectiveness in stratifying the continuing statewide surveys conducted by the Northeastern Forest Inventory and Analysis (FIA) unit of the USDA Forest Service. The three types of imagery were (1) out-of-date black-and-white (B/W), (2) specially flown optical bar camera (OBC), and (3) regularly flown National High Altitude Program (NHAP) color infrared photography. Since the viewing angle constantly changes in OBC imagery, its effects on land-use/land-cover estimates were also tested.

AERIAL PHOTOGRAPHY

Black-and-white aerial photography at photo scales of 1:15,840 to 1:40,000 has long been the standard in natural resources. Much of the photography was taken for the Agricultural Stabilization and Conservation Service (ASCS) and other agencies. The extensive surveys conducted by FIA units have relied on the availability of this imagery. For this study the 14-year-old B/W imagery was inexpensive because it had been used for the previous survey. The B/W photgraphy was of conventional 1:40,000 scale flown during May and September of 1970. It could be expected to perform well only if little change in land use/land cover had occurred between 1970 and 1984.

The ASCS and other federal agencies are participating in the funding of the NHAP to provide complete coverage of the United States on a five-year cycle. Two types of photography are being produced: 1:58,000-scale color infrared (CIR) and 1:80,000-scale B/W. The NHAP is expected to replace the medium-scale B/W photography used in the past. The primary purpose of the NHAP is to classify land use/land cover, and it has been flown under lead-off conditions. The second cycle will be flown during leaf-on conditions and may produce differing results. The CIR prints used in this study were taken in March and April (leaf-off) between 1981 and 1984. The photography had a measured scale of 1:58,000.

The optical bar imagery was taken by the Itek Iris II advanced panoramic camera system, developed by Itek Corporation* for the U.S. Air Force. The OBC photography had a nominal scale of 1:32,500 at nadir, but the scale decreases as the camera scans out to either side of nadir. The OBC imagery used was flown as part of another study and was, therefore, both readily available and inexpensive. OBC coverage for New Jersey was flown in July of 1983 (Ciesla, 1984) during a period of gypsy moth defoliation. Image format was 4.5 by 38 inches (0.114 m by 0.965 m) with a field of view 45 degrees either side of nadir (NASA, 1983). Scale at nadir varied between 1:32,000 and 1:32,500 due to ground elevation changes. Because the field of view was so wide, fewer flight lines were needed, which meant that large areas were photographed in a single day. The resolution on the CIR transparencies was roughly 0.6 metres at nadir (Befort et al., 1979). The OBC imagery used was taken at leaf-on, so it would be expected to perform well in a study involving classification of vegetation characteristics such as timber volume. The National Aeronautics and Space Administration (NASA) only takes OBC imagery on a contractual basis.

METHODS

The study areas were Salem, Warren, and Burlington Counties in New Jersey. These counties represent most of the conditions expected to be encountered in New Jersey. This study comprised part of the planning process for the 1986 New Jersey survey. The area covered 4,000 km², of which about half was forest land (Ferguson and Mayer 1974). The same set of photo points within each country boundary were interpreted on the three sets of photography to determine current land use/land

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0099-1112/87/5302–203$02.25/0

cover. All photointerpretation and field work were conducted by Douglas Griffith. His training for this study consisted only of looking at a few examples of most land-use/land-cover classes on each photo type and visiting those same examples in the field.

A Bausch and Lomb 240 zoom stereoscope with a range in magnification of 3.5× to 10× mounted on a Richards light table was used to monocularly classify 0.4 ha (1 ac) around each point on each of the three formats. Areas less than 0.4 ha were included in the surrounding class.

A 20-point grid within the effective area of the OBC imagery (approximately 35 degrees from either side of nadir) was made on clear acetate and placed on OBC transparencies for each county. The points were approximately 1.6 km apart on a line perpendicular to the line of flight. This spacing was chosen to approximate the spacing used in the previous survey of New Jersey. The current land use/land cover was interpreted for the OBC points. The OBC points were then visually transferred to and interpreted on 1970 B/W prints and on 1981-84 NHAP prints. All points were permanently marked on the OBC imagery for later field identification. The total photo sample size for this study was 1,680 points. The photointerpretation classes were

Code	Definition
FL	*Forest land*: land at least 16.7 percent stocked with forest trees, or land that formerly had such tree cover and is not currently developed for nonforest use. Must be capable of producing more than 0.23 m^3 per ha per year of industrial wood under management.
UF	*Unproductive forest land:* forest land incapable of producing 0.23 m^3 per ha per year of industrial wood.
NF	*Nonforest land without trees:* land that does not support or has never supported forests, and lands formerly forested where use of timber is precluded by development for other uses.
NFT	*Nonforest land with trees:* nonforest land with some tree cover.
W	*Noncensus water:* streams and rivers between 36.6 and 201 m in width, and bodies of water between 0.4 and 16 ha in size.
I	*Indeterminate land use:* land that cannot be easily classified into one of the preceding strata. Used to concentrate classification errors into a single small category, thereby reducing sampling errors.

The first two classes (forest land and unproductive forest land) were of primary interest to forest survey. Use of the other four classes resulted in more precise estimates of forested areas, because the likelihood of misclassifying forest land into each of these classes differed.

A total of 278 points were field checked in the fall of 1984. Rather than taking a proportionate sample across all strata, a fixed ground sample size was selected for the largest OBC strata: forest (FL) and nonforest land (NF and NFT). Larger samples would have been too expensive and unnecessarily precise. All photo points in the smaller OBC strata were observed on the ground, i.e., a 100 percent subsample. Each ground plot was classified by its current land use/land cover using the same classes, except that use of the indeterminate class was not permitted.

Effects of Distance from Nadir for OBC Imagery

To determine the useful area of an OBC image, possible differences in estimated forest area as a function of distance from nadir were tested. Data from the 20-point OBC grid were divided into five classes based on distance (in km) from nadir: 0.8 to 2.1, 3.5 to 5.0, 6.4 to 7.7, 9.0 to 10.3, and 11.4 to 12.7. These corresponded roughly to 4, 12, 20, 27, and 34 degrees from nadir and were chosen so that all five classes had approximately 325 photo points. Unbiased estimates of area in each land-use/land-cover class and estimates of the precision of these estimates were produced by distance class using double sampling for stratification estimators (Cochran, 1977): i.e.,

$$Y_d = A \sum_{h=1}^{6} N_h/N \sum_{i=1}^{n_h} y_{hi}/n_h \quad (1)$$

where

Y_d	=	estimated area (in ha) of a land use/land cover for distance class d (d=4, 12, 20, 27, and 34 degrees from nadir),
A	=	total land area in population of interest,
N_h	=	number of photo points in stratum h,
n_h	=	number of ground plots selected in stratum h,
y_{hi}	=	land-use/land-cover observation for ground plot i,
	=	1, if plot is in land-use/land-cover class of interest,
	=	0, otherwise, and
N	=	total number of photo points.

Assuming A and n were large, the variance of Equation 1 was taken from Cochran (1977) as

$$v(Y_d) = A^2 \left[\sum_{h=1}^{6} (N_h/N)^2 v(\bar{y}_h) + \sum_{h=1}^{6} (N_h/N)\,(\bar{y}_h - Y_d/A)^2/n \right] \quad (2)$$

where

$$\bar{y}_h = \text{estimated stratum mean,}$$
$$= \sum y_{hi}/n_h, \text{ and}$$
$$v(\bar{y}_h) = \text{estimated variance of stratum mean,}$$
$$= \sum (y_{hi} - \bar{y}_h)^2/(n_h - 1)/n_h.$$

A better test would be to repeatedly sample the same area with a different alignment of flight lines, but this would have been very expensive.

Comparison of OBC, NHAP, and B/W Imagery

The three types of photography were used to compare the accuracy and precision of estimating current area by land-use/land-cover class. The estimates were based on 1,680 photo samples and 278 ground samples. Equation 1 was used to produce estimates of the total by land-use/land-cover class. The estimated error was computed as the square root of the variance as given in Equation 2.

RESULTS AND DISCUSSION

Effects of Distance from Nadir for OBC Imagery

A positive bias in area of forest land could have resulted from the ability to see the sides of trees which were away from nadir. Their height could have caused the forest area to be overestimated. However, no significant difference in forest area was detected with OBC imagery as the distance from nadir increased. If any trend existed, it was a decrease in forest area rather than the increase expected as distance increased. In addition, no significant differences in area were detected for the other land-use/land-cover classes. The estimates of area by land-use/land-cover class and by distance class are given in Table 1. The percent sampling errors given are equal to the standard errors expressed as a percentage of the estimated area. The unproductive class was too small to include in this analysis. Plotting the 95 percent confidence intervals of the means by land use/land cover showed that the confidence intervals overlapped (see Figure 1). No bias was detected for any of the land-use/land-cover classes. OBC imagery can be used with confidence to estimate forest area out to 35 degrees from nadir (the effective area in this study).

TABLE 1. ESTIMATED AREA (KM^2) AND SAMPLING ERRORS BY LAND USE/LAND COVER AND DISTANCE CLASS FROM NADIR FOR OPTICAL BAR CAMERA PHOTOGRAPHY OF THREE COUNTIES IN NEW JERSEY.

Land Use/ Land Cover	Distance from nadir 0.8-2.1[1] 4[2]	3.5-5.0 12	6.4-7.7 20	9.0-10.3 27	11.4-12.7 34
FL Forest	2337	1934	2135	2358	1919
	(4.6)[3]	(9.1)	(8.2)	(5.7)	(6.3)
NF Nonforest	1125	1515	1175	1254	1275
Without Trees	(13.7)	(11.0)	(11.7)	(11.6)	(22.4)
NFT Nonforest	495	475	500	287	757
With Trees	(28.1)	(30.5)	(26.6)	(39.7)	(37.0)
W Noncensus	46	44	23	104	52
Water	(51.0)	(55.5)	(70.5)	(63.0)	(49.7)

[1] In km from nadir
[2] In degrees from nadir
[3] Percent sampling error is the standard error expressed as a percentage of the estimated area.

TABLE 2. ESTIMATES OF AREAS (KM^2) AND SAMPLING ERRORS FOR B/W, OBC, AND NHAP PHOTOGRAPHY BY LAND USE/LAND COVER CLASSES FOR THREE COUNTIES IN NEW JERSEY.

Photography	Land-Use/Land-Cover Class FL[2]	UF	NF	NFT	W
1970 B/W	2150	36	1306	456	56
	(3.3)[1]	(58.0)	(5.9)	(14.8)	(28.6)
1983 OBC	2148	36	1307	457	56
	(3.0)	(56.7)	(5.7)	(14.5)	(30.2)
1981-84 NHAP	2107	36	1326	476	58
	(3.0)	(54.1)	(5.2)	(11.7)	(36.5)

[1] Percent sampling error is the standard error expressed as a percentage of the estimated area.
[2] FL = forest land, UF = unproductive forest land, NF = Nonforest land without trees, NFT = nonforest land with trees, and W = noncensus water.

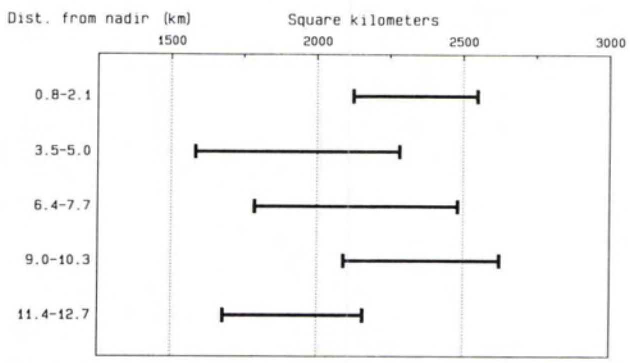

FIG. 1. Ninety-five percent confidence intervals about area (km^2) of forest land by distance from nadir for three counties in New Jersey.

COMPARISON OF OBC, NHAP, AND B/W IMAGERY

The land-use/land-cover area estimates and their sampling errors by type of imagery are given in Table 2. The sampling errors can be used to compute the relative precision of one type of photgraphy with respect to another for a given land-use/land-cover class. In addition, the error or cross-classification matrices for the three imagery types are shown in Tables 3, 4, and 5. Normally, the cells of the matrices would be integers, but, due to the different subsampling rates between strata, the figures have been weighted to a common basis. The classification accuracy, in percent, excluding the indeterminate class (I), was B/W = 76.8 OBC = 82.0, and NHAP = 91.5.

The differences in estimates of area and sampling errors

TABLE 3. CLASSIFICATION MATRIX OF WEIGHTED[1] NUMBER OF GROUND PLOTS FOR 1970 BLACK-AND-WHITE IMAGERY IN THREE COUNTIES IN NEW JERSEY.

Actual Land Use/ Land Cover	Photointerpretation Class FL[2]	UF	NF	NFT	W	I	Weighted Total
FL	127.80	3.00	0.00	14.40	1.00	5.00	151.20
UF	1.68	4.00	0.00	0.00	0.00	0.00	5.68
NF	4.76	0.00	24.00	31.92	1.00	0.00	61.68
NFT	2.76	0.00	1.00	36.18	0.00	2.00	41.94
W	0.00	0.00	0.00	1.50	16.00	0.00	17.50
Interpreted Total	137.00	7.00	25.00	84.00	18.00	7.00	278.00

[1] The number of ground plots within an actual land-use class is adjusted to account for the different subsampling rates between strata.
[2] FL = forest land, UF = unproductive forest land, NF = Nonforest land without trees, NFT = nonforest land with trees, W = noncensus water, and I = indeterminate land use.

TABLE 4. CLASSIFICATION MATRIX OF WEIGHTED[1] NUMBER OF GROUND PLOTS FOR 1983 OPTICAL BAR IMAGERY IN THREE COUNTIES IN NEW JERSEY.

Actual Land Use/ Land Cover	Photointerpretation Class FL[2]	UF	NF	NFT	W	I	Weighted Total
FL	138.91	3.00	0.00	6.34	1.00	5.00	154.25
UF	1.76	4.00	0.00	0.00	0.00	0.00	5.76
NF	2.25	0.00	31.71	28.78	1.00	0.00	63.74
NFT	2.08	0.00	1.29	31.61	0.00	2.00	36.98
W	0.00	0.00	0.00	1.27	16.00	0.00	17.27
Interpreted Total	145.00	7.00	33.00	68.00	18.00	7.00	278.00

[1] The number of ground plots within an actual land-use class is adjusted to account for the different subsampling rates between strata.
[2] FL = forest land, UF = unproductive forest land, NF = Nonforest land without trees, NFT = nonforest land with trees, W = noncensus water, and I = indeterminate land use.

TABLE 5. CLASSIFICATION MATRIX OF WEIGHTED[1] NUMBER OF GROUND PLOTS FOR NHAP IMAGERY IN THREE COUNTIES IN NEW JERSEY.

Actual Land Use/ Land Cover	Photointerpretation Class FL[2]	UF	NF	NFT	W	I	Weighted Total
FL	145.26	2.00	.00	1.41	1.00	2.00	151.67
UF	1.78	4.00	.00	.00	.00	.00	5.78
NF	4.69	.00	53.75	5.95	1.00	.00	65.39
NFT	2.27	.00	2.54	33.64	.00	.00	38.45
W	.00	.00	.71	.00	16.00	.00	16.71
Interpreted Total	154.00	6.00	57.00	41.00	18.00	2.00	278.00

[1] The number of ground plots within an actual land-use class is adjusted to account for the different subsampling rates between strata.
[2] FL = forest land, UF = unproductive forest land, NF = Nonforest land without trees, NFT = nonforest land with trees, W = noncensus water, and I = indeterminate land use.

between OBC and NHAP imagery were small—both performed equally well. The biggest difference between OBC and NHAP was in the classification accuracy, as noted above. As expected, the 1970 B/W imagery was less precise for estimating 1984 forest area than either OBC or NHAP imagery.

While the magnitude of the difference was not large (3.3 versus 3.0 percent for forest land), it may be of practical significance. Based on these estimates for forest land, a 21 percent larger sample of forested land would be reqired to achieve the same precision for the B/W as with either OBC or NHAP imagery. Perhaps the relatively small difference between the older B/W imagery and the newer OBC and NHAP imagery was that only 5.6 percent of the photo plots changed land-use/land-cover classes. In areas with a higher land-use/land-cover disturbance rate, the differences in precision of estimated areas between out-of-date and current photography could be more pronounced.

In this study, the OBC imagery was flown for another project and was acquired for about $14 per frame. The rolls of OBC transparencies were easy to handle on our split light table, which enabled stereo viewing of uncut rolls of film. The OBC transparencies were then cut for field use, and a special field viewer was used to obtain a stereo image. Thus, NHAP and B/W imagery required less specialized equipment in the office. B/W requires less specialized equipment in the field, but, if NHAP transparencies were used in the field, a special field viewer would be needed. The effective area of the OBC (4100 ha) was smaller than that for NHAP (5200 ha) imagery; thus, the costs of purchasing, handling, and interpreting the OBC imagery was greater than the NHAP. Because they were of equal accuracy, the 1981-84 NHAP was more cost effective than the 1983 OBC imagery.

Only some general comments on relative efficiency can be made for B/W versus NHAP imagery, because the cost structure differs by application. At $6 per print, 1:58,000-scale NHAP prints cost about 14 percent more per unit area to acquire than 1:40,000-scale B/W prints at $2.50 per print. But for forest area estimates, the 1981-1984 NHAP was 21 percent more precise than the 1970 B/W photography. Thus, if old B/W imagery were used, 21 percent more photo and/or field work would be required to offset the lack of precision. If the additional survey costs would more than offset the savings in imagery, then NHAP is more cost effective. In addition, photo handling and interpretation costs would also favor NHAP because of the smaller number of images to handle.

Finally, the B/W imagery used in this study was relatively old. It was 11 to 14 years older than the NHAP, which is typical of the time between forest surveys of the Northeastern states. The conclusions drawn here do not apply to more current conventional B/W imagery. NHAP has the advantage of being color infrared. Conventional B/W has a larger scale that helps the interpretation accuracy and improves its relative precision, but larger scales increase the number of photos which increases acquisition and handling costs. Thus, additional research would be needed if more current B/W imagery were available.

CONCLUSIONS

- OBC imagery can be used with confidence to estimate forest area out to 35 degrees from nadir—the effective area used in this study.
- NHAP photography is recommended over OBC photography for stratifying points into the six strata used by forest survey: forest land, unproductive forest land, nonforest land without trees, nonforest land with trees, noncensus water, and indeterminate land use/land cover. NHAP costs less per unit area to acquire than OBC, yet yields estimates of the same precision as OBC.
- While NHAP was 14 percent more expensive per unit area than B/W photography, NHAP was 21 percent more precise at estimating forest area. Thus, if sampling costs are low relative to imagery costs, then B/W would be more cost effective under the conditions studied. In general however, NHAP would likely be more cost effective than out-of-date B/W imagery for stratifying points into the six strata used by forest survey.

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(Received 10 January 1986; revised and accepted 12 August 1986)

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