The Accuracy of Selected Land Use and Land Cover Maps at Scales of 1:250,000 and 1:100,000

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By Katherine Fitzpatrick-Lins

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The Accuracy of Selected Land Use and Land Cover Maps at Scales of 1:250,000 and 1:100,000

By Katherine Fitzpatrick-Lins

Abstract

Land use and land cover maps produced by the U.S. Geological Survey are found to meet or exceed the established standard of accuracy. When analyzed using a point sampling technique and binomial probability theory, several maps, illustrative of those produced for different parts of the country, were found to meet or exceed accuracies of 85 percent. Those maps tested were Tampa, Fla., Portland, Me., Charleston, W. Va., and Greeley, Colo., published at a scale of 1:250,000, and Atlanta, Ga., and Seattle and Tacoma, Wash., published at a scale of 1:100,000. For each map, the values were determined by calculating the ratio of the total number of points correctly interpreted to the total number of points sampled. Six of the seven maps tested have accuracies of 85 percent or better at the 95-percent lower confidence limit.

When the sample data for predominant categories (those sampled with a significant number of points) were grouped together for all maps, accuracies of those predominant categories met the 85-percent accuracy criterion, with one exception. One category, Residential, had less than 85-percent accuracy at the 95-percent lower confidence limit. Nearly all residential land sampled was mapped correctly, but some areas of other land uses were mapped incorrectly as Residential.

Introduction

A Level II land use and land cover classification system for use with remotely sensed data (Anderson and others, 1976) is being used for maps at scales of 1:250,000 and 1:100,000. The maps were prepared with manual interpretation of high-altitude aerial photographs by the U.S. Geological Survey. Scale-stable copies of the topographic map base were used as a mapping base. The land use and land cover classification is shown in table 1. The minimum mapping area according to the specifications is 16 hectares for most categories and 4 ha for Urban or Built-Up Land and such selected categories as Confined Feeding Operations (23), Other Agricultural Land (24), Water (53–54), Strip Mines, Quarries, and Gravel Pits (75), and Transitional Land, if urban (76) (Loelkes, 1977).

Certain of the mapping criteria adhered to, specified by Anderson and others (1976), stated that (1) the land use and land cover maps must be at least 85-percent accurate, (2) the accuracy of the interpretation will be about equal for the several categories, and (3) the results must be repeatable from interpreter to interpreter and from one time to another. Once the maps were compiled, field verification was conducted to assure correct interpretation, and the maps were made available to local users for review. Additional corrections were then incorporated.

Ideally, any land use and land cover classification system designed should have categories that are mutually exclusive. None the less, there are some categories in any system whose identifying signatures can be confused with others or whose functions so closely resemble others that confusion occurs. For this reason, a classification error matrix is useful in recognizing where and why errors occur. For the system employed by the Geological Survey, experienced interpreters can often predict which categories will be in error. Usually these errors are expected within a Level I category or between two or more Level II categories that have similar visual signatures or characteristics.

Certain of these predictable errors may not affect the useability of the land use and land cover map for some purposes. For example, an agency estimating the forest area on a map might not be concerned with the separation of deciduous and evergreen tree types. When the two categories of industrial and commercial land are intermixed in an industrial park, a planner might not be concerned as to whether the area is classified as Commercial (12) or Industrial (13). Some categories such as Cropland and Pasture (21) and Other Urban or Built-Up Land (17) often differ only in where they are located. The land cover may be the same. It is helpful, therefore, for the user to know, not only how accurate the map is but what kinds of errors occurred.

TABLE 1.—*U.S. Geological Survey land use and land cover classification system for use with remotely sensed data*
[From Anderson and others, 1976]

Level I	Level II
1 Urban or Built-Up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-Up Land
	17 Other Urban or Built-Up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Decidous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas Other Than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare-Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

Figure 1 is a classification error matrix highlighting those categories that are most in error because of the definition of the categories. The degree of difficulty of differentiating among these categories differs from one area of the country to another depending on the intermixture of land use patterns and vegetation types.

This research project was undertaken to study quantitatively and objectively the accuracy of the Level II land use and land cover maps and to see if the mapping criteria were being met. From maps of different geographic regions and from maps believed to be characteristic of the map products as a whole, it was possible to determine the map accuracy and to conclude whether or not the mapping accuracy criteria were being met. It was also possible to show through classification error matrices the types of errors that had occurred.

Sample Selection

For this research project to assess accuracy for selected land use and land cover maps across the country, the Tampa, Fla., Portland, Me., Charleston, W. Va., and Greeley, Colo., maps were selected as examples of the 1:250,000 scale. Atlanta, Ga., and Seattle and Tacoma, Wash., maps were selected as examples of these maps at 1:100,000 scale. Specifications for compilation were the same for the 1:100,000-scale and the 1:250,000-scale maps, and, so, the only compilation difference was format. Seattle and Tacoma are formatted as 0.5° (latitude) × 1° (longitude) maps. The standard 1:250,000 quadrangles are 1° × 2° maps, whereas the Atlanta map is in a special format which is centered on the city of Atlanta.

Previous analyses demonstrated that the best method for determining accuracy was by sample points selected according to a stratified systematic unalined sampling design (Fitzpatrick-Lins, 1978). The land use and land cover map was first stratified into 10- × 10-kilometer blocks coinciding with the Universal Transverse Mercator grid system. Within the 10-km blocks, points at the intersection of a 1-km grid cell were selected

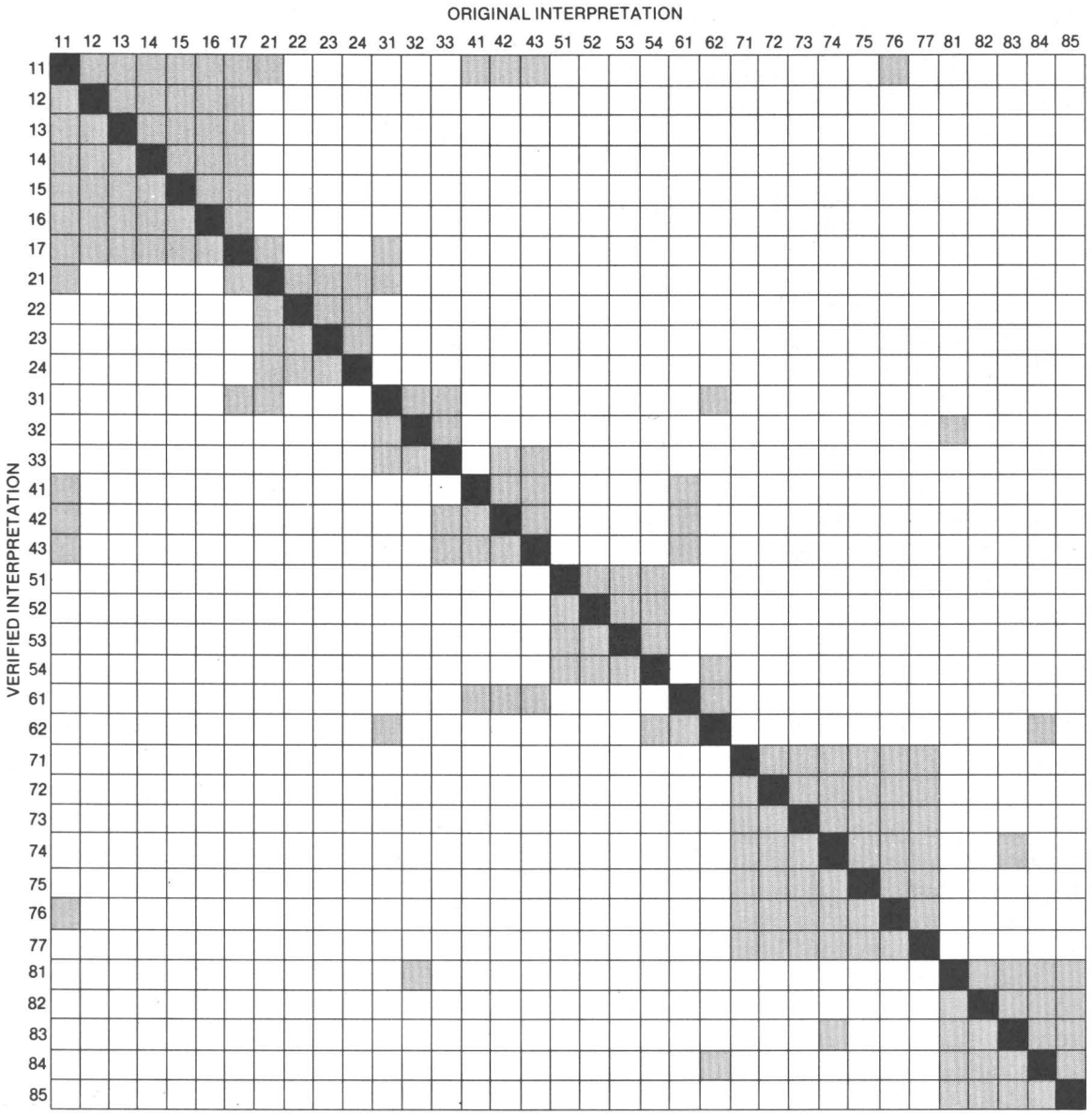

FIGURE 1.—Classification error matrix of predictable errors. The shaded areas indicate the most likely error types. The diagonal is the line of concurrence between the original interpretation and the verified interpretation. For the definition of the numerical categories, see table 1.

for each block by a systematic unalined sample. If a point fell on a boundary between two categories, it was considered as two points so both interpretations could be checked. Each point was examined independently and cross-checked against the original photographs. Any point not easily interpreted would be field-verified when necessary. The points were considered accurate when the original mapped interpretation agreed with that of the accuracy interpreter. If the land use and land cover codes differed, then the original interpretation was considered in error; if they agreed, then the point was considered to be correct. In this way, only two possibilities existed, either the points examined were correct

(1) or they were incorrect (0). For this reason, the binomial probability theory was applicable for determining the number of points to be tested and for determining accuracy. Accuracies were calculated as r/n, the total number of points correct (r), divided by the total number of points (n), and expressed as a percentage.

The ideal number of points to be tested per map was determined from the formulas for the binomial probability theory. The formula for the number of points selected was

$$N = \frac{4pq}{E^2},$$

where p is the expected percent accuracy, q is the difference between 100 and p, E is the allowable error, and N is the number of points to be sampled (Snedecor and Cochran, 1967, p. 517).

For a sample where we expected accuracies of 85 percent and an allowable error of 4 percent (2 standard deviations of 2 percent), the number of points necessary for reliable results would be

$$N = \frac{4(85 \times 15)}{4^2}$$

or 319 points. Fewer points could be sampled if the accuracy was assumed to be greater than 85 percent or the standard deviation acceptable was larger. We selected the 85-percent expected accuracy because the land use classification system specifies that each category should be mapped to at least an 85-percent accuracy. The narrow limits of a 2-percent standard deviation were selected because the methods of sampling involved very little field work and, therefore, should be a precise as possible to offset any procedural errors. As there was very little field work, costs were minimal, and a large sample increased the possibility of sampling an adequate number to test the major categories on the map. The standard error acceptable for each category was set at 10 percent.

With expected map accuracies of 85 percent and an acceptable error of 10 percent, the sample size for each map should be at least 50. As the expected accuracies increase, the sample size required decreases. According to Van Genderen and Lock (1977), the smallest sample size for meaningful results is 20 points, even if the sample is error free.

Accuracy determination for the map

Once the sample was selected, the points were examined for correctness of interpretation. The ratio, p (expressed as a percent), of the number of points correct, r, to the total number of points, n, was the accuracy value for the map. As this value is the test value for comparison to the minimum standard of 85-percent accuracy, a one-tailed test is appropriate. The 95-percent one-tailed lower confidence limit for a binomial distributions is obtained from the equation (derived from Snedecor and Cochran, 1967, p. 211):

$$p = \hat{p} - \{1.645 \sqrt{\hat{p}\hat{q}/n} + 50/n\},$$

where p = the accuracy of the map expressed as a percent;
$\hat{p}$ = the sample value of p or r/n expressed as a percent;
$\hat{q} = 100 - \hat{p}$; and
n = the sample size.

If the p value exceeds the 85-percent criterion at the lower confidence limit, we may accept with 95-percent confidence that the maps meet or exceed the accuracy standards. This is not to say that those maps that fall short of 85-percent accuracy at the lower confidence limit do not meet the accuracy standards, but that we have less confidence that they do. In fact, there is still a possibility that they exceed it.

Accuracy determination for the categories

For the set of sample points for each map sheet, a classification error matrix was constructed showing how reliably each category was interpreted and where the misinterpretations occurred. Although there was a simple accuracy statement with a given lower confidence limit for each map, there were two ways of expressing the percent accuracy of each category—as analyzed for errors of commission and as anlayzed for errors of omission. For many users of land use and land cover data, the question is how well did the categories as mapped depict the real world, or what was the probability of an error of commission? This value can be obtained from the ratio of the number of points correct for

each category to the total number of points for each category sampled from the map.

Another pertinent question less often addressed is how well was the real world depicted by the map, or what were the probabilities of an error of omission? This value can be obtained from the ratio of the number of points correct for each category to the total number of points for each category found in the verification process.

By definition, the sample was designed to select from map data, and, so, we chose to consider primarily the errors of commission. Once these data were analyzed and compared to the verified interpretation, an estimate of the errors of omission was obtained. For each analysis, a two-tailed test was used to find the true range of value for errors of commission and errors of omission. Neither of these estimates can stand alone as the accuracy of the category. It was also possible to compare the classification error matrix for each map sheet with the error matrix of most likely misinterpretations to see if the interpretation difficulties were predictable.

The maps produced at 1:100,000 scale are easier for the user to read, but the information content is the same as the maps at 1:250,000 scale. For the purposes of the accuracy study, the scale consideration was negligible, as all verification was done at the compilation scale. For the maps discussed, the compilation scale was about 1:125,000. For this reason, no comparison of the results for different scales was performed.

Accuracy Assessment

Tampa

The Tampa, Fla., land use and land cover map was produced at the same scale and format as the 1:250,000-scale topographic map base. The nonocean part of the Tampa land use and land cover map portrays about 8,981 square kilometers (7,209 km ^{2} of land categories), extending from the city of Tampa to south of Sanibel Island and including the metropolitan areas of Tampa, Sarasota, and Bradenton. The source material for the compilation was a set of 1:80,000-scale black-and-white transparencies copied from quad-centered color-infrared high-altitude photographs. Compilers mapped the land use and land cover at 1:125,000 scale using an enlarged copy of the topographic map as a base with copies of the black-and-white transparencies at 1:125,000 scale. The minimum mapping unit was 16 ha for most categories and 4 ha for Urban or Built-Up Land (11–17) and such selected categories as Confined Feeding Operations (23), Other Agricultural Land (24), Water (52–54); Strip Mines, Quarries, and Gravel Pits (75), and Transitional Areas (if urban) (76) (Loelkes, 1977).

In the Tampa area, there was a difficulty in distinguishing Herbaceous Rangeland (31) from Nonforested Wetland (62) using the photographs. Often the only way to distinguish between the two was to determine whether there was standing water by detecting sun glint. Transition areas were also causes of difficulty. Forested Wetland (61) often bordered Nonforested Wetland (62). Tall wetland grasses were mixed with brushy mangrove areas. The signature of the forested category usually predominated even in areas where the mangrove had died leaving only bare bushes mixed with tall grasses. Another transition area was from Herbaceous Rangeland (31) to Evergreen Forest Land (42). The categories are not always mutually exclusive, so that a particular interpreter's favoring of one category when drawing a boundary in a transition area was no more correct or incorrect than favoring another category.

As mentioned earlier, points were selected using a stratified systematic unalined sample. A total of 311 points were selected. When a point fell on a boundary, it was considered as two points. There were 43 boundary points on the Tampa map, making a total of 354 points.

For the Tampa land use and land cover map, a computer printout of data from the digitized land use and land cover map was available. It was possible, therefore, to compare the number of points selected with the actual number of hectares in each category. The point sample shown in table 2 proved to be representative of the major categories on the map. The percentage of area and of points for each category compare favorably. By applying a Spearman Rank Correlation Test to compare the number of points sampled

TABLE 2.—*The number of polygons, the area, and the percentage of area in each category with the number of sample points selected and the percentage of points for the land use and land cover map, Tampa, Fla., 1972*

Category	Polygon (No.)	Area (ha)	Area (percentage)	Points (No.)	Points (percentage)
11	411	82,092	9.14	29	9.3
12	295	12,519	1.39	4	1.3
13	43	3,854	.42	2	.6
14	74	6,510	.72	2	.6
15	4	893	.10	---	---
16	11	596	.07	---	---
17	207	7,378	.82	3	1.0
21	457	177,392	19.75	42	13.5
22	424	31,189	3.47	13	4.2
23	6	177	.02	1	.3
24	108	1,397	.16	---	---
31	224	208,255	23.19	90	28.9
32	12	1,072	.12	---	---
33	6	304	.03	---	---
42	534	55,825	6.21	16	5.1
43	4	148	.02	---	---
51	33	5,589	.62	---	---
52	201	3,903	.43	---	---
53	82	2,053	.23	---	---
54	19	177,077	19.72	60	19.3
61	585	67,219	7.49	27	8.7
62	262	12,574	1.40	2	.6
72	46	2,870	.32	1	.3
73	16	981	.11	1	.3
75	30	5,866	.65	2	.6
76	166	30,322	3.38	16	5.1
Total	4,260	898,055	99.98	311	99.7

with the area of each category, we were able to assume an association between the number of points and the area of each category. The null hypothesis of no association was rejected with less than 0.001-percent probability of error, indicating that this method of selecting a sample is area weighted, which is not at all surprising.

The table shows that only the predominant categories are sampled with sufficient points for adequate analysis. Many of the categories that occur occupy only a small percentage of the map area and that infrequently are not sampled or are sampled with too few points to determine their accuracy. Methods are currently being developed to utilize a computer program to sample all categories adequately for each map. This system will be applicable to any map that has been digitized and the data stored on a computer tape.

Of the 354 points sampled on the Tampa land use and land cover map, 329 (93 percent) were found to be correct. The 95-percent one-tailed lower confidence limit for these data would be 91 percent, and, so, the accuracy of the overall land use and land cover map is well above the acceptable accuracy of 85 percent.

It is understandable that water categories, particularly category 54, were almost always mapped correctly. Considering that errors were practically limited to the land-based categories, it was interesting to consider only the land area categories. Of the 354 points, 65 points were classified as category 54. (This doe not include any large bodies of other than inland water such as the Gulf of Mexico.) Of the remaining 289 points from the land surface, 25 were in error and 264 were correct. For this land area, the accuracy percentage is 91 percent with a 95-percent one-tailed lower confidence limit of 87 percent, still in excess of the required value of 85 percent. This particular analysis of only land area was necessary to determine if the large portion of the map showing water might have led to an inflated value of accuracy when considering the accuracy of the overall map. Although the map appeared more accurate when the water category was included, the map was still above the specified accuracy of 85 percent in the land area only.

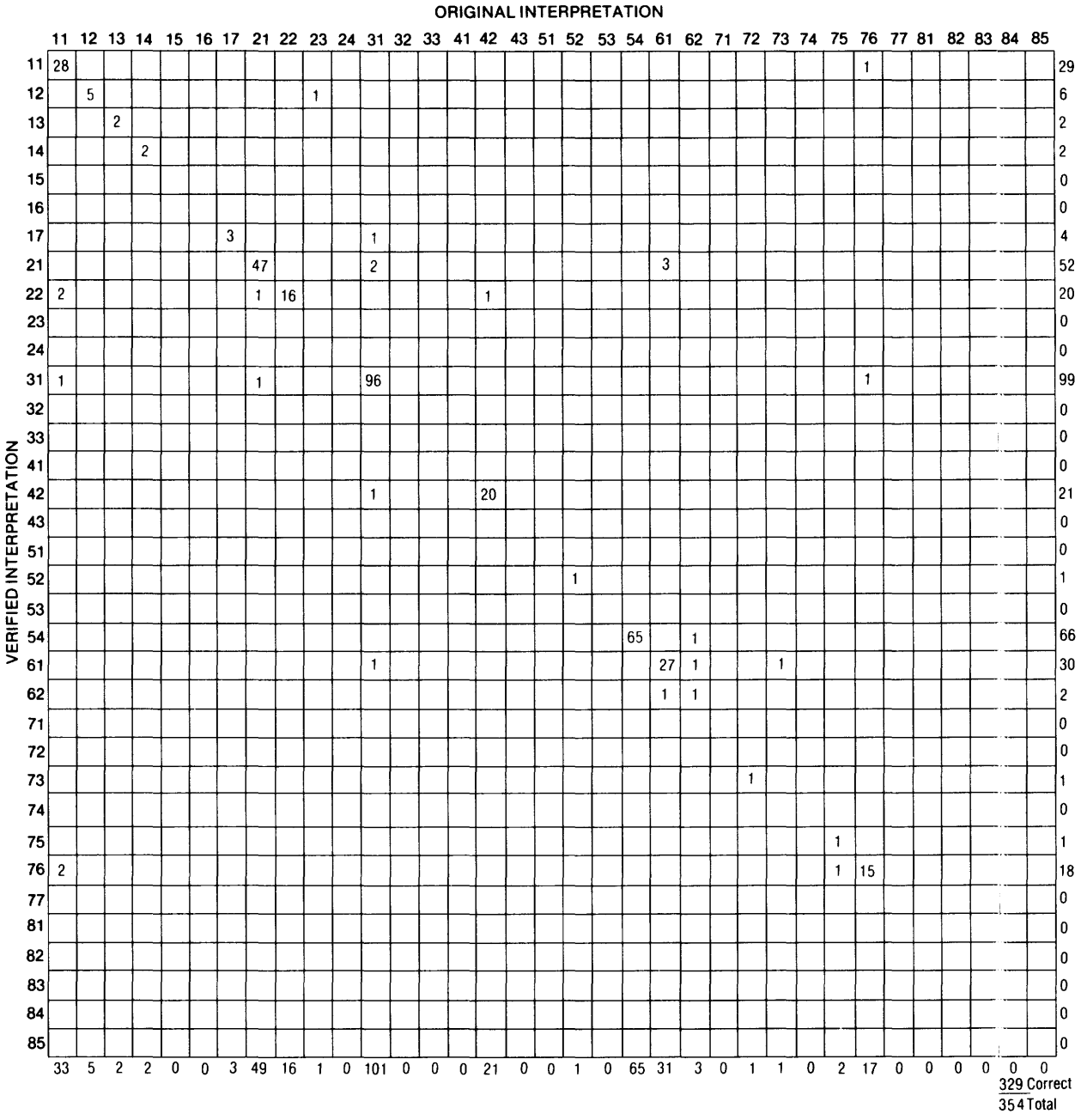

FIGURE 2.—Classification error matrix of the Tampa, Fla., 1:250,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

A classification error matrix of the results for the Tampa land use and land cover map is shown in figure 2.

The major land use and land cover categories on the Tampa map were analyzed for errors of commission (table 3).

TABLE 3.—*Major land use and land cover categories on the Tampa map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits[1] (percentage)
11 Residential _____	28	33	85	73- 99
21 Cropland and Pasture.	47	49	96	89-100
31 Herbaceous Rangeland.	96	101	95	90-100
42 Evergreen Forest Land.	20	21	95	88-100
54 Bays and Estuaries.	65	65	100	98-100
61 Forested Wetland	27	31	87	75- 99

[1] The formula for the 95-percent confidence limits using a two-tailed test is

$$p = \hat{p} \pm \{1.96 \sqrt{\hat{p}\hat{q}/n} + 50/n\}.$$

The categories providing a reliable estimate of the true percentage correct with a 95-percent lower confidence limit within ± 10 percent are Cropland and Pasture (21), Herbaceous Rangeland (31), and Bays and Estuaries (54). Of these categories, all met the criterion of at least 85-percent accurate.

When the data were examined for errors of omission from the point of view of the number of ground truth points for each category correctly identified on the map, the results differ somewhat (table 4). For instance, the number of points of Residential found during field work were sufficient to provide an estimate of the accuracy with ± 10 percent, whereas the ratio of correct points to the map sample points of Residential was too low to provide reliable results. In contrast, Cropland and Pasture appeared to be mapped with less accuracy when the actual occurrence of this category in the field was compared to the number of occurrences mapped. Whereas 52 of the field-checked points were in Cropland or Pasture, only 47 points were identified as such. From this viewpoint, it is apparent that some cropland and pasture was overlooked.

TABLE 4.—*Major land use and land cover categories on the Tampa map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	28	29	97	89-100
21 Cropland and Pasture.	47	52	87	77- 97
31 Herbaceous Rangeland.	96	101	95	90-100
42 Evergreen Forest Land.	20	21	95	88-100
54 Bays and Estuaries.	65	66	98	94-100
61 Forested Wetland	27	30	90	78-100

Portland

The Portland, Me., land use and land cover map was produced at the same scale and format as the 1:250,000-scale topographic map of Portland, Me. The land area is 15,038 km^2 and includes the area from coastal New Hampshire at Portsmouth to north of Portland, Me. At the interior of the map sheet are Sebago Lake, Me., and Lake Winnipesaukee, N.H. The towns of Laconia and Franklin, the city of Concord, and the northern portion of Manchester, N.H., are also included.

The terrain is hilly to mountainous with many small lakes. The urban areas are not large, there is relatively little cropland, and most of the area is forested. The most serious interpretation problem encountered by the compilers was one of separating the forest types.

The Portland land use and land cover map was compiled using the 1:250,000-scale topographic map base enlarged to a scale of 1:128,000. The land use and land cover source materials were black-and-white quad-centered photographs at a scale of 1:80,000 obtained in 1973, 1974, and 1975 along with copies of the same prints reduced to a scale of 1:128,000. Where this coverage was limited, 1973 color-infrared photographs at an approximate scale of 1:128,000 served as the source material. Two small areas of the map for which conventional source material was not available were compiled at the Survey's Special Mapping Center in Reston, Va. Once the land use and land cover data were compiled, the finished maps were reduced to a scale of 1:250,000.

The land use and land cover map was evaluated for accuracy at the scale of compilation using the same photographs used for

the original interpretation. The source material for that portion of the map compiled at the Special Mapping Center was not available and so that portion was not evaluated for accuracy.

A total of 456 points were selected according to a stratified systematic unalined sample. Each point was reexamined on the photographs and compared to the original interpretation. Where any interpretation difficulties remained, the actual land use or land cover was verified in the fields.

Of the total 456 points verified in the Portland land use and land cover map, 410 (90 percent) were found to be correct. At the 95-percent one-tailed lower confidence level, the lower limit of true accuracy was 87 percent. This value was well above the acceptable accuracy of 85 percent. When the land use and land cover categories were considered (excluding category 54, which is not part of the land area of the sheet and not usually subject to interpretation errors), the accuracy of the map remained at 90 percent (402 correct of 448 total points) with a 95-percent one-tailed lower confidence limit of 87 percent. From this, it was apparent that the number of sample points in the water category 54 did not bias the results on this map sheet. The classification error matrix for Portland, Me., is shown in figure 3.

The major land use and land cover categories examined for errors of commission for the Portland, Me., sheet are shown in table 5.

TABLE 5.—*Major land use and land cover categories on the Portland map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential	29	36	81	66- 95
21 Cropland and Pasture.	25	26	95	86-100
41 Deciduous Forest Land.	28	32	88	74-100
42 Evergreen Forest Land.	75	88	85	77- 93
43 Mixed Forest Land.	204	213	95	92- 98

Only Cropland and Pasture (21), Evergreen Forest Land (42), and Mixed Forest Land (43) were reliable with ± 10 percent of the sample results. Of these, Evergreen Forest Land (42) fell short of the acceptable accuracy of 85 percent at the lower confidence limit. The most frequent misclassification of this category was that is was mapped as Mixed Forest Land (43).

When the data were examined for errors of omission rather than errors of commission, the results for these same categories were as shown in table 6.

TABLE 6.—*Major land use and land cover categories on the Portland map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential	29	31	94	82-100
21 Cropland and Pasture.	25	27	93	81-100
41 Deciduous Forest Land.	28	34	82	68- 97
42 Evergreen Forest Land.	75	81	93	87- 99
43 Mixed Forest Land.	204	223	91	88- 95

Those categories having accuracy percentage with ± 10 percent were Evergreen Forest Land (42) and Mixed Forest Land (43). Residential (11), Cropland and Pasture (21), and Deciduous Forest Land (41) have too wide a confidence interval for reliable results.

Residential appeared to be interpreted more correctly when compared to the actual 31 points of Residential found in the field than when compared to the 36 points of mapped Residential. In all probability, Residential is overestimated on the map. The interpretation of Evergreen Forest Land also appeared to be more precise when compared to the field data than when compared to the map data. Much of the land interpreted as Evergreen Forest Land was actually Mixed Forest Land.

Charleston

The Charleston, W. Va., land use and land cover map, at the same scale and format as the Charleston, W. Va., 1:250,000-scale topographic map, encompasses 19,352 km² in the heart of West Virginia. The land is mostly forested mountainous terrain transected by the Kanawha River, which is visible in the lower left corner of the map. Charleston, the capital of West Virginia and the only major city on the map, is at the intersection of the Kanawha and Elk Rivers. The area of the map

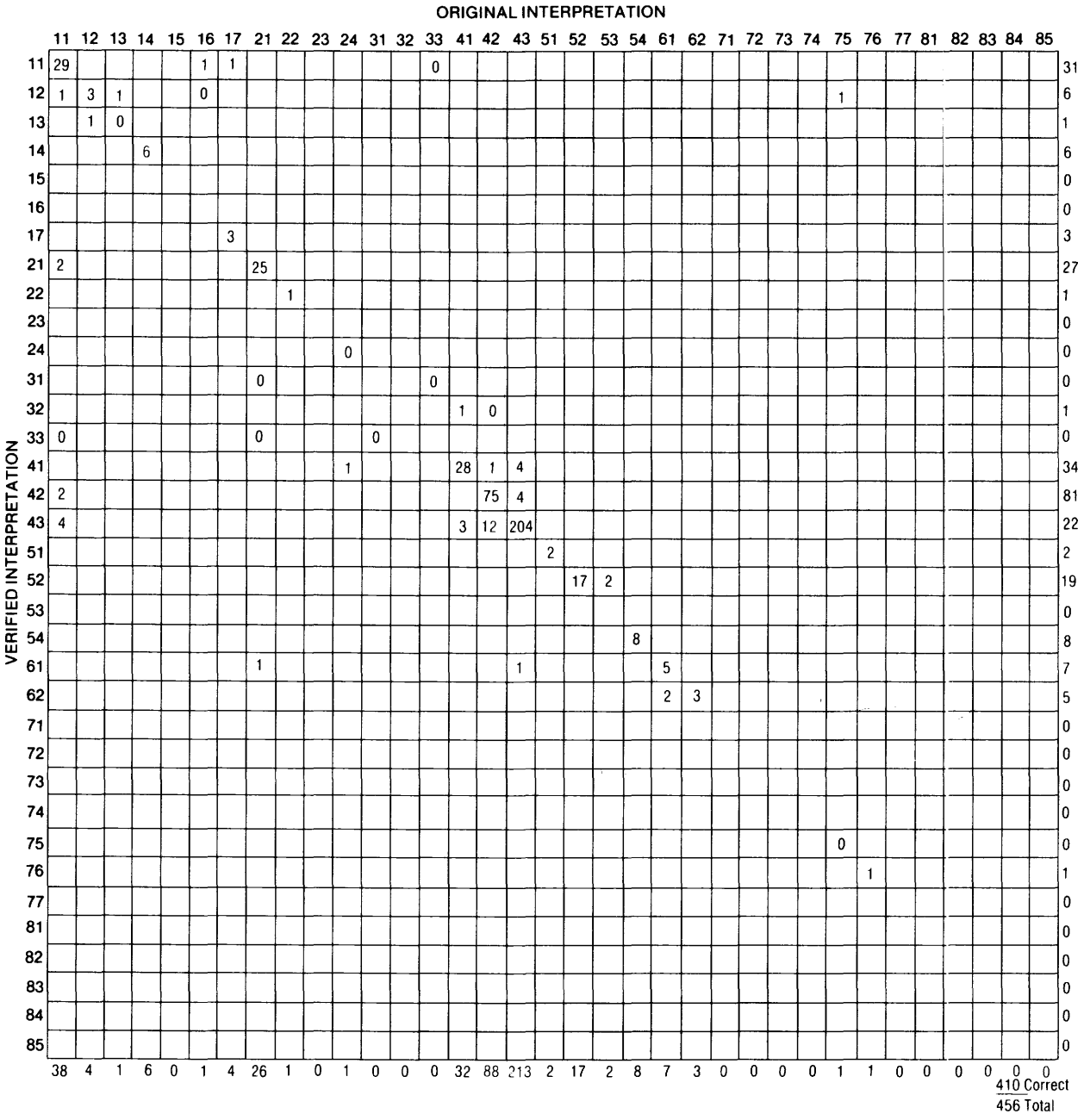

FIGURE 3.—Classification error matrix of the Portland, Me., 1:250,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

is predominantly forested with small rural settlements.

The major categories on the land use and land cover map are Deciduous Forest and Mixed Forest Lands. Very little Cropland and Pasture is present; special specifications were created to map these areas to a minimum width of 200 meters instead of the usual 400 m, so that the few existing agricultural areas would be mapped.

Another land use type in this region given special consideration is the surface strip mine. Where the surface strip mined area was larger than 4 ha and a minimum of 90 m wide, it was mapped as category 75. Ordinarily, this category is mapped for a minimum of 4 ha but must be at least 200 m wide. In evaluating the map for accuracy, these unique situations were taken into account, and care was taken to meet the same specifications.

The land use and land cover map was compiled using 1:125,000-scale high-altitude color-infrared photographs of September 1972 and December 1973. The Kern P.G. 2 stereoplotter[1] was used with the high-altitude photographs and the 1:250,000-scale topographic map base, each at original scale. The stereoplotter allowed for stereoscopic viewing of the photographs and for adjusting this image to the scale of the map base for compilation. The photographs could also be enlarged to two, four, or eight times the original.

After the original land use and land cover mapping was completed, a copy of the map was enlarged to a scale of 1:125,000, the same scale as the original photographs. For quality control, the photographs were registered to the enlarged map for direct comparison without the use of the P.G. 2 stereoplotter. The accuracy check involved this same technique, overlaying the photographs with the map, to verify the interpretation at selected sample points.

The 424 sample points were selected using a stratified systematic unalined sample. The same specifications and special considerations approved for compilation were followed for the accuracy check.

[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Of the 424 points checked for accuracy on the Charleston land use and land cover map, 393 (93 percent) were found to be correct. The 95-percent one-tailed lower confidence limit was 90 percent. The classification error matrix for Charleston is shown in figure 4.

Of the 424 points checked, 353 were in two forest categories, Deciduous Forest (41) and Mixed Forest (43) Lands. The next significant category in the sample was Cropland and Pasture (21) with 53 points. Thus, 406 points (96 percent) represent these three major land use categories. The results for each of these three categories analyzed for errors of commission are shown in table 7. Neither category 21 or category 43 is mapped with the necessary accuracy of 85 percent at the lower confidence level.

TABLE 7.—*Major land use and land cover categories on the Charleston map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
21 Cropland and Pasture.	46	53	87	77- 97
41 Deciduous Forest Land.	207	214	97	94-100
43 Mixed Forest Land.	123	139	88	83- 94

When the sample was considered for errors of omission, these three categories were found to have the accuracies shown in table 8.

TABLE 8.—*Major land use and land cover categories on the Charleston map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
21 Cropland and Pasture.	46	49	94	86-100
41 Deciduous Forest	207	229	90	86- 94
43 Mixed Forest Land.	123	127	97	93-100

All three categories above exceed the required accuracy of 85 percent at the lower confidence limit when examined for errors of omission.

After comparing the tables of errors of omission and of commission, we reexamined the map data to analyze the difference and concluded that the size of smaller polygons

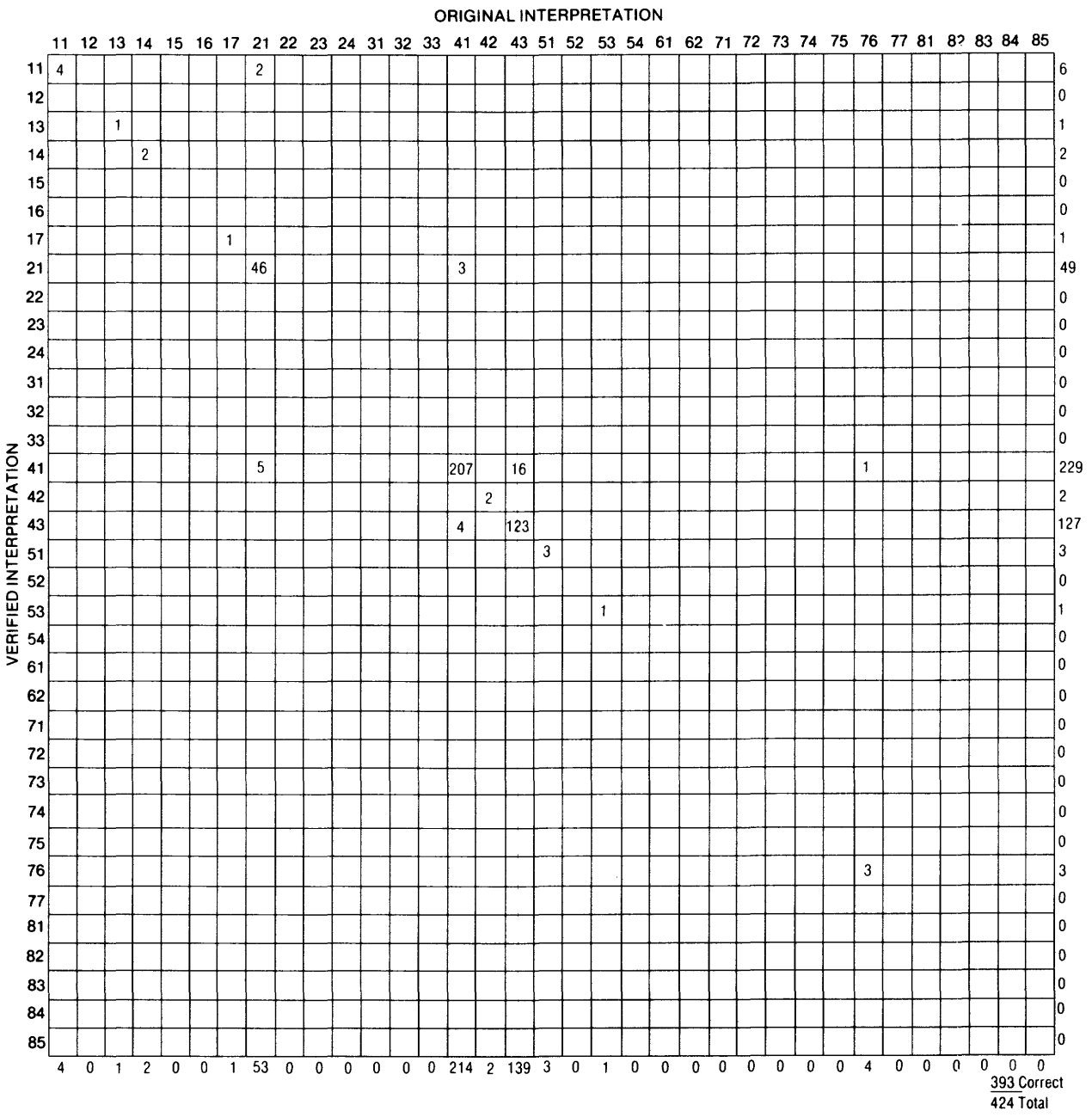

FIGURE 4.—Classification error matrix of the Charleston, W. Va., 1:250,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

of land use were increased even larger than the unique specifications would allow to insure their inclusion on the map, thereby decreasing the errors of omission for these categories but increasing the errors of commission. This practice appeared to be the primary cause of error for Cropland and Pasture (21); frequently, the surrounding Forest Land was included in the polygon mapped as Cropland so that the polygon would meet the minimum mapping size.

Mixed Forest Land (43) was also less than 85 percent accurate at the lower confidence limit. The primary cause of error in category 43 appeared to be that it was often used for convenience even when the predominant forest type was Deciduous Forest Land (41). There were 16 sample sites where category 41 was mapped as category 43. This error, one of misclassifying one forest type for another, might not be as serious from a users point of view as mistaking Forested Land for Cropland and Pasture.

In spite of these specific error types, the overall accuracy of the Charleston land use and land cover map exceeded the required accuracy of 85 percent at the lower confidence level.

Greeley

The Greeley, Colo., land use and land cover map, 1979, at a scale of 1:250,000 is representative of the land use and land cover types of Colorado's eastern plains and mountain slopes. The land area of the map is 18,855 km². The western portion of the map includes parts of the southern Rocky Mountains with their forest and alpine vegetation, and the eastern portion of the map is in the eastern plains of Colorado with its cropland, pasture, and rangeland vegetation. In the central portion of the map are the cities of Boulder, Longmont, Loveland, and Greeley, Colo.

The compilers mapped the land use and land cover categories using high-altitude black-and-white photographic transparencies acquired in 1975 and 1976 as the primary source material. Reductions of these transparencies were overlaid with a copy of the topographic map base at a common scale of 1:128,000. The land use and land cover compilation was made directly on the 1:128,000-scale copy of the topographic base map. To assist in the interpretation, the compilers also employed high-altitude color or color-infrared transparencies. These photographs were from 1972 and were used only as auxiliary source materials to the more current black-and-white photographs. No stereo processes were employed during compilation, so registration was a problem in the mountainous regions. Valley bottoms were often correctly registered, whereas the ridgelines were often misregistered. No measure of the resulting misregistration was made during the accuracy check.

Specific problem categories for the interpreters using the black-and-white photographs were in separating Cropland and Pasture (21) from Herbaceous Rangeland (31), separating Deciduous Forest Land (41) from Evergreen Forest Land (42), separating Herbaceous Tundra (82) from Bare-Ground Tundra (83), and separating Herbaceous Rangeland (31) from Mixed Rangeland (33).

In the eastern portion of the map, the rangeland may be either a shrub and brush rangeland with much sagebrush and sand sages, rangeland of grasses and forbs, or a mixed rangeland. It was often not possible to recognize these vegetation types on the photographs alone. The graininess of the film produced more texture than the pattern of vegetation types (Eldon Jessen, personal commun., 1978).

Where range management was practiced, the signature of Herbaceous Range (31) was almost identical to that of Cropland and Pasture (21). For pasture to be classified as category 21, it is required that it be in permanent use and maintenance as pasture. Often, brush control was the only modification, and, therefore, the grazing land would be classified as Herbaceous Rangeland (31). In these areas, once the shrub brush had regrown, the proper category was Mixed Rangeland (33).

Even cropland in the wheat areas is not permanent. Much former cropland has been abandoned and reverted to rangeland, and new areas of rangeland have been cultivated in wheat. Often cropland scars are apparent long after the land has been allowed to revert to rangeland. Abandoned cropland would be

classified as Rangeland; however, fallow cropland would still be in the Cropland and Pasture category.

Because of these difficulties in interpreting the land use and land cover categories in the eastern portion of the map, this area was extensively field checked at the time of compilation. The original field-check photographs were actually more beneficial to an accuracy check than current field work would have been, considering how transitional the land cover is.

In the western portion of the map, the land cover is more static. Aspen was difficult to distinguish from the coniferous trees on the summer black-and-white photographs. The color-infrared photographs were the most useful for separating the Deciduous Forest (41) and Evergreen Forest (42) Lands. Herbaceous Tundra (82) and Bare-Ground Tundra (83) were difficult to separate on the black-and-white photographs. For these areas, the color-infrared photographs were helpful. During the accuracy check, stereo viewing was also beneficial.

According to a stratified systematic unalined sampling design, a sample of 375 points was initially chosen. Of these, 38 fell on a boundary and were considered to be double points, giving a total of 413 points. Each point on the map was checked against the original compilation materials. Where questions occurred, the points were located on the 7.5-minute topographic map and checked against the original precompilation data by those who had spent time in the field.

The result of the accuracy check of the Greeley, Colo., land use and land cover map is that the overall accuracy was 399 points of 413 points total, or 97-percent correct with a 95-percent one-tailed lower confidence limit of 95 percent. This result far exceeds the expected accuracy of 85 percent.

Of those categories with more than the required number of points to provide reliable accuracy data, the results for errors of commission are as shown in table 9. All these categories exceed the expected accuracy of 85 percent at the lower confidence limit.

When these same categories are considered from the point of view of errors of omission, or the field-identified points that were correctly interpreted, the results are as shown in table 10.

TABLE 9.—*Major land use and land cover categories on the Greeley map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
21 Cropland and Pasture.	124	126	98	96-100
31 Herbaceous Rangeland.	72	74	97	93-100
33 Mixed Rangeland	52	56	93	85-100
42 Evergreen Forest Land.	103	104	99	97-100

TABLE 10.—*Major land use and land cover categories on the Greeley map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
21 Cropland and Pasture.	124	124	100	98-100
31 Herbaceous Rangeland.	72	76	95	90-100
33 Mixed Rangeland	52	56	93	85-100
42 Evergreen Forest Land.	102	106	97	94-100

Again, these categories exceed the expected accuracy of 85 percent at the lower confidence limit. From the classification error matrix (fig. 5), it is apparent that Mixed Rangeland (33) is occasionally misinterpreted as Herbaceous Rangeland (31), while Herbaceous Rangeland (31) is misinterpreted as either Cropland and Pasture (21) or Mixed Rangeland (33), and Evergreen Forest Land (42) is occasionally misinterpreted as Mixed Forest Land (43). These errors, few as they are, are the very errors expected from the interpretation difficulties on this sheet.

Atlanta

A 1:100,000-scale land use and land cover map was compiled for the Greater Atlanta Region, Ga. The published map covered 20,554 km² and was centered on the city of Atlanta. Part of the area of the map was initially compiled using 1:24,000-scale orthophotoquads at that scale as a base and were mapped with a minimum mapping unit of 1 ha. The land use and land cover data were then generalized from the 1:24,000-scale

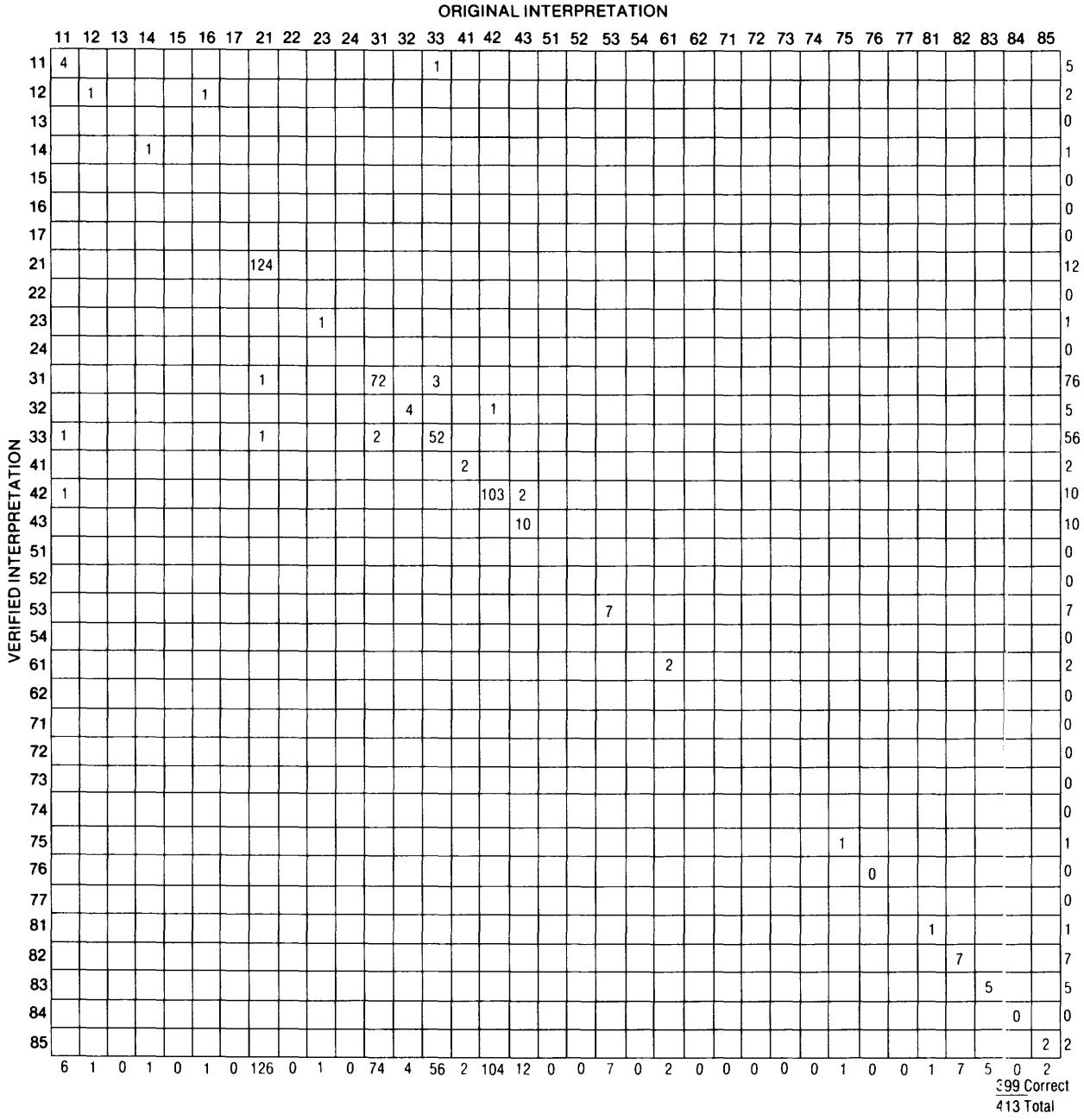

FIGURE 5.—Classification matrix of the Greeley, Colo., 1:250,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

parts to 1:100,000 scale. The minimum mapping unit for the 1:100,000 scale land use and land cover maps was increased from 1 ha at 1:24,000 scale to 4 or 16 ha at 1:100,000 scale, according to the specifications (Loelkes 1977, p. 18). The remaining portion of the map was compiled using a stable base copy of a 1:100,000-scale topographic base and black-and-white high-altitude photographs at a contact scale of 1:76,000 and at a reduced scale of 1:100,000. The specifications for the minimum mapping unit remained consistent.

The compilers experienced the greatest difficulties in interpretation of the forest land categories. The black-and-white aerial photographs were obtained in February, April, and May 1974, and the degree of foliation varied with the time of photography. For this reason, the shades of gray on the photographs varied for evergreen and deciduous trees from month to month, so that there was no consistent signature for forest types. The interpreters had the greatest difficulty separating evergreen and deciduous forests on the May photographs, as both forest types had similar gray tones. This problem was as difficult to resolve at 1:24,000 scale as it was at 1:100,000 scale.

These same difficulties were experienced in verifying the land use and land cover interpretation at the 381 sample points when the same photographs were used. As a result of these and other problems, 72 points were examined in the field. Most of these points were in areas of Evergreen Forest, Deciduous Forest, and Mixed Forest Lands.

The number of correct interpretations for the Atlanta land use and land cover map at the 1:100,000 scale was 343 (90 percent) of 381 points sampled as seen in the matrix (fig. 6). The 95-percent one-tailed lower confidence limit is 87 percent.

The results, obtained by a stratified systematic unalined selection of 381 points, represented the complete map at a scale of 1:100,000. Only 13 of the 21 land use and land cover categories on the map appeared in the sample. Of the 13 categories included, only 5 had more than 20 occurrences in the point selection. The results for these five categories examined for errors of commission are as shown in table 11.

TABLE 11.—*Major land use and land cover categories on the Atlanta map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	30	32	94	83-100
21 Cropland and Pasture.	86	92	93	83-100
41 Deciduous Forest Land.	21	26	81	64- 98
42 Evergreen Forest Land.	44	53	83	72-94
43 Mixed Forest Land.	138	148	93	89- 98

Only Mixed Forest Land (43) exceeds the specified accuracy of 85 percent at the lower confidence limit. Residential (11) and Cropland and Pasture (21) at 83 percent for the lower confidence limit approach the criterion of 85 percent accurate. A larger sample for all categories except for Mixed Forest Land would give more reliable results and would narrow the confidence interval.

When these same data are examined for errors of omission the results were as shown in table 12.

TABLE 12.—*Major land use and land cover categories on the Atlanta map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	30	32	94	83-100
21 Cropland and Pasture.	86	92	93	87- 99
41 Deciduous Forest Land.	21	27	78	61- 95
42 Evergreen Forest Land.	44	49	90	81- 99
43 Mixed Forest Land.	138	152	91	86- 96

From these results, it appears that the accuracies of four of these categories approach or exceed the criterion of 85-percent accuracy. Category 41 was less accurate, yet the range in accuracy was so great that it would be necessary to test several more points for more precise results. The overall accuracy of the land use and land cover maps exceeded the criterion of 85-percent accuracy at the scale of 1:100,000.

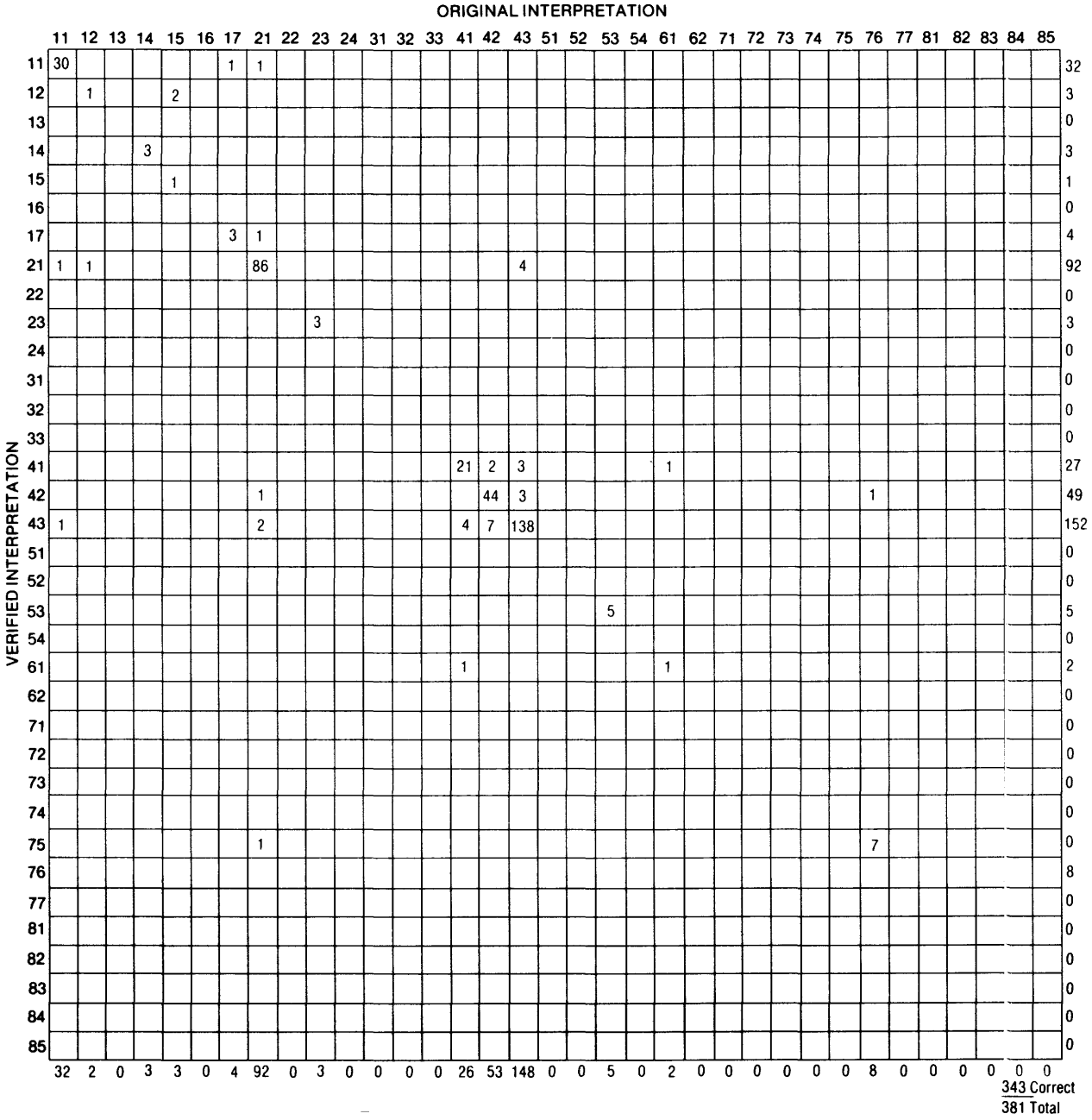

FIGURE 6.—Classification error matrix of the Atlanta, Ga., 1:100,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

Seattle and Tacoma

The Seattle and Tacoma, Wash., land use and land cover maps were each produced at a scale of 1:100,000. The area of each sheet is one-quarter of the standard 1:250,000 1° × 2° topographic map of the Seattle area. The Seattle 1:100,000-scale map includes the northeast corner of the standard 1:250,000-scale topographic map between lat 47°30′ and 48° N. and long 122° and 123° W. Most of Puget Sound and all but the southern portion of the city of Seattle is shown. The land area of the Seattle sheet is 3,326 km².

Between lat 47° and 47°30′ N. just south of the Seattle sheet is the Tacoma 1:100,000-scale map. The Tacoma sheet includes the southern portion of Puget Sound and of the city of Seattle and all of the city of Tacoma. The land area of the Tacoma sheet is 4,110 km². Both the Seattle and the Tacoma land use and land cover maps include major metropolitan areas, but the majority of the mapped area is nonurban agricultural or forest lands.

The maps were compiled at a scale of 1:125,000 using 1:125,000-scale color-infrared high-altitude photographs acquired during September 1975. Once the maps were compiled, they were enlarged to a scale of 1:100,000. The minimum mapping units for the 1:100,000-scale maps were the same as the minimum mapping units as 1:250,000 scale.

The forest categories provided the most difficulty on the Seattle and the Tacoma maps. This problem was further complicated by the presence of Western Larch, a deciduous conifer having the same signature as most evergreen trees but correctly classified as Deciduous Forest Land. Later, it was decided that this particular species would be considered correct as either Evergreen Forest (42) or Deciduous Forest (41) Lands.

A total of 196 points were selected on the Seattle sheet and 202 points on the Tacoma sheet. Those points falling on boundaries were considered to be double points and thereby increased the number of points on the Seattle map to 212 and the number of points on the Tacoma sheet to 235. The land use and land cover interpretation was verified from the same photographs used for the original compilation. Only those points providing interpretation difficulties were field verified.

The results were not consistent between the Seattle and the Tacoma map sheets. Of the 212 points sampled on the Seattle land use and land cover map, 206 (97 percent) were correct. The 95-percent one-tailed lower confidence limit was 95 percent. When the land area alone was considered, 162 points of a total 168 (96 percent) were correct. The 95-percent one-tailed lower confidence limit for the land area data was 93 percent, well above the criterion of 85 percent accurate.

For the Tacoma land use and land cover map, 202 points (86 percent) of the total 235 points were correct. The 95-percent one-tailed lower confidence limit was 82 percent. When the land area with the exception of category 54 was considered, the accuracy dropped to 83 percent or 167 correct points of the 202 points of land-area categories. The 95-percent one-tailed lower confidence limit for the land area only was 78 percent, considerably below the accuracy criterion of 85 percent.

Classification error matrices for Seattle and Tacoma are presented in figures 7 and 8.

The major land use and land cover categories for Seattle analyzed for errors of commission are as shown in table 13.

TABLE 13.—*Major land use and land cover categories on the Seattle map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	47	48	98	94-100
42 Evergreen Forest Land.	32	33	97	89-100
43 Mixed Forest Land.	43	44	98	92-100
54 Bays and Estuaries.	44	44	100	97-100

The major land use and land cover categories for Tacoma analyzed for errors of commission are as shown in table 14.

The primary cause of error on the Tacoma map sheet was misinterpretation of category 11, as evidenced by figure 8. Six of the points of residential land were actually Cropland and Pasture (21). Although farmsteads or small clusters of buildings may have been visible on the photographs and in the field, such areas should not have been classified as Residential according to the mapping specifications.

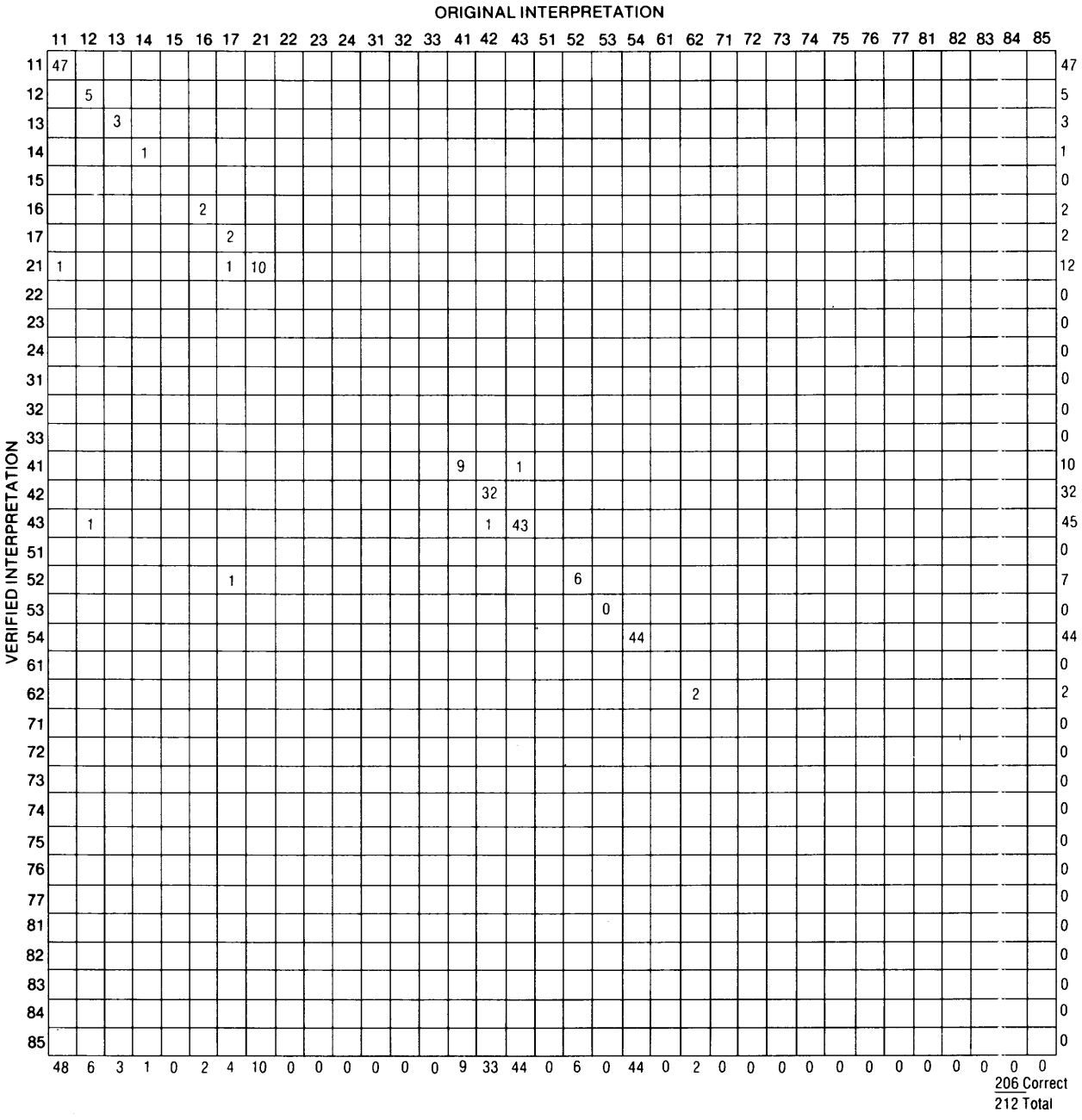

FIGURE 7.—Classification error matrix of the Seattle, Wash., 1:100,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

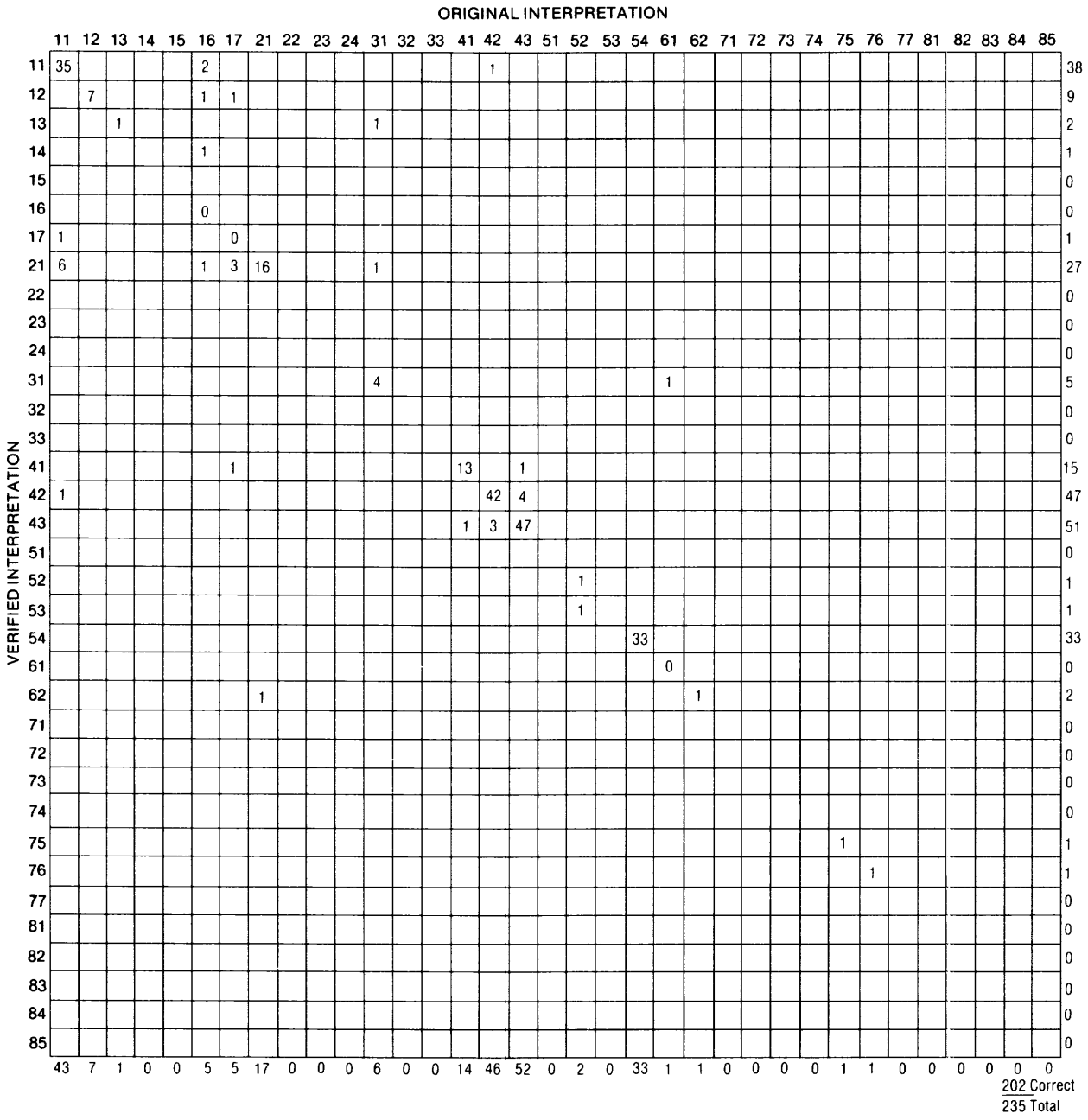

FIGURE 8.—Classification error matrix of the Tacoma, Wash., 1:100,000-scale land use and land cover map. For the definition of the numerical categories, see table 1.

TABLE 14.—*Major land use and land cover categories on the Tacoma map analyzed for errors of commission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	35	43	81	68- 94
42 Evergreen Forest Land.	42	46	91	82-100
43 Mixed Forest Land.	47	52	90	81- 99
54 Bays and Estuaries.	33	33	100	96-100

Those categories of forest land believed to cause difficulties for the interpreter were actually mapped with a high degree of accuracy.

From figures 7 and 8, it was possible to determine the errors of omission. Major land use and land cover categories of Seattle expressed in terms of errors of omission are as shown in table 15.

TABLE 15.—*Major land use and land cover categories on the Seattle map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	47	47	100	96-100
42 Evergreen Forest Land.	32	32	100	95-100
43 Mixed Forest Land.	43	45	96	87-100
54 Bays and Estuaries.	44	44	100	96-100

The major land use and land cover categories of Tacoma expressed in terms of errors of omission are as shown in table 16.

TABLE 16.—*Major land use and land cover categories on the Tacoma map analyzed for errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential _____	35	38	92	82-100
21 Cropland and Pasture.	16	27	59	39- 79
42 Evergreen Forest Land.	42	47	89	79- 99
43 Mixed Forest Land.	47	51	92	84-100
54 Bays and Estuaries.	33	33	100	95-100

The most obvious difference in the data for errors of omission and the data for errors of commission was on the Tacoma sheet. Cropland and Pasture (21) on the Tacoma map sheet was often overlooked. Much of the Cropland and Pasture land was misclassified as Residential (11) or Other Urban and Built-Up Land (17) resulting in large errors of commission for Residential Land and large errors of omission for Cropland and Pasture. Should these errors be corrected, Cropland and Pasture would become a more significant category on this map sheet.

Combined Results

When all the point data for these maps were merged, a combined classification error matrix was constructed as shown in figure 9. A sufficient number of points was accumulated to provide a reliable estimate of the interpretability of nine categories. Residential (11), Cropland and Pasture (21), Herbaceous Rangeland (31), Mixed Rangeland (33), Deciduous Forest Land (41), Evergreen Forest Land (42), Mixed Forest Land (43), Lakes (52), and Bays and Estuaries (54) were all 85-percent accurate or better at the lower confidence limit when tested for errors of commission. Only Residential (11) was less accurate at the lower confidence limits. The p values calculated from errors of commission for these categories where p is estimated at ± 10 percent of its true value are shown in table 17.

TABLE 17.—*Accuracy of combined data: errors of commission*

Category	Points correct	Points total	Percent correct	95 percent confidence limits (percentage)
11 Residential _____	177	204	87	82- 92
21 Cropland and Pasture.	354	373	95	93- 97
31 Herbaceous Rangeland.	172	181	95	92- 98
33 Mixed Rangeland	52	56	93	85-100
41 Deciduous Forest Land.	280	297	94	91- 97
42 Evergreen Forest Land.	318	348	91	88-94
43 Mixed Forest Land.	565	608	93	91- 95
52 Lakes _____	25	26	96	87-100
54 Bays and Estuaries.	150	150	100	97-100

For comparison, these same categories calculated from errors of omission are shown below in table 18.

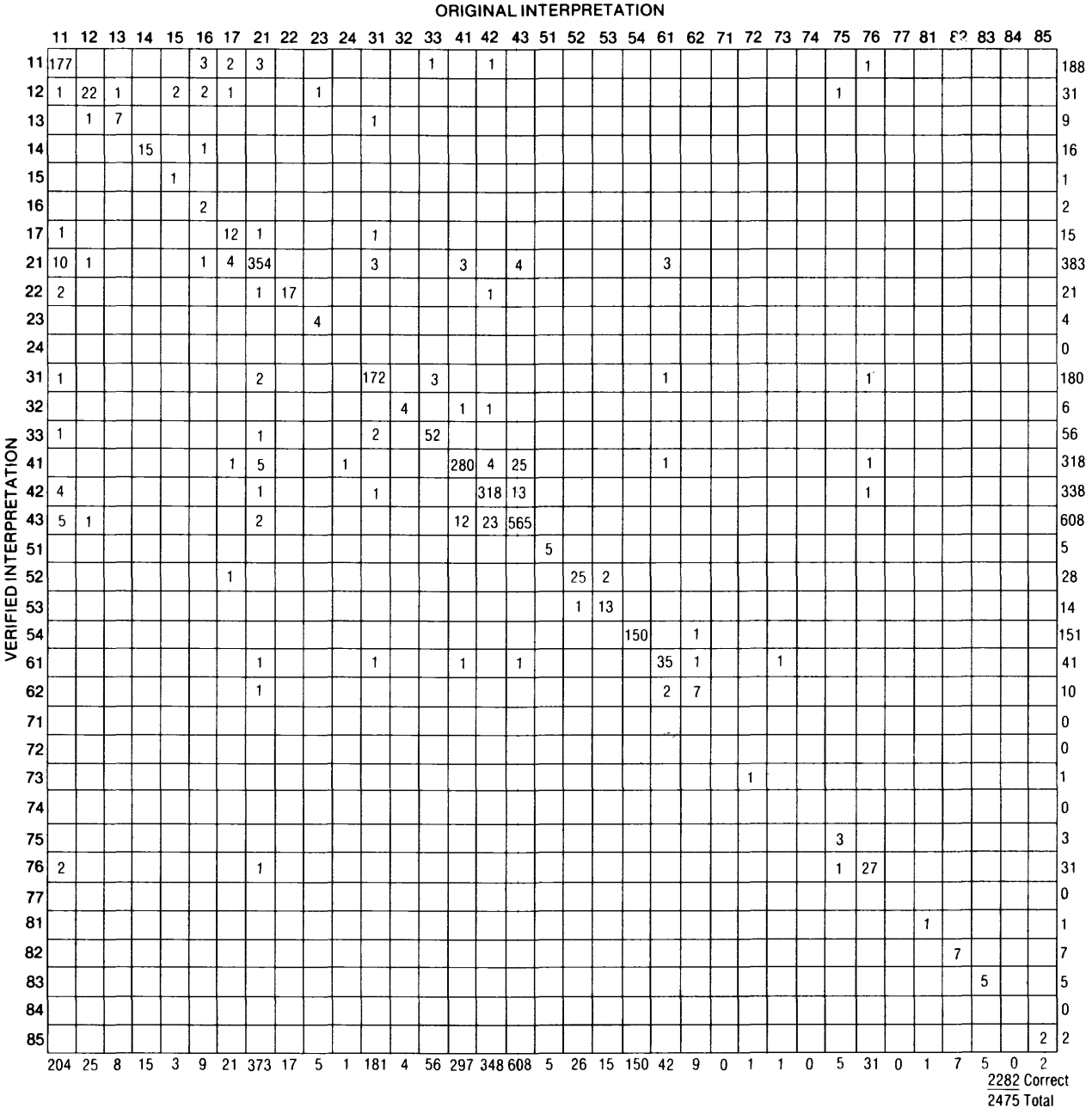

FIGURE 9.—Classification error matrix of the combined results. For the definition of the numerical categories, see table 1.

TABLE 18.—*Accuracy of combined data: errors of omission*

Category	Points correct	Points total	Percent correct	95-percent confidence limits (percentage)
11 Residential	177	188	94	90- 98
21 Cropland and Pasture.	354	383	92	89- 94
31 Herbaceous Rangeland.	172	180	96	92- 99
33 Mixed Rangeland	52	56	93	85-100
41 Deciduous Forest Land.	280	318	88	84- 92
42 Evergreen Forest Land.	318	338	94	91-97
43 Mixed Forest Land.	565	608	93	91- 95
52 Lakes	25	28	89	76-100
54 Bays and Estuaries.	150	151	99	97-100

Both Deciduous Forest Land and Lakes were less than 85-percent accurate at the 95-percent lower confidence limits. However, the value for Deciduous Forest Land is calculated to be 84.33 which is acceptable as a lower confidence limit. Lakes, on the other hand, had too wide a confidence interval to be a reliable estimate of the accuracy. A larger sample of Lakes would be necessary for a reliable comparison of the errors of commission and of omission.

The accuracy for all points combined was 92 percent or 2,282 points of a total of 2,475 points with a 95-percent lower one-tailed confidence limit of 91 percent.

Conclusions

The selected land use and land cover maps interpreted from high-altitude photographs meet the criterion that they be mapped with an accuracy of 85 percent. Table 19 is a summary of these results. The single exception to this for those maps tested was the Tacoma, Wash., map sheet where the accuracy was less than 85 percent at the lower confidence limit. Those categories causing interpretation difficulties were not the same on all map sheets, and the number of errors were not always the highest for these categories. Errors committed in general were predictable errors between categories of similar signatures or within a Level I category. Categories in error for the most part were found to fall within the predictable error types shown in figure 1. Each user must judge the seriousness of any of these error types for his needs.

TABLE 19.—*Land use and land cover map accuracies for selected maps*

Map sheet	Scale	Points correct	Points selected	Percent correct	95-percent one-tailed lower confidence limit (percentage)
Tampa	1:250,000	329	354	93	91
Portland	1:250,000	410	456	90	87
Charleston	1:250,000	393	424	93	90
Greeley	1:250,000	399	413	97	95
Atlanta	1:100,000	343	381	90	87
Seattle	1:100,000	206	212	97	95
Tacoma	1:100,000	202	235	86	82

When all points sampled for these map sheets were combined, the results yielded sufficient points to provide reliable results for nine categories. All categories sampled with a significant number of points exceed the required accuracy of 85 percent. Only one category on the maps, Residential (11), was less than 85-percent accurate at the lower confidence limit. Although the sample value exceeds 85 percent, the lower confidence limit is 82 percent, indicating there may be problems in mapping that category. The errors of overestimating Residential would be a serious disadvantage to may users, and so extra caution should be employed when mapping this category.

Although the lower confidence limit is the lowest value accepted (with 95-percent confidence) as the true accuracy of the map, there is just as much chance that the maps exceed the measured accuracy as fall short of it. The lower confidence limit, therefore, is a conservative estimate of whether the maps meet the accuracy criteria of 85 percent. Those categories whose sample results fall short of 85-percent accuracy at the lower confidence limit may still meet or exceed 85-percent accuracy in the true population.

A more precise accuracy statement would be possible if all categories on the map were sampled with a sufficient number of points to be analyzed reliably with a narrow confidence interval, a procedure which would require a

presample knowledge of all categories on the map. Such a sampling technique, using digitized land use data, is being developed at the Survey to sample an optimum number of points for each category.

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