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Landsat for Practical Forest Type Mapping: A Test Case

Computer classified Landsat maps agreed to within 5 percent of a conventional inventory of forest lands in northern Maine.

ABSTRACT: *In a cooperative project, computer classified Landsat maps were compared with a recent inventory of forest lands in northern Maine. Over the 196,000 hectare (485,000 acre) area mapped, estimates of area of softwood, mixed wood, and hardwood forest types by the two methods agreed to within 5 percent. Cost of the Landsat maps is estimated at 6.5 cents per hectare (2.6 cents per acre). Although the information derived from Landsat is not yet refined enough to be incorporated in current forest inventories, the techniques used are worth developing.*

INTRODUCTION

MANY PEOPLE have used Landsat data in mapping natural resources and cultural features (Bauer *et al.*, 1978; Dejace *et al.*, 1977; Gaydos and Newland, 1978; George *et al.*, 1977; Krebs and Hoffer, 1976; Mukai and Takeuchi, 1979; Odenyo and Pettry, 1977). In particular, researchers across North America have reported use of Landsat data in mapping forest resources (Beaubien, 1979; Dodge and Bryant, 1976; Harding and Scott, 1978; Johnson *et al.*, 1979; Kalensky *et al.* 1979; Kirby *et al.*, 1975; Kourtz, 1977; Mead and Meyer, 1977; Sayn-Wittgenstein, 1977; Titus *et al.*, 1975; Williams and Haver, 1976).

The goal of the Dartmouth forestry section of the Goddard Institute for Space Studies is to use computer classification of Landsat data to make fores type maps which are useful to the field forester Thus, the person who cruises the forest rather thar the upper level manager is the "user" for whom the Landsat maps are being developed.

SEVEN ISLANDS PROJECT

The Seven Islands project developed from a contact with a potential Landsat data user employed by the Seven Islands Land Company, Bangor, Maine. Seven Islands manages 690 thousand hectares (1.7 million acres) of forest land in northern Maine and New Hampshire. They require information about forest types on their lands for management decisions and for taxation purposes. (The state of Maine taxes forest land by applying different values to softwood, mixed wood, and hardwood forest areas.) A detailed inventory of the Seven Islands lands was underway at the time the contact was made. This presented a rare opportunity to test Landsat's ability to meet practical user information needs: the user requirements were well defined (in the inventory specifications) and there was a product, the standard inventory, against which to measure Landsat mapping performance.

With the cooperation of the Seven Islands Land

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 46, No. 12, December 1980, pp. 1575-1584.

Company, a project was started. The goal was to match their inventory specifications as closely as possible using computer classification of Landsat data, and to create, quickly and inexpensively, a product suitable to submit to the Bureau of Taxation. There is a difference between this and some other Landsat applications projects. Success is measured by agreement with a given inventory, not by agreement with "ground truth" gathered by the Landsat investigators. A positive aspect of this approach is the elimination of biases which Landsat investigators might introduce in gathering their own ground truth.

More specific goals of the project were

- To map the Ashland District portion of the Seven Islands lands (Figure 1);
- To match computer-classified Landsat categories with Seven Islands inventory categories: softwood, mixed wood, and hardwood forest types, non-forest areas, water, and roads;
- To calculate area for each category in each Seven Islands management unit (units are usually townships or parts of townships); and
- To produce geometrically corrected computer printout maps of the area at 1:24,000 scale.

The following constraints were put on the project in order to approximate an operational situation:

- Minimize the amount of ground truth used in creating and checking the Landsat classification (methods dependent on large amounts of ground truth are suitable only for research situations); and
- Keep track of expenses—human and computer time, cost of data and supplies—to give an estimate of cost per unit area.

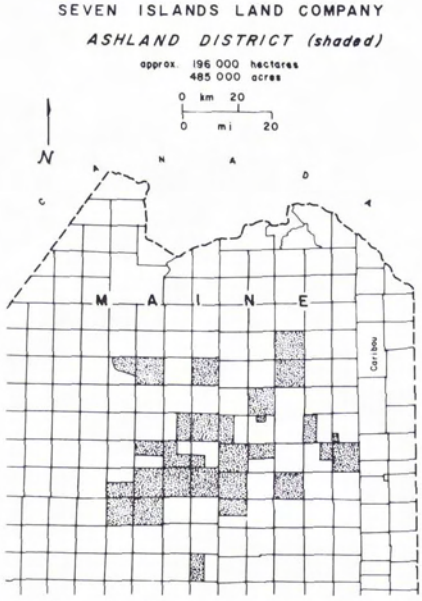

FIG. 1. Ashland District portion of Seven Islands Land Company lands, an area of about 196,000 hectares (485,000 acres). Individual parcels are not always contiguous and range in size from 400 to 10,500 hectares (1,000 to 26,000 acres).

THE ASHLAND DISTRICT

The Ashland District, managed by Seven Islands Land Company, consists of land in 29 townships in northern Maine located between 46 and 47 degrees north latitude. In most of the area, the political subdivisions are "unincorporated townships" where there is very little permanent human settlement.

The individual parcels or townships in the Ashland District are not always contiguous and range in size from 400 to 10,500 hectares (1,000 to 26,000 acres). The District comprises a total of 196,356

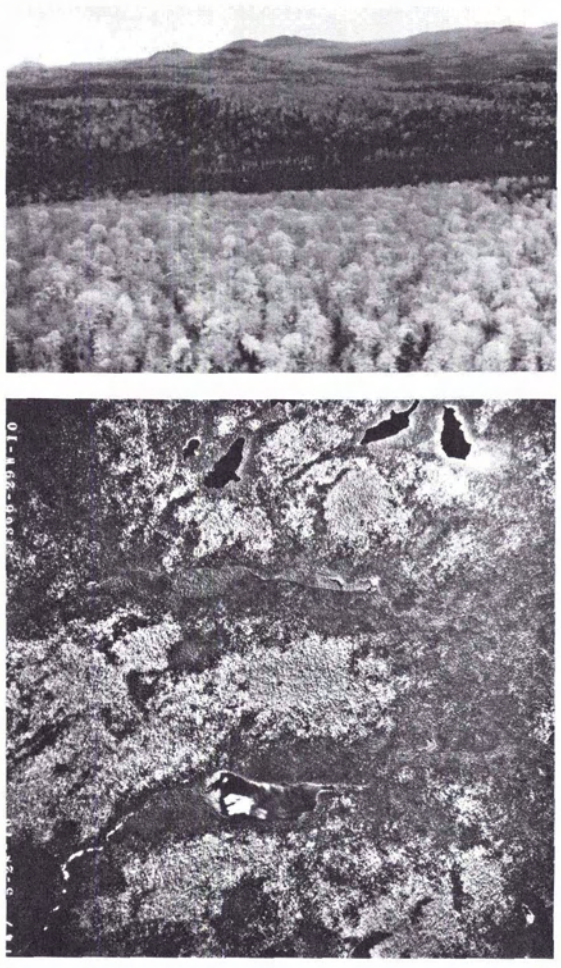

FIG. 2. Oblique (above) and vertical (below) views of a portion of the Ashland District. The vertical view is an example of the black-and-white infrared photos used in the Seven Islands inventory (original scale 1:15,840; photos taken in May, 1976).

hectares (485,310 acres) (Figure 1). The most common forest types in this area are

- spruce-fir (*Picea sp.—Abies balsamea*)
- maple-beech-birch (*Acer saccharum—Fagus grandifolia—Betula alleghaniensis*)
- northern white cedar—black spruce (*Thuja occidentalis—Picea mariana*)

Figure 2 shows oblique and vertical views of part of the Ashland District.

THE SEVEN ISLANDS INVENTORY

The Seven Islands inventory is based on aerial photo-interpretation, "3-P" (probability proportional to prediction) field sampling, and the STX computer program (a standard forest measurement program). Figure 2 includes an example of the photos used in the inventory. The inventory consists of type maps, acreage tallies, and volume estimates. This project concentrated on matching the maps and acreage tallies, leaving volume estimation to other techniques.

The Seven Islands maps distinguish vegetation by type, size, and density to a 10 acre minimum. Acreage is determined for each forest stand, and totals are computed by type for each township. For tax purposes, the many forest types distinguished in the inventory are grouped into three more general types according to the proportion of softwood (conifer) to hardwood (deciduous) trees in an area:

- softwood—at least 75 percent of the trees are softwood.
- hardwood—at least 75 percent of the trees are hardwood.
- mixed wood—the proportion of softwood to hardwood trees lies between those of the softwood and hardwood categories as defined above.

The above are the general forest categories that were to be matched in the Landsat classification.

PROCEDURE

GENERAL OUTLINE

The project employed computer programs to make maps and acreage tallies from Landsat multispectral scanner (MSS) digital data. A supervised classification approach was used. It was developed at the Goddard Institute for Space Studies (GISS) by Stephen G. Ungar and is described in Merry *et al.* (1977). With the GISS classification algorithm, the program user defines a volume in four-dimensional color space around an average signature for each land cover category. The signature is usually the average reflectance of a land cover type as taken from a representative sample of the MSS data (a "training site"). The user can create a classification category for which there is no training site, if there is another source of signatures.

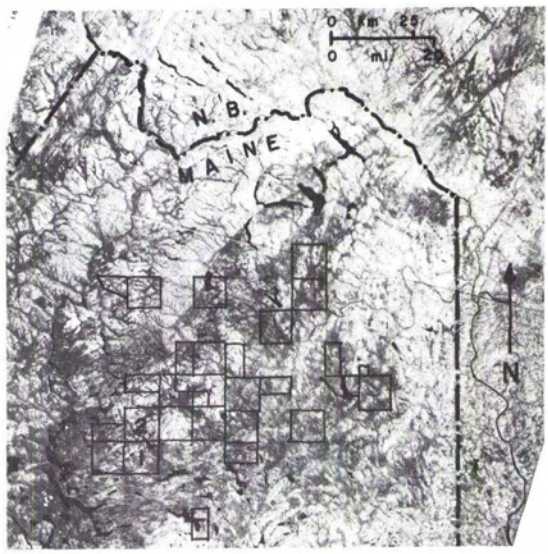

FIG. 3. MSS band 6 image of the 11 August 1976 Landsat scenes used in classifying the Ashland District (scene identification numbers 5480-14040 and 5480-14043). Ashland District is outlined; sample townships are labeled 1 and 2. Water is black, softwood dark gray, and hardwood light gray.

DETAILS OF THE SEVEN ISLANDS PROJECT

Landsat data used in the Seven Islands project was recorded on 11 August 1976. Scene identification numbers are 5480-14040 and 5480-14043 (Figure 3).

Ground truth consisted of

- Representative copies of the photos used in the Seven Islands inventory (Figure 2);
- Seven Islands inventory maps and acreage tallies for two of the 29 townships in the District;
- Personal knowledge from an overflight of the area;
- Prints of photo-mosaics used for location of forest harvests (scale 1:31,680); and
- Topographic maps (scale 1:62,500).

There was no ground checking except indirectly through the inventory information.

We chose signature training sites in the MSS data (usually 10 to 30 pixels in size) for softwood, hardwood, water, bog, and open categories using the aerial photographs. Mixed wood signatures were made by interpolating between hardwood and softwood signatures.

The tolerance parameters for the forest categories were adjusted so that the acreage tallies would agree with the Seven Islands inventory on two sample townships (Table 1). Discrepancy in acreage figures on the two townships taken together was under 3.5 percent; it was under 10 percent when they were considered separately. The two townships comprise 19,000 hectares (47,000 acres), about 10 percent of the Ashland District (Figure 3).

TABLE 1. FOREST TYPE AREA ESTIMATES FOR SAMPLE TOWNSHIPS FROM SEVEN ISLANDS LAND COMPANY AND LANDSAT INVENTORIES.*

Forest Type	7 Islands Tally (ha)	Landsat Tally (ha)	Percent Diff.
Sample Township #1			
Softwood	4 331	4 573	+5.6%
Mixed Wood	3 320	3 117	−6.1%
Hardwood	830	906	+9.2%
Total For.	8 481	8 596	+1.4%
Sample Township #2			
Softwood	4 247	4 017	−5.4%
Mixed Wood	3 286	3 591	+9.3%
Hardwood	1 826	1 667	−8.8%
Total For.	9 360	9 275	−0.9%
Sample Townships #1 and #2 Combined			
Softwood	8 578	8 591	+0.2%
Mixed Wood	6 606	6 707	+1.5%
Hardwood	2 656	2 572	−3.2%
Total For.	17 840	17 870	+0.2%

* Both Seven Islands and Landsat tallies were normalized so that total area in each township matched the deeded acreage as listed in the Seven Islands records.

Boundaries of the management units (townships) were superimposed on the Landsat data using a masking program. They were taken from topographic maps, using water bodies as control points.

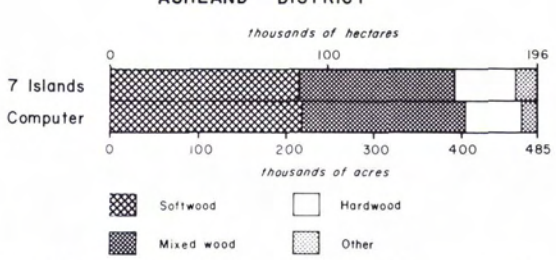

FIG. 4. Seven Islands Land Company inventory tallies for the Ashland District and Landsat computer classification results for the same area.

RESULTS

RESULTS RELATIVE TO THE GOALS

Map the District. A printout map and acreage tally by category was made for each management unit in the Ashland District.

Match Seven Islands categories. Area comparison is one measure of how well the Landsat categories match Seven Islands categories. Area tallies for the entire district are shown in Table 2 and Figure 4. Differences between Landsat and Seven Islands forest type acreage estimates are under 5 percent. As is to be expected, they are larger for the individual township tallies. Figure 5 shows Seven Islands versus Landsat acreage estimates for the individual townships for softwood, mixed wood, hardwood, total forest, water, and open categories. Both the Landsat and the Seven Islands inventory acreage tallies were normalized so that the total acreage in each township matched

TABLE 2. AREA ESTIMATES OF FOREST TYPES AND RELATED FEATURES IN THE ASHLAND, MAINE DISTRICT DERIVED FROM SEVEN ISLANDS LAND COMPANY INVENTORY AND LANDSAT COMPUTER CLASSIFICATION.

	Seven Islands		Landsat		Difference	
	Hectares Acres	% of Total	Hectares Acres	% of Total	Hectares Acres	%
Softwood	87 104 215 285	44.4%	88 884 219 683	45.3%	+1 780 +4 398	+ 2.0%
Mixed Wood	71 976 177 895	36.7	74 498 184 127	37.9	+2 522 +6 232	+ 3.5
Hardwood	27 482 67 924	14.0	26 121 64 561	13.3	−1 361 −3 363	− 5.0
Water	5 911 14 609	3.0	4 695 11 605	2.4	−1 216 −3 004	−20.6
Open Land	823 2 035	0.4	663 1 639	0.3	− 160 − 396	−19.5
Bog	3 060 7 562	1.6	242 599	0.1	−2 818 −6 963	−92.1
Unclassified*	....	.....	1 255 3 102	0.6	....	.....
Total Forest	186 562 461 104	95.0	189 503 468 371	96.5	+2 941 +7 267	+ 1.6
Total Area**	196 356 485 310	100.0	196 356 485 310	100.0	....	.....

* The Seven Islands inventory included no "unclassified" category.

** Both Seven Islands and Landsat tallies were normalized so that total area in each township matched the deeded acreage as listed in the Seven Islands records.

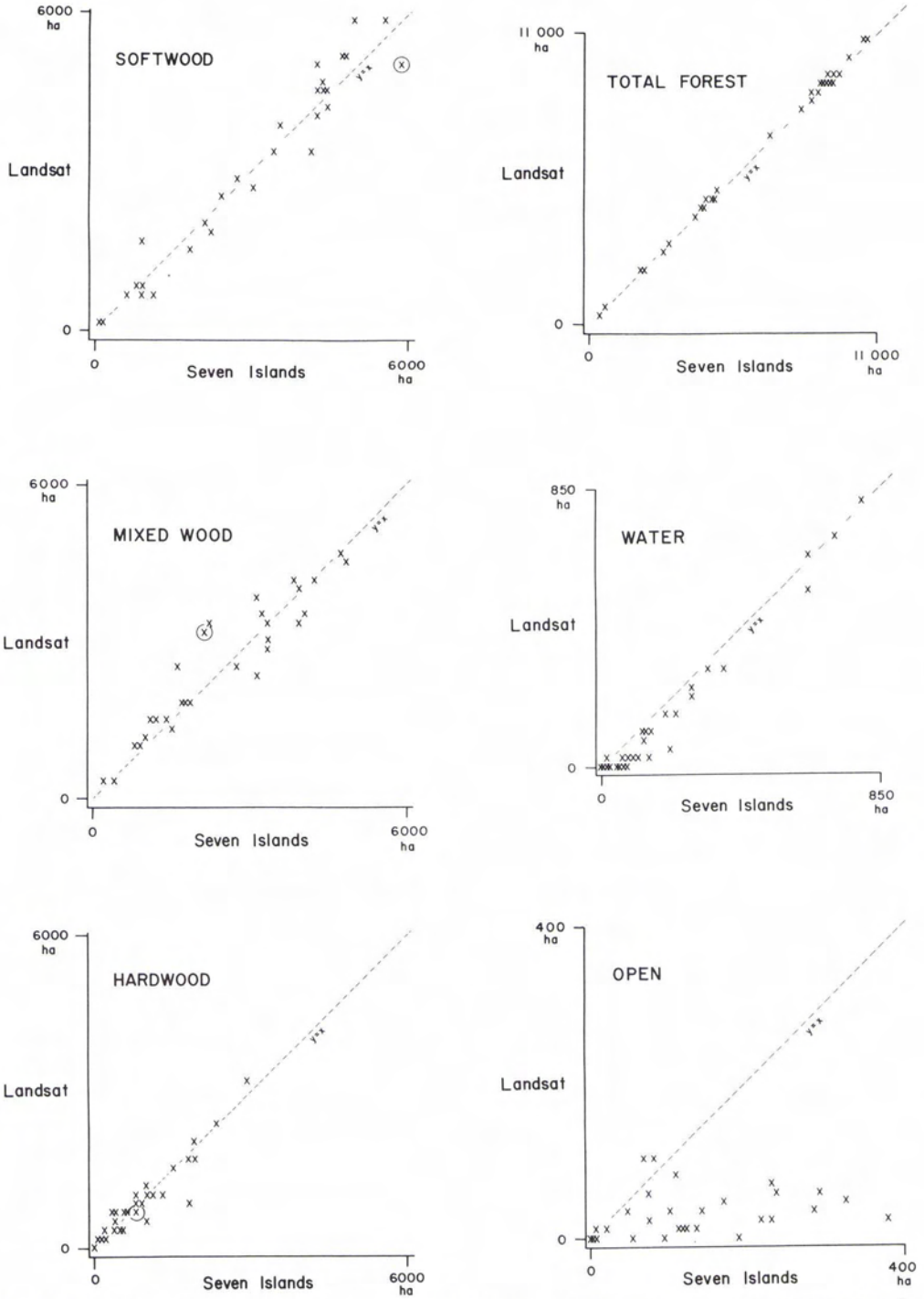

FIG. 5. Seven Islands inventory tallies for each management unit (township) are plotted against Landsat computer classification results for six land cover classes. Discrepancies in one township could be attributed to differences in classification of partially cut areas (data point is circled).

its deeded acreage as listed in the Seven Islands records.

Agreement in locations of features on maps was desired as well as area agreement. An informal comparison of Landsat maps and Seven Islands inventory maps shows that the positions and shapes of the forest stands generally coincide (Figure 6). As a more formal test of locational agreement, 130 sample pixels in one ground truth township were selected at random, and their Landsat and Seven islands categories were compared. Results are in Table 3. The overall agreement (diagonal entries in the table divided by the total number of samples; 83/130) is 63 percent. While this seems rather low, other Landsat applications studies involving forest types have similarly low overall agreement, depending on exactly what the categories are, how they are aggregated, and how the samples are chosen (Table 4). Overall agreement ranges from 43 percent to 98 percent.

This single pixel method of measuring classification accuracy has inherent problems. Minimum feature size classified on the ground truth maps is often greater than one pixel (0.4 hectares or 1.1 acres); in this case it was 4 hectares (10 acres). Exact location of one-pixel samples on ground truth maps is uncertain. Each of these problems can lower the measured accuracy of a classification, regardless of its actual accuracy.

In the non-forest categories, it was found that roads were not located with enough accuracy to be useful; also, bogs were often classified as forest, and small streams were not identified.

Tallies for each township. Acreage by township and category is in Figure 5 as mentioned above. Locating township boundaries was very time consuming but essential for comparison with the standard inventory results.

Geocorrected data. The Landsat geometric correction used was a systematic correction applied to the entire Landsat scene, using a nearest neighbor resampling scheme. The accuracy was acceptable over the one-township size units (8000 hectares or 20,000 acres) used in the Seven Islands project.

REMARKS ON THE CONSTRAINTS

Minimize ground truth. Originally, the Seven Islands inventory of the two sample townships

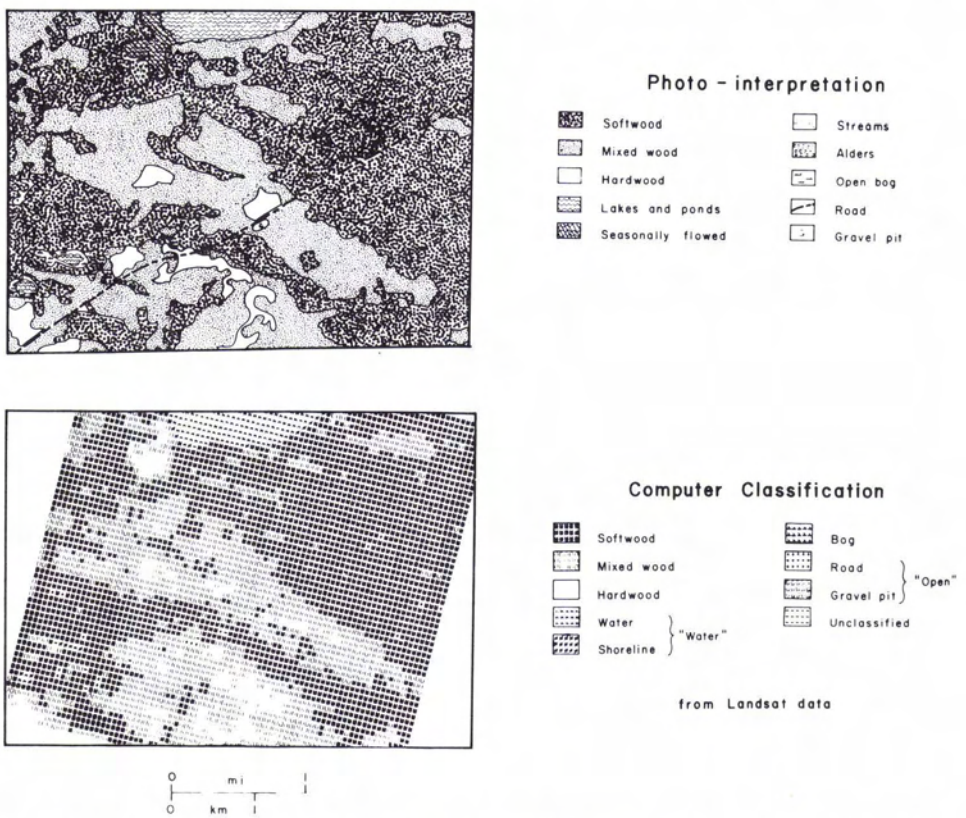

FIG. 6. Seven Islands inventory map (above) and Landsat computer classification (below) from one of the two sample townships. Informal comparison shows that positions and shapes of forest stands generally coincide. Landsat data has been systematically geometrically corrected (original scale 1:24,00).

TABLE 3. COMPARISON OF SEVEN ISLANDS AND LANDSAT CLASSIFICATIONS. THE 130 ONE-PIXEL SAMPLES WERE SELECTED AT RANDOM FROM ONE SAMPLE TOWNSHIP.

Landsat Category	Seven Islands Categories						
	Soft	Mixed	Hard	Water	Open	Other	Total
Softwood	41	12	1	1	0	3	58
Mixed Wood	16	23	3	0	0	2	44
Hardwood	0	8	6	0	0	1	15
Water	0	0	0	12	0	0	12
Open	0	0	0	0	0	0	0
Other	0	0	1	0	0	0	1
Total	57	43	11	13	0	6	130

Sum of diagonal entries = 82, or 63% of the 130 samples total.

was not included in ground truth. Preliminary results, however, showed a large discrepancy between Landsat and inventory maps. The only way to match given categories was to have a sample of them, not just the inventory specifications. Since the size of the ground truth sample townships was large, the original goal was expanded from mapping three townships to mapping the entire district.

Costs. The cost estimates for this project are listed in Table 5. The overall cost of 6.5 cents per hectare (2.6 cents per acre) includes human time at ten dollars per hour, computer time at 600 dollars per hour (on an IBM 360/95), and ground truth. The cost of ground truth for the two sample townships is 37 percent of the total cost—2.4 cents per hectare (0.99 cents per acre). The cost also reflects inefficiencies which would be eliminated in subsequent projects. The estimate excludes cost of software development, depreciation on the computer, photo-mosaics, topographic maps, and geocorrection of data. Classification of a larger area would reduce the per area cost; estimated cost for 800,000 hectares (2 million acres) is 2.4 cents per hectare (0.96 cents per acre). Table 6 compares this cost estimate with those from other Landsat applications projects. They vary from 0.078 to 8.6 cents per hectare (0.032 to 3.5 cents per acre). Much of this variation is due to differences in the items included in the estimates (sometimes ground truth is excluded) and the cost assigned to the items (cost of human time varies from 5 to 21 dollars per hour).

The information derived by computer-classification of Landsat data could also be derived from standard photo-interpretation techniques. The company that did the Seven Islands inventory gave a ball-park estimate of the cost as 11.0 to 16.0 cents per hectare (4.5 to 6.5 cents per acre). (Rate for the Seven Islands inventory itself would be higher because it is more detailed).

DISCUSSION

Although acreage results on the forest categories were within 5 percent, those for the remaining categories (water, bog, open land) had much larger discrepancies (Table 2; Figure 5). Possible explanations of these discrepancies follow. First, there is a smaller sample: together the open, bog, and water categories comprise only 5 percent of the

TABLE 4. COMPARISON OF LOCATIONAL AGREEMENT RESULTS.

Reference	# Categories	# Diagonal Entries (Pixels)	Total # of Samples (Pixels)	Overall Agreement (Percent)	Sample Selection Scheme
Bryant *et al.*	6	82	130	63%	Random
Harding and Scott 1978	5	142	302	47%	Stratified
Johnson *et al.* 1979	6	107	200	54%	Grid
Johnson *et al.* 1979	3	169	200	85%	Grid
Kalensky and Scherk 1975	4	1119	1342	83% (4-date)	*
Kalensky and Scherk 1975	4	*	*	67%-82% (1-date)	*
Kalensky *et al.* 1979	9	4024	4123	98%	Control Areas
Kalensky *et al.* 1979	9	4061	4123	98%	Control Areas
Kalensky *et al.* 1979	9	3978	4123	96%	Control Areas
Kirby *et al.* 1975	6	401	676	59%	Pixel Columns
Mead and Meyer 1977	11	560	1305	43%	Pixel Rows
Mead and Meyer 1977	11	779	1478	53%	Pixel Rows
Williams and Haver 1976	6	162	232	70%	Random
Williams and Haver 1976	3	208	232	90%	Random

* Information not provided.

TABLE 5. SEVEN ISLANDS PROJECT COST ESTIMATES.
SIZE OF AREA CLASSIFIED: 196 400 HECTARES (485 310 ACRES).

Item	Cost (Dollars)	% of Total	Cost/ha (Cents)	Cost/a (Cents)
Materials[1]	$ 699	5.4%	0.36¢	0.14¢
Field Expenses[2]	780	6.1	0.40	0.16
Inventory of Sample Townships[3]	4 800	37	2.4	0.99
Signature Development[4]	4 490	35	2.3	0.93
Subtotal: Initial Costs	$10 769	84 %	5.5 ¢	2.2 ¢
Run-off and Tally of Ashland District[5]	$ 2 070	16 %	1.1 ¢	0.43¢
Total Cost	$12 839	100 %	6.5 ¢	2.6 ¢
Projected Cost Estimate for 800 000 hectares (2 000 000 acres)				
Initial Costs (As Above)	$10 769	56 %	1.3 ¢	0.54¢
Run-off and Tally	8 600	44	1.1	0.43
Total Cost	$19 369	100 %	2.4 ¢	0.97¢

[1] Includes air photos, Landsat images, Landsat CCT's, and computer supplies.
[2] Includes travel and labor costs. (Labor valued at $10 per hour.)
[3] Estimated cost for 19 500 hectares (48 000 acres) at 25¢ per hectare (10¢ per acre).
[4] Includes 305 hours labor and 144 minutes computer time (valued at $10 per minute).
[5] Includes 106 hours labor and 99 minutes computer time.

area classified; the rest is forested. Next, the resolution of Landsat (80 metres) is coarse relative to streams and narrow roads. These features are absorbed into the surrounding forest types. This may account for the Landsat underestimation of water and open categories.

Confusion in Landsat categories may account for the underestimation of the bog category. Bogs were often classified as mixed wood or hardwood.

Forest acreage tallies for some individual townships had noticeably large discrepancies. In one case (circled in Figure 5) this could be attributed to difference in classification of partially cut areas which included many small softwood trees and a few large hardwood trees. The photo-interpretation in the Seven Islands inventory, which is based on numbers of trees, indicated softwood; the computer classification, based on average reflection, indicated mixed wood.

A factor influencing forest classification is sun illumination. Classifications of forest areas within terrain shadows have a bias toward softwood. Merging of digital topographic data and Landsat data could improve this situation (Krebs and Hoffer, 1976; Strahler *et al.*, 1979). Over a large enough area, these differences balance each other out.

There are some problems which researchers cannot solve. One is New England weather, which is relatively cloudy. It is possible that in some years there would be no Landsat coverage at the desired times of year. Another problem is the acquisition of data. At this point there is a long turnaround time in ordering Landsat computer compatible tapes (CCT's). Also some private organizations do not want to depend on government sources for their data.

CONCLUSION

Bearing in mind the objective to give quick, inexpensive, and accurate acreage estimates of forest types to the Bureau of Taxation, the following conclusions are drawn. Results were very good on the district as a whole, but were not good for the individual townships. Each township has unique records of accounting and ownership and must have proven and precise forest type information. In some cases this is needed for portions of a township that are as small as 400 hectares (1000 acres). The 400 hectare tract requires the same level of precision that was reached in this project with the tallies for the 200,000 hectare tract.

On the other hand, the energy situation is becoming more burdensome, and satellite information will become more important as a supplement to aerial photographs and other information sources. Further research in satellite data processing techniques could bring the information to a more useable level and is worth pursuing.

RECOMMENDATIONS

More experience using satellite data in practical situations is recommended. Computer classification may currently be as reliable as photo-

TABLE 6. COST ESTIMATE COMPARISON.

Reference	Items Included: Lndst Data	Geocor. of Data	Grnd Trth	Computer Time	Computer Depreciatn.	Value of Human Time ($/hr)	Related to Other Maps?	Size of Subunits 1 000ha	Size of Subunits 1 000a	Total Area Classified 1 000ha	Total Area Classified 1 000a	Total Cost ($)	Cost per ha (¢)	Cost per a. (¢)
Bryant *et al.*	yes	no	yes	yes	no	$10	15' USGS	6.8	16.7	196	485	$12 839	6.5 ¢	2.6 ¢
Gaydos, 1978	yes	yes	no	yes	a/	7	1:250 000	1 700	4 200	560	1 400	442	0.078	0.032
Hill-Rowley & Enslin, 1979	a/	a/	a/	yes	a/	a/	1:250 000	1 700	4 200	2 300	5 600	5 420	0.24	0.097
Kalensky *et al.*, 1979	no	yes	a/	yes	yes	22	UTM	10	25	250	617	21 512	8.6	3.5
Krebs and Hoffer, 1976	no	yes	no	yes	a/	5	7.5' USGS	58	144	464	1 148	2 900	0.63	0.25
Krebs and Hoffer*	a/	yes	yes	yes	a/	5	7.5' USGS	58	144	464	1 148	17 907	3.9	1.6
Roberts and Merritt, 1977	yes	a/	no	yes	no	a/	a/	50	123	50	123	400	0.80	0.32
Williams and Haver, 1976	yes	a/	no	yes	a/	0	7.5' USGS	58	144	263	650	2 250	0.86	0.34

* Includes merging Landsat data with digital topographic data and manual analysis of imagery.
a/ Information not provided.

interpretation, but there are differences, and they need to be identified. Perhaps some of the information missing in the current Landsat maps can be extracted from higher resolution data such as the quarter acre resolution projected for Landsat D (Williams and Stauffer, 1979). Already, examination of Landsat 3 RBV imagery suggests that woods roads will be much more distinct with 30 metre resolution.

SUMMARY

Landsat classification maps were made for a forested area in northern Maine, managed by the Seven Islands Land Company. Over the 200,000 hectare (half million acre) district, results agreed with a standard inventory to within 5 percent on area of general forest types. Cost was estimated at 6.5 cents per hectare (2.6 cents per acre). Accuracy measurements and cost estimates were comparable with other Landsat forestry applications projects.

The techniques described here are promising, but are not yet practical for Seven Islands Land Company's needs. Further research and perhaps better spatial resolution are needed to ensure reliable Landsat results on smaller geographic areas.

ACKNOWLEDGMENTS

This project was supported by NASA Science Grant 5014. We wish to thank Seven Islands Land Company for their cooperation and for the use of inventory data.

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(Received 30 May 1979; revised and accepted 5 June 1980)