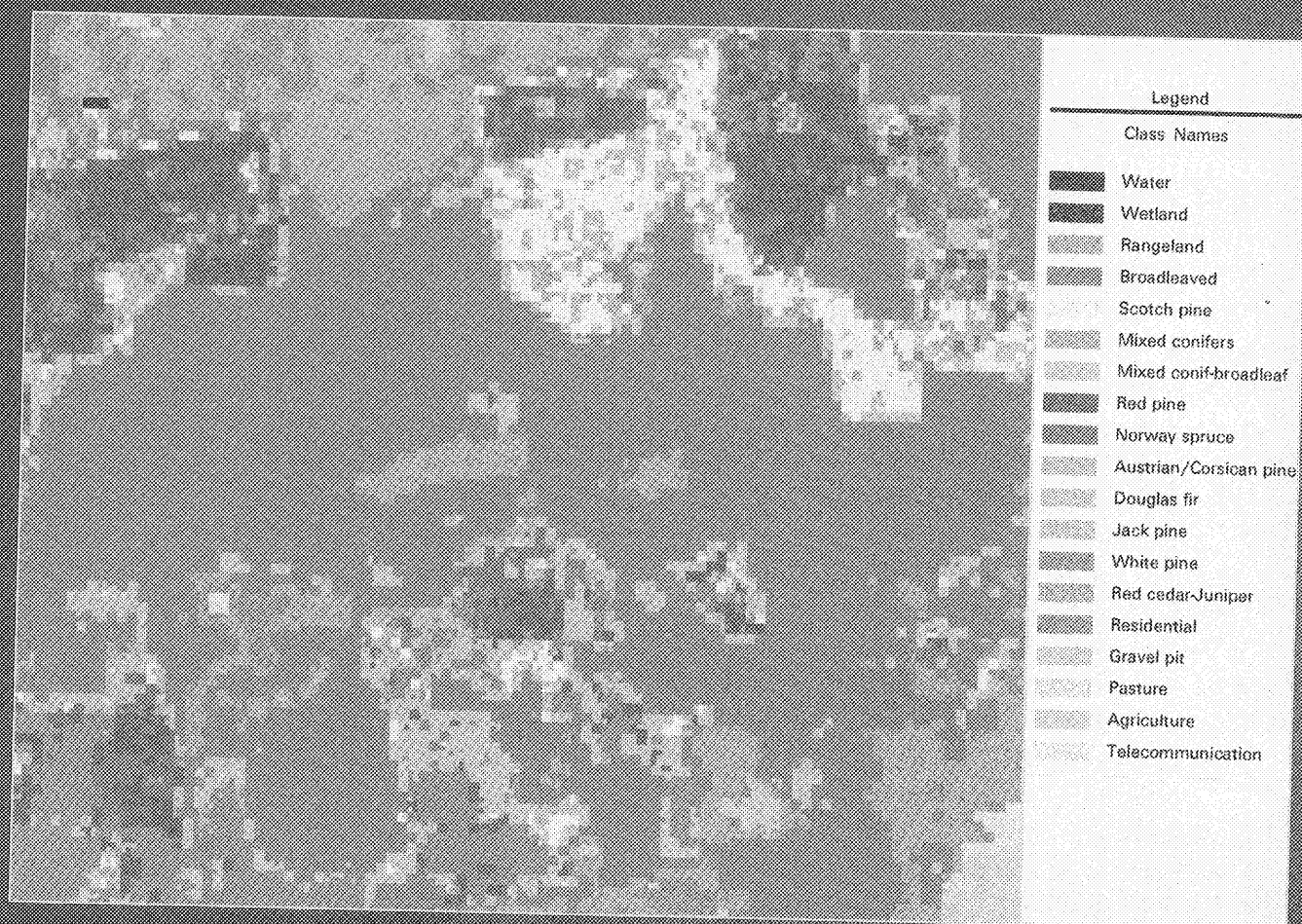




# The Significance of Spatial Resolution

## *Identifying Forest Cover from Satellite Data*

Dumitru Salajanu and Charles E. Olson Jr.

### ABSTRACT

The objective of this study was to determine if decreasing pixel size increases overall accuracy with which forest species can be separated using satellite data. Classification accuracy achieved with Landsat Thematic Mapper (TM) channels 2, 3, and 4 were compared with results from SPOT-XS. Reference data prepared from enlarged prints of aerial photographs and field checks included 19 cover types, nine of which were coniferous. Results with SPOT-XS alone yielded an overall accuracy of 70.1 percent, and with Landsat TM 57.1 percent at species level. Overall accuracy increased by 3 percent when either SPOT-XS or Landsat TM data were integrated with SPOT-PAN data.

**Keywords:** biometrics; land use; remote sensing

Twenty-five years ago, a National Academy of Sciences report identified species identification as a requirement if satellite data are to reach their full potential in forest inventory and monitoring; the report suggested that improving spatial resolution to 10 meters would probably be required (Committee on Remote Sensing Programs for Earth Resource Surveys [CORSPERS] 1976). Conversations with federal, state, and private forest managers confirm that this species identification requirement persists, and that an accuracy of 90 percent is required when separating broadleaved from conifer stands. This article describes a study to determine the effect of spatial resolution (pixel size) on the accuracy with which forest tree species can be identified from digital satellite data on a stand basis.

### Background

Satellite data from sensors with different spatial and spectral resolution have been used for land cover classification. The most common classification schemes are derivatives of the hierarchical system defined by Anderson et al. (1976). Level I classes are the most general (e.g., urban, agriculture, rangeland, forest). Each level I class may be subdivided into more specific level II classes, and these further divided into even more specific level III classes. Separation of broadleaved from conifer forest occurs at level II and further separation to species at level III.

Overall and individual classification accuracies vary widely depending on satellite data source, classification algorithm, pixel size, size of each cover type, number of cover types used in classification, and study site location. Most accuracy assessments have been based on statistical samples, but effects of some factors on accuracy assessment were analyzed in several studies with Landsat Thematic Mapper (TM), Landsat multispectral scanner (MSS),

synthetic aperture radar (SAR), and SPOT-XS satellite data for totally enumerated reference data sets at the Sleeping Bear Dune test site in Leelanau County, Michigan (Ma 1985; Nugroho 1992; Dondurur 1994). Total enumeration of the reference data set resulted in the observation that brightness value distributions were neither normal nor symmetrically distributed about their means for any cover type or spectral band (Olson and Ma, 1989; Olson 1992).

Ma (1985) compared results from Landsat MSS data with those obtained from Landsat TM data for land cover-use classification to level I. He achieved 76 percent overall accuracy with TM band-4 alone in a parallelepiped classifier. When all seven TM bands were used with a linear discriminant function classifier, overall accuracy was 85 percent. His attempt to classify forest area to level II resulted in a decrease in overall accuracy to 73 percent with TM and 71 percent when MSS data were used. Overlap in the brightness value ranges of many cover types was a factor in the decreasing accuracy with both sensors (Ma and Olson 1989). The higher accuracy using TM was attributed to its greater spatial resolution.

Nugroho (1992) used SPOT-XS data with a texture measure as an extra data channel to classify seven land cover types at level II. He used several different classifiers and achieved an overall accuracy of 76 percent with a linear discriminant function and 75 percent with a parallelepiped classifier. He concluded that forest classification accuracy was greater when band ratio (3/2) and the texture measure were combined with the three original SPOT-XS data channels.

Dondurur (1994) used Landsat TM, SPOT-XS, and airborne SAR data to classify 3,950 acres. He used a supervised classification and achieved an overall accuracy of 87 percent with TM, 85 percent with SPOT-XS, and 85 percent with SAR C-band when results were compared with the totally enumerated reference data set. Even though significance tests indicated that

TM data provided significantly better results than SPOT-XS, he concluded there was little practical difference in terms of overall accuracy, but attributed the higher overall accuracy of the TM classification to its higher spectral resolution compared to SPOT-XS.

Similar work was also being done elsewhere. Lillesand et al. (1985) evaluated both manual and computer-assisted image interpretation techniques to level II, where textural and tonal contrast aided in the separation of hardwoods and conifers. Differentiation between conifer species was observed in some instances, but accuracy of identification of Norway spruce was only 45 percent. The authors reported difficulties in differentiating small agricultural areas from recently logged areas. They also reported some problems distinguishing nonforest features, such as roads, plowed fields, and highly reflective wetlands. After these were eliminated, more accurate classifications were obtained. The authors reported an overall and class average accuracy, based on assessment of homogeneous test areas, of 93 and 85 percent, respectively.

Borri et al. (1990) compared the performance of conventional digital classification techniques with visual interpretation of digitally enhanced monotemporal SPOT images for the identification of tree species in Belgium. A panchromatic scene was used to determine the contribution of 10 × 10 meter spatial resolution to visual interpretation. To assess the value of the information gained at different stages in the phenological cycle, four SPOT (XS) multispectral images were selected to correspond with distinct stages of the phenological process. They used five enhancement procedures to prepare SPOT images for visual interpretation and a supervised, per-point classification. Interpretation results were compared to cover-type maps obtained from color infrared photographs and classification accuracy was determined statistically. They reported an increase in interpretation accuracy for the September images when the panchromatic and multi-

**Opposite:** Classified map of Stinchfield Woods area in Michigan, from SPOT-XS integrated data.



**Table 1. Cover type distribution within the reference maps.**

| Cover type                      | Scientific name                 | SPOT-XS |         | Landsat TM |         |
|---------------------------------|---------------------------------|---------|---------|------------|---------|
|                                 |                                 | Pixels  | Percent | Pixels     | Percent |
| 113 Residential                 |                                 | 82      | 0.87    | 30         | 0.66    |
| 145 Telecommunications          |                                 | 4       | 0.04    | 2          | 0.04    |
| 171 Gravel pit                  |                                 | 25      | 0.26    | 19         | 0.42    |
| 211 Cropland                    |                                 | 125     | 1.32    | 23         | 0.51    |
| 212 Pasture                     |                                 | 9       | 0.10    | 27         | 0.59    |
| 300 Rangeland                   |                                 | 1,187   | 12.54   | 520        | 11.46   |
| 411 Broadleaf forest            | <i>Quercus/Acer spp.</i>        | 4,859   | 51.34   | 2,277      | 50.20   |
| 421 White pine                  | <i>Pinus strobus</i>            | 1,011   | 10.68   | 503        | 11.09   |
| 422 Red pine                    | <i>Pinus resinosa</i>           | 538     | 5.69    | 256        | 5.64    |
| 423 Jack pine                   | <i>Pinus banksiana</i>          | 50      | 0.53    | 24         | 0.53    |
| 424 Scotch pine                 | <i>Pinus sylvestris</i>         | 528     | 5.58    | 259        | 5.71    |
| 425 Austrian-Corsican pine      | <i>Pinus nigra/spp. laricie</i> | 166     | 1.75    | 74         | 1.63    |
| 426 Norway spruce               | <i>Picea abies</i>              | 195     | 2.06    | 98         | 2.16    |
| 427 Douglas fir                 | <i>Pseudotsuga menziesii</i>    | 82      | 0.87    | 39         | 0.86    |
| 428 Red cedar                   | <i>Juniperus virginiana</i>     | 12      | 0.13    | 3          | 0.07    |
| 429 Mixed conifer               |                                 | 237     | 2.50    | 121        | 2.67    |
| 431 Mixed conifer and broadleaf |                                 | 339     | 3.58    | 255        | 5.62    |
| 500 Water                       |                                 | 5       | 0.05    | 3          | 0.07    |
| 600 Wetland                     |                                 | 10      | 0.11    | 3          | 0.07    |
| Total                           |                                 | 9,464   |         | 4,536      |         |

spectral channels were combined; but, for both visual interpretation and digital classification, images obtained during the spring yielded better results. They also reported no increase in classification accuracy of tree species discrimination when band ratio (3/2) was combined with the three original SPOT-XS data channels. For images collected in June, overall classification accuracy (nine cover types) varied from 62 percent (producer accuracy) to 65 percent (user accuracy); the authors concluded that neither visual nor digital classification using a monotemporal approach produced acceptable results

for forest management in Belgium.

Hopkins et al. (1988) used a maximum-likelihood algorithm to classify Landsat TM data in two Lake States study sites. The first site had 15 cover types with a mixture of forest and other cover types characteristic of the southern Great Lakes region, and the second site had 11 cover types in a commercially managed forest area of the northern Great Lakes region. All seven TM channels were used in a supervised classification with a maximum-likelihood algorithm. At site 1 overall classification accuracy was 85 percent. Individual cover type accuracy ranged from 18 percent for the

central hardwood cover type to 100 percent for the developed (urban) cover type. Overall classification accuracy at site 2 (11 cover types) was 93 percent, varying from 53 percent for the roads-developed cover type to 100 percent for the gravel pit cover type.

# Methods

A 980-acre area in Washtenaw County, Michigan, at latitude 42°23' to 42°25' N and longitude 83°54' to 83°57' W, was selected for this study. The site straddles a large kame with slopes varying from nearly flat to over 40 percent. Overall, the site is 86 percent forested, including natural

**Table 2. Spectral bandwidth and pixel size for the three data sets used.**

| Channels used | Landsat TM     |                | SPOT-XS        |                | SPOT-PAN       |                |
|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
|               | Bandwidth (nm) | Pixel size (m) | Bandwidth (nm) | Pixel size (m) | Bandwidth (nm) | Pixel size (m) |
| 1             |                |                | 500–590        | 20             | 510–730        | 10             |
| 2             | 520–600        | 30             | 610–680        | 20             |                |                |
| 3             | 630–690        | 30             | 790–890        | 20             |                |                |
| 4             | 760–900        | 30             |                |                |                |                |

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| REFERENCE DATA |                    |      |     |      |      |      |      |      |      |      |      |      |     |      |      |      |     |      |      |      |       |
|----------------|--------------------|------|-----|------|------|------|------|------|------|------|------|------|-----|------|------|------|-----|------|------|------|-------|
| Code           | Cover Type         | 113  | 145 | 171  | 211  | 212  | 300  | 411  | 421  | 422  | 423  | 424  | 425 | 426  | 427  | 428  | 429 | 431  | 500  | 600  | Total |
| 113            | Residential        | 10   |     | 1    | 4    | 3    | 78   | 52   |      |      |      |      |     |      |      |      |     | 3    |      | 1    | 154   |
| 145            | Telecommunic       |      |     |      |      |      |      |      |      |      |      |      |     |      |      |      |     |      |      |      | 0     |
| 171            | Gravel Pit         |      |     | 14   |      |      | 11   | 5    |      | 2    |      |      |     |      |      |      |     | 1    |      |      | 33    |
| 211            | Cropland           | 2    |     |      | 18   | 1    | 3    | 1    |      |      |      |      |     |      |      |      |     |      |      |      | 25    |
| 212            | Pasture            | 4    |     |      | 1    | 21   | 30   | 25   | 2    |      |      |      |     |      |      |      |     | 1    |      |      | 84    |
| 300            | Rangeland          | 13   | 1   | 2    |      | 2    | 339  | 263  | 7    |      |      | 1    |     | 1    |      |      |     | 24   | 1    |      | 654   |
| 411            | Broadleaved Forest |      | 1   | 1    |      |      | 38   | 1558 | 10   | 1    | 2    | 7    | 6   |      | 2    |      |     | 43   |      |      | 1668  |
| 421            | White Pine         |      |     |      |      |      | 3    | 81   | 171  | 35   | 2    | 23   | 16  | 18   | 8    |      | 10  | 32   |      |      | 399   |
| 422            | Red Pine           |      |     |      |      |      |      | 5    | 90   | 182  |      | 19   | 17  | 11   | 2    |      | 29  | 12   |      |      | 347   |
| 423            | Jack Pine          |      |     |      |      |      | 14   | 11   |      |      | 9    | 16   | 1   | 1    | 2    |      | 13  | 11   |      | 1    | 79    |
| 424            | Scotch Pine        | 1    |     |      |      |      | 6    | 43   | 39   | 6    | 3    | 151  | 7   | 3    | 3    |      | 21  | 42   |      |      | 325   |
| 425            | Aust.-Corsic. Pine |      |     |      |      |      |      |      | 4    | 6    |      |      | 6   |      |      |      | 2   | 1    |      |      | 19    |
| 426            | Norway Spruce      |      |     |      |      |      | 1    | 5    | 95   | 36   | 3    | 5    | 15  | 57   | 2    |      | 21  | 11   |      |      | 251   |
| 427            | Douglas Fir        |      |     |      |      |      |      | 7    | 53   | 1    | 2    | 17   | 3   | 6    | 18   |      | 13  | 15   |      |      | 135   |
| 428            | Red Cedar-Juniper  |      |     |      |      |      |      |      | 1    | 1    | 1    | 2    | 1   |      |      |      | 1   | 2    |      |      | 9     |
| 429            | Mixed Conifer      |      |     |      |      |      |      | 21   | 4    | 3    | 1    | 7    |     |      |      |      | 1   | 3    | 8    |      | 49    |
| 431            | Mixed Con/Brdlvd   |      |     |      |      |      | 10   | 197  | 15   | 3    | 1    | 9    | 2   | 1    | 2    |      | 1   | 7    | 49   |      | 297   |
| 500            | Water              |      |     |      |      |      |      |      |      |      |      |      |     |      |      |      |     |      | 2    |      | 2     |
| 600            | Wetland            |      |     |      |      |      | 1    |      | 1    |      |      |      |     |      |      |      |     | 2    |      | 1    | 5     |
| Total          |                    | 30   | 2   | 19   | 23   | 27   | 520  | 2277 | 503  | 256  | 24   | 259  | 74  | 98   | 39   | 3    | 121 | 255  | 3    | 3    | 4536  |
| PCC %          |                    | 33.3 | 0.0 | 73.7 | 78.3 | 77.8 | 65.2 | 68.4 | 34.0 | 63.3 | 37.5 | 58.3 | 8.1 | 58.2 | 46.1 | 33.3 | 2.5 | 19.2 | 66.7 | 33.3 | 57.1  |

K hat = 44.6%      Tau = 39.7%

K hat = 44.6%      Tau = 39.7%

Figure 1. Contingency table for classified map from Landsat TM channels 2, 3, and 4—original data.

broadleaved stands interspersed with conifer plantations. All of the plantations were more than 40 years old.

Reference data sets used in accuracy assessment were derived from 400-foot-per-inch enlargements of black-and-white aerial photos taken in April 1990 and 1995 to provide the closest possible agreement to conditions on the dates of satellite data acquisition. All photo interpretations were field checked. Three reference data sets were compiled by total enumeration of land cover on 10, 20, and 30 meter grids that matched the SPOT panchromatic, SPOT-XS, and Landsat TM satellite data. A grid was prepared on Unix and printed on clear mylar to represent the SPOT 10 × 10 meter raster at a scale of 1 inch = 400 feet. This grid was positioned over the enlarged aerial photo print using reference points identifiable in both the SPOT image and air photo print. Using each 10 × 10 meter grid cell as a pixel, land cover was determined for each pixel of the reference data set. A similar procedure was used to derive reference data sets for the SPOT-XS and Landsat TM data sets. The small number of pixels dominated by roads were considered part of adjacent cover types. Six cover types were identified at level I, 10 at level II, and 19 at level

III. The number of pixels in each cover type for the 20-meter (SPOT-XS) and 30-meter (Landsat TM) grids is given in table 1.

SPOT-XS data from May 1, 1988, Landsat TM data from May 22, 1994, and SPOT panchromatic data from July 11, 1995 data were used in this study. Data for the same date from all three sensors were not available. All satellite data had been acquired in the 1B format, requiring no geometric correction. To provide the closest possible spectral match between the SPOT-XS and Landsat data, only TM channels 2, 3, and 4 were used. Spectral and spatial characteristics of the satellite data are presented in table 2.

An integration—merging process was used to improve overall land use classification and interpretability. Both the SPOT-XS and Landsat TM data sets were registered to the SPOT panchromatic data set using ground control points selected from both images. Registration accuracy was 0.42 meters for SPOT-XS and 1.28 meters for Landsat TM. The registered images were resampled to a 20-meter (SPOT-XS) and 30-meter (Landsat TM) grid using the nearest-neighbor resampling method. Integration algorithms were used to merge the images into two new ones. Registration and rectification

were done in ERDAS Imagine, and the integration process was done in Microsoft Excel.

Training sets were identified for each cover type in each of the satellite images based on field checks and comparison with existing aerial photographs. Quality of the training sets was assessed in terms of the spectral separability using signature evaluation tools in ERDAS Imagine.

Land cover classification was accomplished in a supervised classification with a maximum likelihood decision rule. Data from SPOT-XS and Landsat TM channels 2, 3, and 4 were first classified separately, and then merged with the SPOT panchromatic data for additional tests. These are referred to here as the "original" and "integrated" data sets.

Each classification was quantitatively evaluated based on overall and individual cover type accuracies. These assessments were based on analyses of contingency tables prepared in ERDAS Imagine using methods similar to those described by Congalton et al. (1983). A separate contingency table was prepared for each classified image. The percentage of pixels correctly classified (PCC), Tau, and Cohen's Kappa indices were determined for each contingency table (Cohen 1960). Even

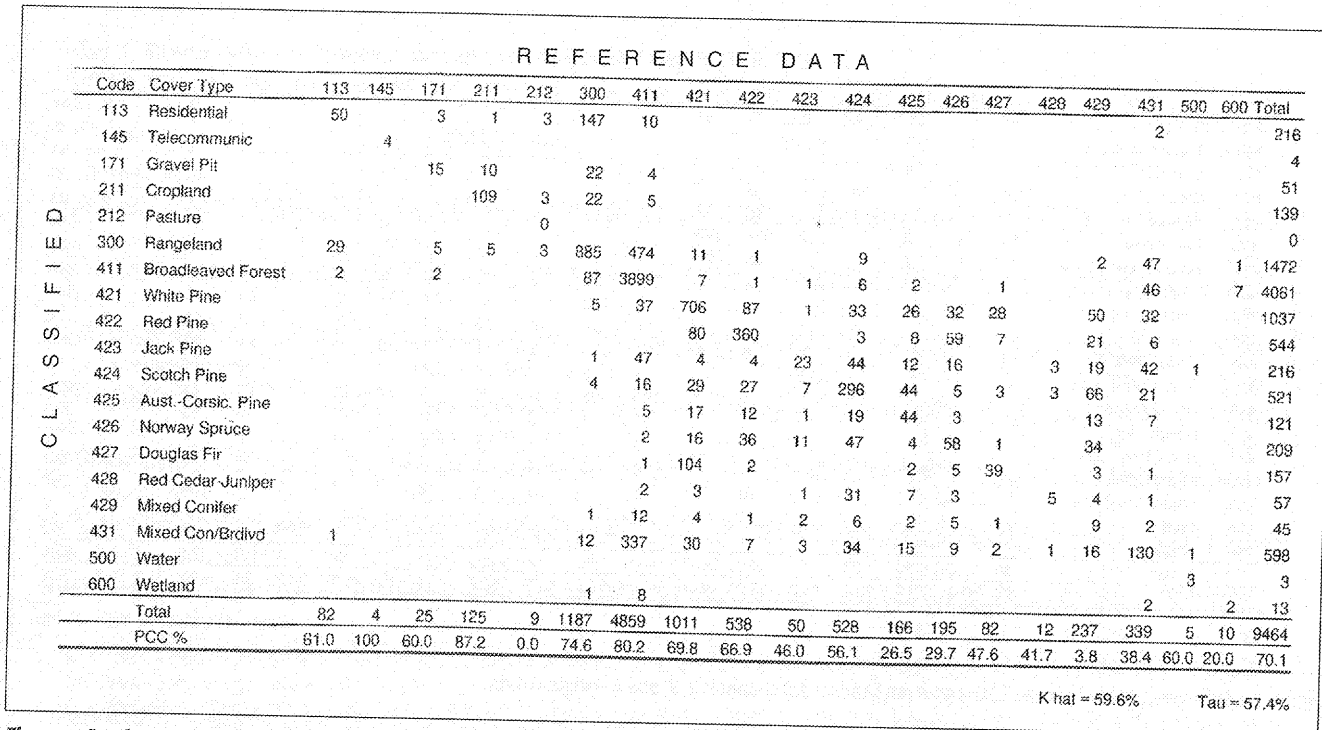


Figure 2. Contingency table for classified map from SPOT-XS channels 1, 2, and 3—original data.

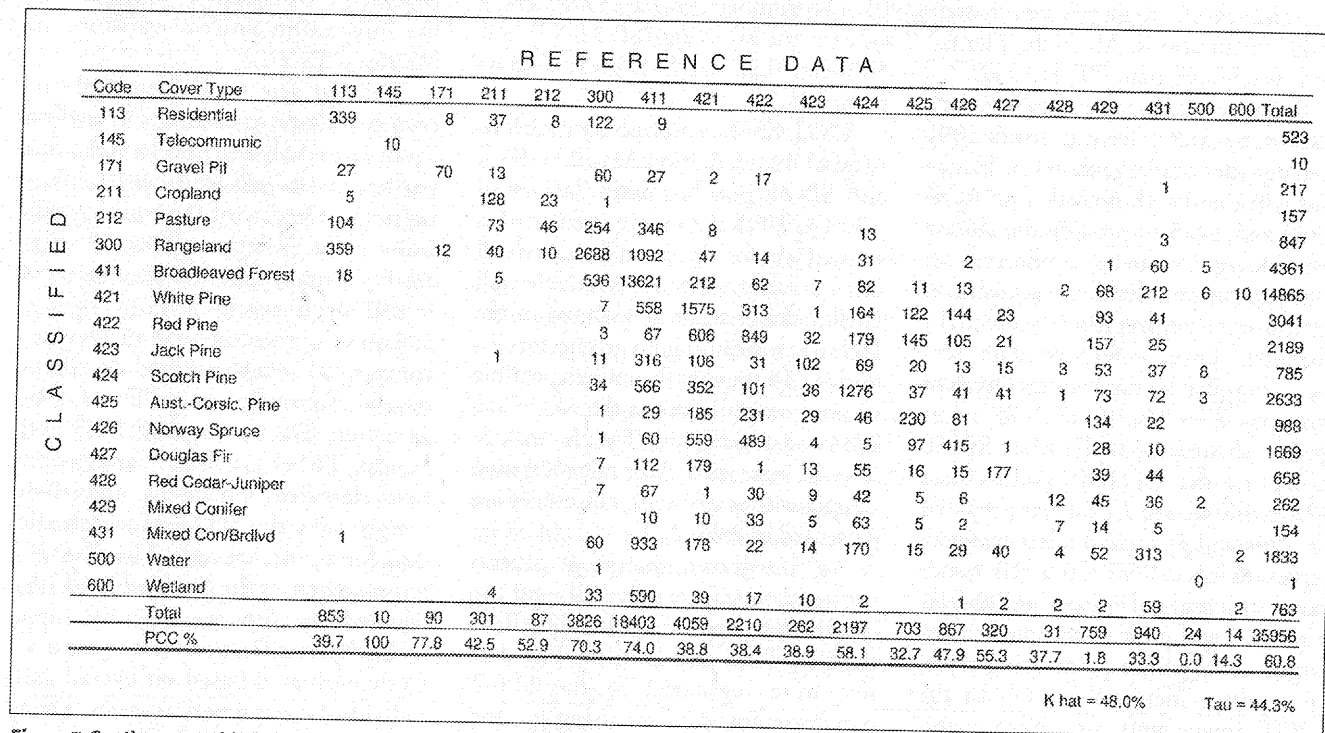


Figure 3. Contingency table for classified map from Landsat TM channels 2, 3, and 4—integrated data.

though PCC includes some pixels classified correctly solely due to chance, this is the measure of most interest to forest managers. The other measures can be used to evaluate the relative effectiveness of different classification approaches.

### Results and Discussion

No attempt was made to compensate for the effect of slope or aspect on the brightness values recorded by the sensors. Nevertheless, overall classification accuracy for the six level I classes was 91.5 percent for SPOT-XS and

89.2 percent for Landsat TM channels 2, 3, and 4 using the original data. At level II, with 10 classes, accuracy was 84.7 percent with SPOT-XS and 77.8 percent with Landsat TM original data. When all 19 level III classes were included, accuracy was 70.1 percent

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|       |                    | REFERENCE DATA |     |      |      |      |      |       |      |      |      |      |      |      |      |      |     |      |      |     |       |
|-------|--------------------|----------------|-----|------|------|------|------|-------|------|------|------|------|------|------|------|------|-----|------|------|-----|-------|
| Code  | Cover Type         | 113            | 145 | 171  | 211  | 212  | 300  | 411   | 421  | 422  | 423  | 424  | 425  | 426  | 427  | 428  | 429 | 431  | 500  | 600 | Total |
| 113   | Residential        | 532            |     | 8    |      | 6    | 154  | 7     |      |      |      |      |      |      |      |      | 1   |      |      |     | 708   |
| 145   | Telecommunic       | 6              | 10  |      |      |      |      |       |      |      |      |      |      |      |      |      |     |      |      |     | 16    |
| 171   | Gravel Pit         | 49             |     | 77   | 10   |      | 37   | 1     | 1    | 1    |      | 1    |      |      |      |      |     |      | 1    |     | 178   |
| 211   | Cropland           | 10             |     |      | 255  | 2    |      |       |      |      |      |      |      |      |      |      |     |      |      |     | 267   |
| 212   | Pasture            | 30             |     |      | 35   | 78   | 7    |       |      |      |      |      |      |      |      |      |     |      |      |     | 150   |
| 300   | Rangeland          | 208            |     | 5    | 1    | 1    | 3182 | 636   | 14   | 1    |      | 15   |      |      |      |      | 1   | 43   | 4    | 1   | 4082  |
| 411   | Broadleaved Forest | 1              |     |      |      |      | 451  | 18610 | 152  | 59   | 8    | 166  | 25   | 9    | 6    |      | 27  | 467  | 7    | 11  | 17999 |
| 421   | White Pine         |                |     |      |      |      | 4    | 32    | 2092 | 281  | 16   | 53   | 166  | 147  | 43   |      | 171 | 12   |      |     | 3017  |
| 422   | Red Pine           |                |     |      |      |      | 17   | 747   | 1248 | 13   | 12   | 36   | 214  | 8    |      |      | 36  | 5    |      |     | 2336  |
| 423   | Jack Pine          |                |     |      |      |      | 123  | 49    | 25   | 110  | 91   | 75   | 77   | 5    |      | 1    | 89  | 72   | 1    |     | 718   |
| 424   | Scotch Pine        |                |     |      |      |      | 4    | 110   | 67   | 78   | 14   | 1162 | 67   | 16   | 10   | 10   | 131 | 48   |      |     | 1717  |
| 425   | Aust.-Corsic. Pine |                |     |      |      |      |      | 36    | 86   | 82   | 16   | 251  | 222  | 45   |      |      | 87  | 18   |      |     | 843   |
| 426   | Norway Spruce      |                |     |      |      |      |      | 12    | 226  | 309  | 36   | 13   | 16   | 301  |      |      | 70  | 3    |      |     | 986   |
| 427   | Douglas Fir        |                |     |      |      |      | 3    | 48    | 335  | 31   |      | 19   | 5    | 2    | 224  |      | 5   | 8    |      |     | 680   |
| 428   | Red Cedar-Juniper  |                |     |      |      |      |      | 34    | 11   | 4    | 14   | 202  | 21   | 6    | 4    | 15   | 33  | 6    |      |     | 350   |
| 429   | Mixed Conifer      |                |     |      |      |      | 6    | 119   | 34   | 40   | 17   | 31   | 10   | 25   | 1    |      | 33  | 16   | 3    |     | 335   |
| 431   | Mixed Con/Brdlvd   | 1              |     |      |      |      | 11   | 618   | 260  | 51   | 18   | 181  | 45   | 23   | 19   | 3    | 79  | 242  | 2    | 2   | 1554  |
| 500   | Water              |                |     |      |      |      | 4    |       |      |      |      |      |      |      |      |      |     |      | 6    |     | 10    |
| 600   | Wetland            |                |     |      |      |      |      |       |      |      |      |      |      |      |      |      |     |      |      | 0   | 0     |
| Total |                    | 836            | 10  | 90   | 301  | 87   | 3843 | 18403 | 4074 | 2210 | 262  | 2197 | 688  | 865  | 320  | 29   | 763 | 940  | 24   | 14  | 36956 |
| PCC % |                    | 63.6           | 100 | 85.5 | 84.7 | 89.7 | 82.3 | 90.3  | 51.4 | 56.5 | 42.0 | 52.9 | 32.3 | 34.8 | 70.0 | 51.7 | 4.3 | 25.7 | 25.0 | 0.0 | 73.4  |

K hat = 62.6%

Tau = 62.1%

K hat = 62.6%      Tau = 62.1%

Figure 4. Contingency table for classified map from SPOT-XS channels 1, 2, and 3—integrated data.

with SPOT-XS and 57.1 percent with Landsat TM original data (channels 2, 3, and 4). At all three levels of classification, overall accuracy with SPOT-XS data was greater than with Landsat TM channel 2, 3, and 4 data. As the bandwidths of the SPOT-XS channels are quite similar to those of Landsat TM channels 2, 3 and 4, it seems likely that the difference in ground resolution between SPOT-XS (20 meters) and Landsat TM (30 meters) is the main source of the difference in overall classification accuracy.

When the integrated data sets (SPOT-XS and Landsat TM registered to SPOT panchromatic data) were used, overall classification accuracy at level III increased by 3 percent in each case, to 73.3 percent and 60.8 percent, respectively. This result is important primarily because it reveals no loss of accuracy due to the resampling necessary to integrate the multispectral data sets with the SPOT panchromatic data.

Contingency tables used in the accuracy assessments for level III classifications with both the original and integrated data sets are presented in figures 1–4. Statistical analyses indicate that the results with integrated data sets

were significantly better ( $p = 0.01$ ) than with the original data. Individual classification accuracies for each cover type are shown at the bottom of the contingency tables. Accuracy with both SPOT and TM data was better for types characterized by high crown density covering large areas, such as broadleaved forest. The contingency tables reveal that each sensor proved to be better at discriminating some cover types than others. Within-class variation was a factor in many cases.

The white pine cover type, for example, included three types of stands: sawtimber with large variations in crown closure and many boles covered with poison ivy and Virginia creeper rising into the crowns, unthinned small-pole stands with high crown closure, and mixed large-pole stands with 75 percent white pine and 25 percent red pine having large variations in crown density and understory vegetation. Such variation is not unusual, but caused some white pine pixels to be classified as broadleaved (vines in crown) or red pine.

No plantation was truly a monoculture. Each included a small mixture of broadleaved trees and other conifer species that had seeded in as volunteers

and reached the codominant crown class, and the presence of vines in the crowns was not limited to white pine stands. Also, some broadleaved stands had significant conifer components, especially Norway spruce and white pine, with many of these trees in the codominant crown class.

Austrian and jack pine occurred in several narrow strips less than 20 meters wide, making recognition difficult and resulting in low classification accuracy. Many residential pixels with houses were surrounded by large trees or lawns; these pixels were often classified as forest, rangeland, or even pasture and were considered incorrectly classified when compared to the reference map.

## Conclusion

Based on the work described, it seems reasonable to conclude that overall accuracy of land cover–use classification is greater with smaller pixel size. Although the increases in accuracy were not large, they are meaningful when one is trying to reach an overall accuracy of 90 percent.

This result should not be interpreted to mean that SPOT-XS is superior to Landsat TM for forest species

classification. Landsat TM has seven spectral channels, whereas SPOT-XS has only three. This increase in spectral information was ignored during this study because the primary goal was to assess the effect of smaller pixel size (increased spatial resolution) on classification accuracy. Results suggest that merging the spectral information from Landsat TM with higher spatial resolution data is worth the effort.

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*Dumitru Salajanu (dsalajanu@fs.fed.us) is forester, USDA Forest Service, Savannah River, PO Box 700, Ellenton, SC 29809; Charles E. Olson Jr. is professor emeritus, School of Natural Resources and Environment, University of Michigan, Ann Arbor.*



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