EVALUATION OF IKONOS SATELLITE IMAGERY FOR DETECTING ICE STORM DAMAGE TO OAK FORESTS IN EASTERN KENTUCKY

W. Henry McNab and Tracy Roof
USDA Forest Service, Southern Research Station, Asheville, NC 28802

Jeffrey F. Lewis
USDA Forest Service, Daniel Boone National Forest, Morehead District, Morehead, KY 40351

ABSTRACT

Ice storms are a recurring landscape-scale disturbance in the eastern U.S. where they may cause varying levels of damage to upland hardwood forests. High-resolution Ikonos imagery and semi-automated detection of ice storm damage may be an alternative to manually interpreted aerial photography. We evaluated Ikonos multispectral, winter and summer imagery as a tool for detecting forest canopy damage to oak dominated forests resulting from an ice storm that occurred in the Daniel Boone National Forest in February 2003. The objectives of this exploratory study were to determine if classification accuracy was affected by: (1) spectral band, (2) size of training window, and (3) season of imagery. Within a 100 km^2 study area, field sites representing three land cover types (forested with none to light canopy damage, forested with moderate to heavy canopy damage, and non-forested) were established or identified to provide image training signatures. Classification accuracies averaged between 65 and 70 percent overall for the three cover types and was highest (>80 percent) for the non-forest type. Results of this pilot study suggest that Ikonos imagery is useful for detecting ice storm damage to upland hardwood forests based on multispectral analysis. Additional study is needed, however, to determine if classification results from the small training areas can be expanded to produce a landscape-scale map of estimated forest damage with accuracy adequate for resource management purposes.

KEYWORDS. Classification accuracy, cross validation, multispectral analysis, Kappa coefficient, MultiSpec software, spectral bands.

INTRODUCTION

Ice storms are a major recurring disturbance in deciduous forests of the eastern U.S. (Irland, 1998). A major ice storm occurred on February 15, 2003, in a large area of northeastern Kentucky and southeastern Ohio that included parts of the Daniel Boone and Wayne National Forests. Up to 5 cm (2 in) of ice accumulated on exposed surfaces, causing a range of damage to tree canopies, from little or none to conspicuous breakage of limbs and stems, and uprooting (Figure 1). A report for the Wayne National Forest indicated that damage "...appeared to be light

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to moderate over the entire district, with many trees having some crown damage. In smaller pockets, ranging up to hundreds of acres in size, damage ranged from heavy to severe ..." (USDA Forest Service, 2003).

Figure 1. Canopy damage resulting from the February 2003 ice storm in upland hardwood forests on the Daniel Boone National Forest ranged from none to light (left side and background of photo) to moderate and heavy (right side and foreground) where broken and uprooted tree stems occurred. This scene illustrates an abrupt transition between an area of severe canopy damage and an adjacent area of little damage; the transition was less clearly defined in other damaged areas.

The extent and severity of storm damage in managed forests must be mapped and assessed so that economic loss can be estimated, products salvaged, and recovery activities planned. Aerial photography and aerial sketch-mapping are typically used for such assessment following large-scale disturbance events (Scarr et al., 2003; Lewis, 2004). In an earlier study, change detection methodology was used with moderate resolution (30 m) Landsat Thematic Mapper imagery to detect ice storm disturbance in hardwood forests (McNab et al., in press). The change detection method requires imagery made before and after the disturbance and presents problems related to correction for atmospheric characteristics (Song, 2004). However, conventional methods of image classification that employ simple multispectral methods and single, detailed satellite images might also prove useful for detecting ice storm damage (Coburn and Roberts, 2004).

An in-depth, detailed evaluation of high resolution imagery was beyond the scope of this study. Ours was a pilot study to investigate general characteristics of such imagery for detecting hardwood canopy damage using multispectral methods. The objectives of this study were to determine if classification accuracy was affected by: (1) spectral band, (2) size of training window, and (3) season of imagery. The study was intended to provide insights we could use in designing a more detailed and exhaustive study on using high resolution imagery to detect canopy damage resulting from ice storms.

METHODS

Study Site and Data Collection

An area representative of prevailing forest types and typical ice damage was selected near Morehead, KY, in the Morehead District of the Daniel Boone National Forest. More than 40 tree species are present in the study area, and these are distributed primarily in relation to soil moisture regime. The overstory is dominated by several species of oaks (*Quercus* spp.) that range up to 90 cm (36 in) in diameter at breast height (dbh) (Table 1). Understory vegetation consists of smaller arborescent species tolerant of shading, such as maples (*Acer* spp.). Elevation ranges from 250 to 375 m (800 to 1,250 feet) in the study area. Two conspicuous categories of land cover dominate the study area: forest, which occupies approximately 80 percent of the area, and non-forest, which consists primarily of urban-related features such as structures and roads. Agricultural land use is not common in the hilly terrain of the study area.

Table 1. Summarized arborescent vegetation data from sample plots installed in the study area on the Morehead District of the Daniel Boone National Forest in eastern Kentucky.

Tree species	Percent species composition[a]	Median dbh (cm)	Maximum dbh (cm)	Maximum crown diameter (m)[b]	Maximum plot diameter (m)[c]
Acer rubrum L.	26	2	66	12	44
Quercus prinus L.	10	20	56	10	37
Quercus alba L.	8	15	64	12	42
Liriodendron tulipifera L.	6	15	91	16	60
Fraxinus americana L.	5	2	50	10	33
Quercus velutina Lam.	4	30	91	16	60
Carya spp. Nutt.	3	2	48	9	32
Ulnus spp. L.	3	2	28	6	18
Quercus rubra L.	2	25	64	12	42
Other[d]	33	2	15	3	10

[a] Estimated from the number of stems ≥1 cm dbh.
[b] Determined from data on file at Bent Creek Experimental Forest using the relationship: Crown diameter(m) = 0.75 + 0.173 * dbh (cm).
[c] Calculated from the maximum dbh based on a plot radius limiting distance for a wedge prism with a basal area factor of 10 ft^2/ac (2.296 m^2/ha).
[d] Includes species such as *Oxydendron arboreum* (L.) DC., *Acer saccharum* Marsh., *Cercis canadensis* L., and several others that occur primarily in the midstory or understory.

Aerial photography was obtained soon after the storm for mapping the extent of the disturbance and assessing the severity of damage to forests. A study area of approximately 1,375 ha (3,400 ac) was selected on the basis of ground reconnaissance and aerial photography to include the range of disturbance. The 1:10,000 scale, dormant season, panchromatic photography was electronically scanned at 800 dpi, orthorectified to establish a coordinate system and remove image distortions resulting from camera and terrain sources, and displayed on a computer monitor at a scale of approximately 1:24,000. Areas of forest damaged by ice were visually delineated as polygons (Figure 2). Forested plot locations were selected from a computer-

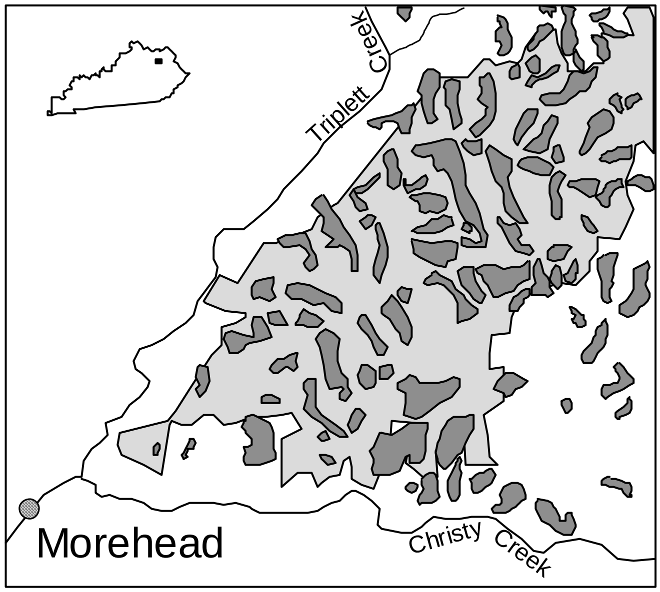

Figure 2. The area studied was in a portion of the Morehead District of the Daniel Boone National Forest (large, light-shaded polygon), near Morehead, in northeastern Kentucky. The ice storm of February 2003 affected areas of upland hardwood forest (small, dark-shaded polygons) that were delineated on aerial photography and classified as light (<25%) or moderate to heavy (≥25%).

generated grid overlaid randomly on the image; the grid intersections defined the center of potential field sample sites. Intersections were randomly selected and a standard aerial photography density grid was used to assign plots to two levels of forest canopy damage: (1) None to Light (no apparent canopy damage to less than 25 percent of canopy damage), or (2) Moderate to Heavy (25 percent or more of the canopy damaged) (Figure 1). These locations were used as the centers of training sites to characterize the spectral "signature" of relatively undisturbed and disturbed forest canopies after the ice storm.

The levels of damage were defined prior to classification of the sample plots on the digital image and had been used by the third author in an unreported investigation of windstorm disturbance in the same area of the Morehead District in 1995 (Lewis 2004). Selection of grid intersections continued until approximately 60 plots were chosen in each level of canopy damage. Coordinates of the location of each plot were recorded from the scanned photographic images using geographic information system software. Each plot selected from the aerial photographs was located in the field during the summer of 2004, using a geographic positioning system to navigate to the recorded map coordinates. A wedge prism calibrated to 10 ft^2/ac (2.296 m^2/ha) basal area was used to define the sample area around the plot center.

In addition to selecting training areas that represented the two levels of forest damage, we subjectively chose an equal number (60 samples) in non-forested areas that were identifiable in the 1-m panchromatic Ikonos imagery. The non-forested land cover consisted primarily of readily identified types of human-related land use: roads, buildings, bare fields, vegetated fields, and power line rights of way. Water features, primarily small rivers, were also included in the non-forest category. The six types of non-forested land cover were largely concentrated in the relatively flat terrain along Triplett and Christy Creeks in the study area (Figure 2). Therefore, three major types of land cover were evaluated for classification accuracy: (1) None to Little (NL) damaged forest, (2) Moderate to Heavily (MH) damaged forest, and (3) non-forest (NF).

We obtained a cloud-free Ikonos image of the study area made during the winter dormant season and summer growing season in 2004. The Ikonos image covers an area about 6.9 km by 8.3 km in extent and consists of a grid of about 3.57 million picture elements, or pixels. Each 4 m square pixel represents a ground area of approximately 0.0016 ha. Data associated with each pixel consists of values for four spectral bands: visible blue (444.7 - 516.0 nm), green (506.4 - 595.0 nm), red (631.9 - 697.7 nm), and near infrared (757.3 - 852.7 nm). The numerical value of each Ikonos pixel ranges from 0 to 2,047 for each band. The value of each pixel represented the solar radiance in a specific wavelength band reflected from the ground. The most obvious differences between the two seasons of imagery were the presence of shadows cast by hilly terrain resulting primarily from the lower sun angle during the winter (Table 2) and lack of photosynthesizing foliage on the deciduous hardwood trees in March.

Table 2. Sun and sensor parameters for the two Ikonos images used in the study of damage caused by the February 2003 ice storm to upland hardwood forests on the Morehead Ranger District of the Daniel Boone National Forest, in eastern Kentucky.

Parameter	Dormant season	Growing season
Date of imagery	10 March 2004	6 July 2004
Time (GMT)	16:43	16:41
Sun elevation (degrees)	45.88	70.30
Sun azimuth (degrees)	157.90	137.60
Sensor elevation (degrees)	66.74	77.06
Sensor azimuth (degrees)	342.56	243.55

We used freeware image analysis software (MultiSpec version 5.1.11) for viewing and analysis of the Ikonos imagery (Landgrebe and Biehl 2001). Three variables that affect classification accuracy were examined: spectral band, size of the training window, and season of the year. The effect of spectral wavelength on accuracy was determined by comparing all combinations of the four bands, which resulted in 15 combinations. Size of the training area, termed window size, was examined by varying the number of pixels surrounding the center pixel in which the field plot was located. The center pixel (1 x 1) was expanded in radius by 1 to 4 pixels, resulting in four larger windows ranging in size from 3 x 3 pixels to 9 x 9 pixels. We varied window size to examine the effect of canopy and disturbance variation on classification accuracy. Ground areas ranged in size from 4 x 4 m to 36 x 36 m. An Ikonos pixel measures 4 m x 4 m, which approximates the dimensions of the crown of an upland oak 20 cm in dbh. Therefore, the Ikonos image consists of individual pixels that approximate the area of single crowns or fractions of single crowns (Table 1). The effect of imagery date on accuracy was evaluated by comparing the five window sizes utilizing all four spectral bands for the winter and summer satellite scenes.

<u>Data Analysis</u>

Cross validation tables provided estimates of agreement between the actual and classified values for each of the three cover types. The predictive capability, or accuracy, of the maximum likelihood classifier algorithm was estimated by the leave-one-out procedure (Gong 1986). In this procedure, a training plot is omitted from the data set and the classifier algorithm is solved with the reduced data set, which is then tested with the plot left out. The excluded plot is returned to the training data, another is omitted, and the procedure is repeated until all plots have been left out. The results are then pooled to obtain an assessment of accuracy. For this exploratory study we utilized primarily the overall accuracy (OA) of the three combined cover types (CT), expressed as a percentage:

$$OA(\%) = ((\sum CT_{NL} + \sum CT_{MH} + \sum CT_{NF}) / \sum ALL)100 \qquad [1]$$

where CT_{NL}, CT_{MH}, and CT_{NF} are the number of pixels classified correctly for the NL, MH, and NF cover types, respectively, and ALL is the total number of pixels for the window size under consideration (i.e. 177 for the 1x1 window; see table 5). We also present the producer's accuracy (the probability of a training site being classified correctly) and the user's accuracy (the probability that a site classified in the image represents that class on the ground). The Kappa coefficient (Congalton and Green 1999) was used to measure agreement between the actual pixel classification and the predicted classification. A Kappa coefficient of 0 indicates no agreement between the actual and predicted classifications; a value of 1 indicates complete agreement. The Z statistic was used to test for significant differences between multiple pairs of Kappa coefficients (Congalton and Green 1999):

$$Z = (K_1 - K_2) / (Var(K_1) + Var(K_2))^{0.5} \qquad [2]$$

where K_1 and K_2 are values of Kappa for the two classifications being tested and $Var(K_1)$ and $Var(K_2)$ are their estimated variances. We used a value of 1.96 (for a 95% confidence level) to test hypotheses that selected pairs of Kappa coefficients were equal.

RESULTS

Field evaluation of the potential forested plots selected from aerial photography indicated 58 and 59 were suitable for use in the damage categories None to Light and Moderate to Heavy, respectively. Those 117 plots, together with the 60 plots selected as non-forest directly from the panchromatic imagery, resulted in a total of 177 plots available for analysis.

Spectral Bands

The median level of overall accuracy in classification of the three types of land cover for the 1 x 1 window size was about 67 percent and ranged from 75 percent to 38 percent (Table 3). Multiple spectral bands tended to produce the highest classification accuracies for the winter imagery, but not for the summer imagery. For the winter imagery, there were no significant differences among the top 11 ranks of Kappa coefficients. Classification accuracy for the summer imagery varied significantly only when band 3 was used alone.

The highest level of overall accuracy was 74.6 percent, obtained with a combination of three bands (1, 2, and 4) using winter imagery (Table 4). The producer's and user's accuracies provide a more detailed means of assessing classification performance and indicate that the greatest accuracy was associated with prediction of the non-forest cover type. The user's accuracy averaged about 66 percent for the two cover types associated with canopy damage resulting from the ice storm.

Table 3. Overall classification accuracy resulting from various combinations of four spectral bands for training windows 1x1 pixel in size in upland forests damaged by the February 2003 ice storm on the Daniel Boone National Forest in northeastern Kentucky.

Rank	Winter			Summer		
	Bands[a]	Overall[b]	Kappa[c]	Bands	Overall	Kappa
1	1, 2, 4	74.6	61.9	4	68.4	52.6
2	1, 2, 3, 4	71.9	57.6	1, 2, 3, 4	68.4	52.5
3	1, 4	71.8	57.6	1, 4	68.4	52.5
4	2, 4	71.2	56.8	3, 4	67.8	51.7
5	2, 3, 4	70.6	55.9	2, 3, 4	67.2	50.9
6	1, 3, 4	70.6	55.9	1, 3, 4	67.2	50.9
7	1, 2	68.9	53.4	1	66.7	50.0
8	2, 3	67.2	50.8	1, 3	66.7	50.0
9	1, 2, 3	65.5	48.3	1, 2	65.5	48.3
10	3, 4	65.5	48.3	2, 4	65.0	47.5
11	1	65.5	48.3	1, 2, 4	64.4	46.6
12	1, 3	63.3	44.9	2, 3	63.8	45.8
13	2	63.3	44.9	1, 2, 3	62.7	44.1
14	3	58.2	37.3	2	62.1	43.2
15	4	55.9	34.0	3	38.4	7.6

[a] Four spectral bands: 1 = visible blue (444.7 - 516.0 nm), 2 = green (506.4 - 595.0 nm), 3 = red (631.9 - 697.7 nm), and 4 = near infrared (757.3 - 852.7 nm).
[b] Overall accuracy (N = 177) calculated as: (Total samples classified correctly / 177)*100.
[c] Any two Kappa coefficients in a column followed by the same line are not significantly different at the α=0.05 level.

Table 4. Classification matrix of three land cover types based on the optimum band combination (1, 2, 4) identified in Table 3 using a 1x1 window size and winter season of the Ikonos imagery in upland forests damaged by the February 2003 ice storm on the Daniel Boone National Forest in northeastern Kentucky.

Predicted cover type	Actual NL damage	Actual MH damage	Actual Non-forest	Producer's accuracy
NL damage	38	20	0	65.5%[a]
MH damage	15	42	2	71.2%
Non-forest	3	5	52	86.7%
User's accuracy	67.9%[b]	62.7%	96.3%	74.6%[c]

[a] Calculated as (38/58)100.
[b] Calculated as (38/56)100.
[c] Overall accuracy calculated by Eq. [1]: ((38+42+52)/177)*100.

Classification area

Overall classification accuracy in relation to window size of the classified area ranged from 71.8 percent to 66.3 percent (Figure 3). Accuracy was consistent for window sizes of 1x1 and 3x3 pixels for both seasons. Classification accuracy, however, decreased linearly as window size increased from 3 x 3 to 9 x 9 pixels. Confidence intervals were widest for the smallest (1x1) window and decreased as window sizes increased.

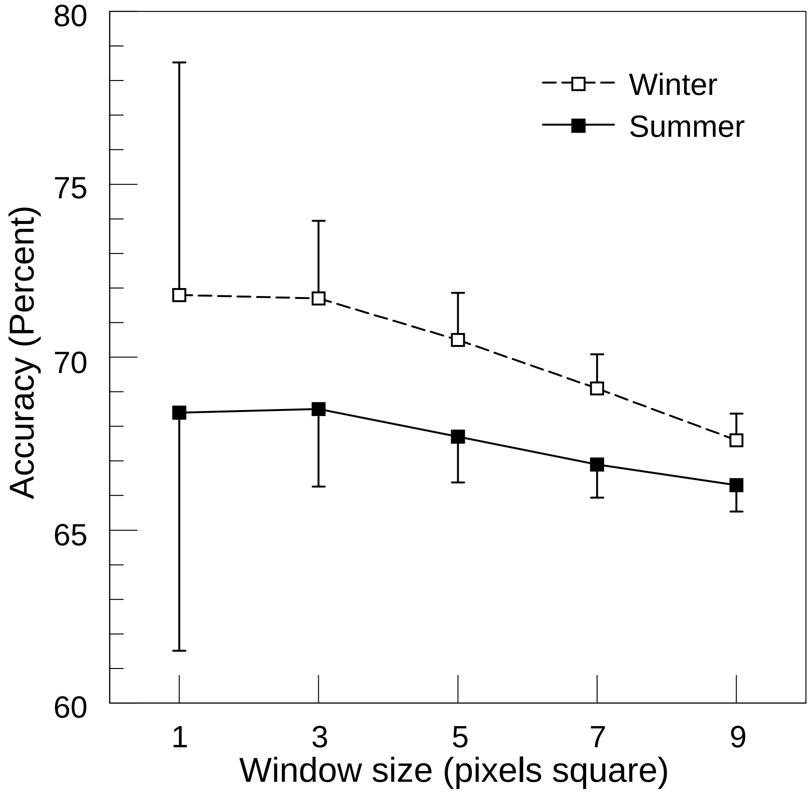

Figure 3. Overall classification accuracy (±95 percent confidence limits) of land cover type in relation to season of Ikonos imagery and size of training window, in upland forests damaged by the February 2003 ice storm on the Daniel Boone National Forest in northeastern Kentucky.

Season of imagery

Accuracy of classification was similar for both winter and summer imagery, averaging about 69 percent (Table 5). Kappa coefficients varied much as the classification accuracies varied and were not significantly different by season. Although classification accuracy was consistently higher for winter than for summer imagery, differences were small and of little practical advantage.

Table 5. Overall classification accuracy (percent) and Kappa coefficient (in parentheses) by season of Ikonos imagery and training window size using all four spectral bands for the study area in upland forests damaged by the February 2003 ice storm on the Daniel Boone National Forest in northeastern Kentucky.

Season of imagery	Window size (pixels)				
	1x1 (N=177)[a]	3x3 (N=1,593)	5x5 (N=4,425)	7x7 (N=8,673)	9x9 (N=14,337)
Winter	71.9 (57.6)[b]	71.7 (57.7)[b]	70.5 (55.8)[b]	69.1 (53.7)[b]	67.6 (51.4)[b]
Summer	68.4 (52.5)	68.5 (52.9)	67.7 (51.6)	66.9 (50.4)	66.3 (49.5)

[a] Sample size (pixels) utilized in the analysis of classification accuracy.
[b] Pairs of Kappa coefficients in the same column do not differ at the α=0.05 level of significance.

DISCUSSION AND CONCLUSIONS

Accuracy in classifying the three cover types studied was not dependent on spectral bands used in the analysis. In general, accuracy was least with single bands, particularly for the winter imagery, and was greatest with three or four bands. Band 3 (red) was least important for both the winter and summer imagery, although its inclusion did increase overall accuracy by a small but not statistically significant amount. Our findings agree partially with those of Read (2003) who reported red and near-infrared Ikonos bands were most useful in detecting canopy openings used for storing logs that were associated with logging in the Amazon rainforest. Also, Coburn and Roberts (2004) found that red and near infrared bands of high resolution imagery were most useful for classifying young conifer stands of varying species composition in western Canada. Song (2004) found that the transformation of two bands, the red and near infrared, to form the normalized difference vegetation index (NDVI) was particularly useful for detection of relative differences in the amount of photosynthesizing foliage. Transformation of bands 3 and 4 for calculation of NDVI was beyond the scope of our study.

We found an inverse relationship between window size and classification accuracy. Classification accuracy based on the 1x1 and 3x3 windows varied little, possibly because position error associated with actual location of the plot in the field using uncorrected GPS coordinates could have placed the plot in any one of the pixels surrounding the central pixel. As window size increased beyond 3 x 3, however, the training area likely included additional pixels that differed in canopy damage from the classification viewed on the aerial photography. Our results are similar to those of Coburn and Roberts (2004) who evaluated classification window size in Canadian pine stands and found that accuracy decreased as size of the training area increased. Also, our findings agree with Wang et al. (2004), who utilized Ikonos imagery to map species mixtures of relatively uniform mangrove forests and reported decreasing accuracy as window size increased from 3 to 9 pixels.

Conventional wisdom suggests that tree crown damage should be manifested by less foliage, which would be more apparent in the summer, but our findings agree with those of Haapanen et al. (2004) who reported increased classification accuracy with winter imagery. One explanation is that sprouting of broken branches in the canopy together with growth response of understory vegetation to increased light tended to mask spectral differences between undamaged and damaged plots during summer. Duguay et al. (2001) reported a differential species response, with >85% of oak and maple showing sprouting within one year following ice storm damage; these two species groups dominated the stands of our study area in northeastern Kentucky. Although we did not determine the effects of the increased canopy shadow present in the winter image on classification, it likely increased pixel variation and decreased accuracy. Asner and Warner (2003) found that canopy shadow varied with species, crown architecture, stand density, leaf area index, and other factors in tropical forests and can be a significant source of spectral variability, particularly in the red band of highly detailed Ikonos images.

In summary, our pilot study indicates that Ikonos imagery is useful for detecting ice storm damage based on multispectral analysis. Although our study did not address development of maps of forest damage, in hilly terrain a combination of multispectral imagery and topographic modeling may be necessary for best results (Olthof et al., 2004; Im and Jensen, 2005; King et al., 2005). Additional evaluation of the Ikonos imagery is desirable to determine if the classification results achieved with the small training areas can be expanded to a landscape scale map with accuracy suitable for use in making management decisions regarding forest resources.

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