Mapping the Natchez Trace Parkway

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Acknowledgments

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m²)

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
Area		
square meter (m²)	0.0002471	acre
square meter (m²)	10.76	square foot (ft²)

The map projection used for all products is the World Geodetic System of 1984 (WGS 84), Universal Transverse Mercator (UTM) Zones 15N and 16N (coordinates are in meters).

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By Amina Rangoonwala,[1] Terri Bannister,[1] and Elijah Ramsey III[2]

Abstract

Based on a National Park Service (NPS) landcover classification, a landcover map of the 715-km (444-mile) NPS Natchez Trace Parkway (hereafter referred to as the "Parkway") was created. The NPS landcover classification followed National Vegetation Classification (NVC) protocols. The landcover map, which extended the NPS field site-based landcover classification to the entire Parkway, was based on color-infrared (CIR) photography converted to 1-m raster-based digital orthophoto quarter quadrangles (DOQQs), according to U.S. Geological Survey (USGS) mapping standards. Mapping landcover within the Parkway was problematic because of the lack of NPS field sites (mode=1, and average=4.5) per NVC alliance.

Our goal was to include as many alliance classes as possible in the Parkway landcover map. To reach this goal while maintaining a consistent and quantifiable map product throughout the Parkway extent, a mapping strategy was implemented based on the migration of class-based spectral-texture signatures and the congruent progressive refinement of those class signatures along the Parkway. Progressive refinement provided consistent mapping by evaluating the spectral textural distinctiveness of the alliance-association classes, and where necessary, introducing new map classes along the Parkway. By following this mapping strategy, the use of raster-based image processing and geographic information system (GIS) analyses for the map production provided a quantitative and reproducible product.

Although field-site classification data were severely limited, the combination of spectral migration of class membership along the Parkway and the progressive classification strategy produced an organization of alliances that was internally highly consistent. The organization resulted from the natural patterns or alignments of spectral variance and the determination of those spectral patterns that were compositionally similar in the dominant species as NVC alliances. The final classes were (1) grasses, (2) oak (*Quercus* sp.) mix, (3) white oak (*Quercus alba*), (4) sweetgum (*Liquidambar* sp.), (5) pine (*Pinus*)-oak, and (6) pine. The overall mapping accuracy was 74 percent, and user and producer accuracies were above 58 percent. Nine additional map classes, including swamp forest, water, aquatic vegetation, plantation, invasive species, road and developed, scrub-shrub, scattered trees, and the "irregular" forest alliances were manually mapped (by using on-screen digitizing). The manually mapped alliances were seldom represented by more than one or two field observations. Manual classifications made up less than 8 percent of the mapped Parkway landcover.

Overall, the mapped landcovers represented the existent spectral textural patterns that defined and encompassed the complex variety of compositional alliances and associations of the Parkway. Based on that mapped representation, forests dominate the Parkway landscape, making up 66 percent of the 100-m buffered Parkway landcovers. The forest makeup is 24 percent oak (includes white oak in the southern sections), 19 percent pine-cedar, 10 percent pine-oak, 9 percent sweetgum, and 4 percent white oak (as mapped in the northern sections). Grass is the second largest Parkway land cover at 22 percent, followed by scrub-shrub and shrubland classes (5 percent) and pine plantations (2 percent). The map provides a good representation of the landcover patterns and their changes over the extent of the Parkway, south to north.

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Introduction

The U.S. Geological Survey (USGS) mapped the landscape of the Natchez Trace Parkway (hereafter referred to as the "Parkway"), which is managed by the National Park Service (NPS), from September 2004 to August 2010 (fig. 1). The USGS mapping extended the field site-based, National Vegetation Classification (NVC)-based landcover classification (text box) performed by the NPS. The complexities of the NVC system required expertise in defining associations (containing varied stand compositions in a complex vegetation landscape of species) that represented repeatable class units. As part of the same agreement with NPS, USGS scientists also mapped the landscape of the Vicksburg National Military Park, which was completed ahead of the Parkway mapping and for which a final report (and all other required products) was submitted to NPS in 2007. The scope of the current report is to describe mapping of the Parkway.

Imagery Spatial Resolution

The mapping of the Parkway included criteria that largely defined the mapping methods and, in large part, the ability to map the NVC classes located and classified by NPS through field sampling. The most critical mapping criterion was the spatial resolution of the source imagery to be used for the mapping. That resolution was set by the NPS request that small features (such as road markers) along the Parkway be visually identifiable. To obtain visual discrimination would have required submeter spatial resolutions, most likely less than 15–20 cm; however, mapping of natural resources such as grasslands is best performed at resolutions 1–5 m and forests at 5–30 m (Fassnacht and others, 2006). Although necessary for visual identification of fine features such as road markers, mapping at the 15–20-cm resolution would have severely impacted the performance of the resource mapping. The selected spatial resolution of the source imagery had to permit visual discernment of fine features on the images but not severely hamper the mapping classification of the mixed forest-to-grassland landcovers.

Seasonal Timing of Imagery Collection

A second critical mapping criterion was set because of the NPS request that mapping be conducted during green leaf-on conditions that occur from late spring to early fall. Because the project supported only a single date of data collection, a summer-to-early fall (during full foliage) image collection was used. This timing posed a problem because in southern forests, spectral differences among major forest classes are often diminished during leaf-on conditions. The ubiquitous full green-leaf canopies combined with the inherent composition variability within any forest association class further increased complexities in the spectral discernment among identified NVC classes.

The NVC is hierarchical—the higher the level, the less numerous and more generalized. The highest level is the Division, followed by Order, five physiognomic levels that describe the structure and life form of the plant community, and two floristic levels that mainly describe the dominant species. The Division divides the earth into nonvegetated and vegetated levels, and the Order further divides the vegetated Division into tree, shrub, dwarf shrub, herbaceous, and nonvascular life forms. Physiognomic class defines the relative percent canopy cover of each Order at the peak of the growing season. Subclass describes the predominant leaf phenology of woody plants (evergreen, deciduous, mixed evergreen-deciduous) and the leaf type and periodicity of herbaceous plants. Group relates to a combination of climate, leaf morphology, and leaf phenologic factors. Subgroup divides the physiognomic group level into natural/seminatural and planted/cultivated categories. The final physiognomic level, formation, divides the physiognomic subgroup into common environmental and additional physiognomic factors (for example, upland, seasonally flooded, pavement [sparsely vegetated]). The floristic levels, alliance and association, currently are not required as part of the NVC, but they are a required part of all NPS classifications. Alliance represents an aggregation of associations. Association, as the finest floristic level in the NVC, describes a diagnostic species that is shared by a physiognomically uniform group of vegetation stands that are generally found in similar habitat conditions. A complete overview and detailed explanation of the hierarchy is provided by the Federal Geographic Data Committee (2008).
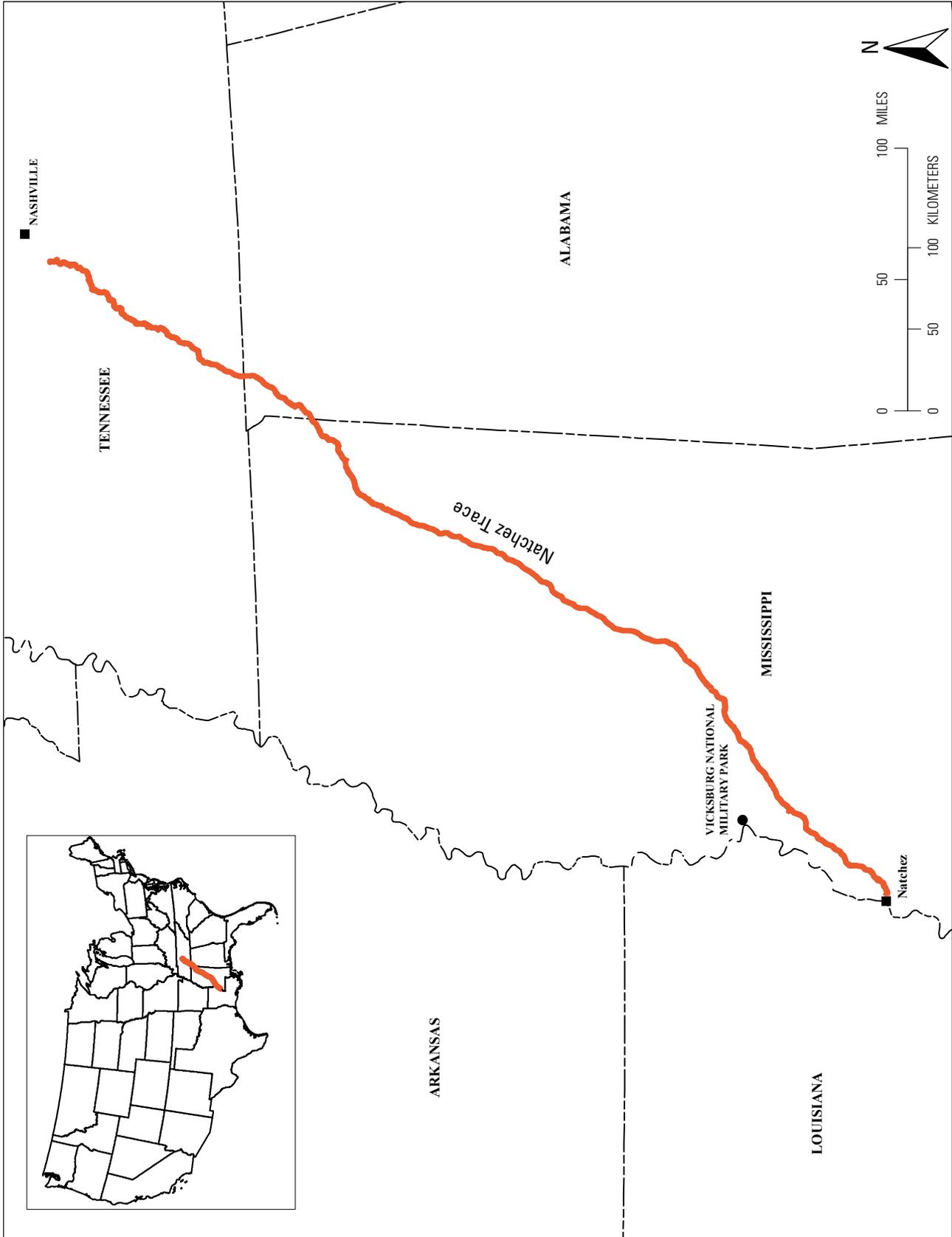
Figure 1.   The 715-km long Natchez Trace Parkway extends across Mississippi, Alabama, and Tennessee. Vicksburg National Military Park is also shown. Appendix 1 provides the locations corresponding to the centers of color-infrared photographs.

Map Classification Accuracy Assessment

A third mapping criterion involved the number of field-site observations per NVC alliance or association. In mapping a spatially extensive landscape based on classes containing composite mixtures, 30 field-site observations is the acceptable minimum (Congalton, 1991; Congalton and Green, 1999; Grenier and others, 2008). This minimum is acutely pertinent when mapping the 715-km south to north extent of the Parkway. In mapping, a rule of thumb is to collect data at 30 reference sites for guiding the mapping classification and an additional 50 sites for assessing accuracy (Congalton, 1991; Congalton and Green, 1999).

Map Classification Spatial Complexity

A fourth critical mapping criterion was related to the desired spatial complexity of the map. NPS prescribed that relatively large, spatially contiguous mapped classes were more desirable than small, discrete classes. Based on the NPS response to a relatively discrete classification of Vicksburg Military Park (unpublished data), a more generalized map that would be more amenable to the NPS concept of forest association portrayal was sought by USGS. As an initial part of the USGS attempt to provide NPS with the desired spatial generalization, we applied a spatial filter matching the 2004 NPS field-site dimensions to the CIR bands. Aggregation of NVC classes and postprocessing procedures were also used to increase spatial uniformity and extents of mapped classes.

Parkway Spectral Varibility Related to Mapping

From a mapping perspective, and considering the south to north spatial extent, the Parkway landscape was spatially and spectrally complex. In reconnaissance performed by USGS scientists, it was found that the southern region of the Parkway was highly disturbed. In the more central sections of the Parkway, spatial complexity was high to moderately high because of the changing composite mixtures of most forest stands and the variability in forest stand canopy closures (changing top-of-canopy closure). This complexity persisted even though the forested regions for the most part occupied fairly flat and nondissected terrains (ravines and ridges were more common in the south and north). The southern and northern portions of the Parkway contained more topographic variability. When compositing and closure variability were accounted for, many forests were moderately uniform and spatially extensive; however, many forested regions were spatially complex even if considered to be in a single NVC class, and some were moderately to highly disturbed, with different mixtures of canopy and subcanopy trees, shrubs, and sometimes vines. Grasslands were mixed between groomed (mowed) and nongroomed.

Mapping Classification Procedures

Creating a mapping classification based on spectral features is a process by which all pixels in an image are automically categorized into landcover classes or themes. Typically, multispectral data (more than a single color band) are input, and the pixel spectral hue and intensity are used as the numerical bases for categorizing each pixel. Categorizing pixels as a basis for mapping classifications can be accomplished with a variety of image processing methods. Two widely used methods apply supervised and unsupervised modes.

Supervised Landcover Mapping

In supervised landcover mapping, the analyst uses *a priori* knowledge of the land covers and their locations in the landscape. The knowledge is used to define training sites (regions containing a single vegetation type or association). These training sites are then used to compile a numerical "interpretation" or "spectral key" that describes the spectral attributes of each landcover class of interest. Each pixel in the dateset is compared numerically with the interpretation key and labeled with the landcover class to which it is spectrally most similar.

Unsupervised Landcover Mapping

Unsupervised classification mapping does not require that the analyst select training sites. All class definitions and memberships are accomplished numerically and impartially (with little user bias) by aggregating the pixels into spectral groupings, or clusters, based solely on the spectral distribution present in the image. The analyst then determines the landcover identity of these spectral groups by associating the classified image data with ground reference data. We used unsupervised classification for our data and applied an iterative self-organizing data analysis technique. An unsupervised technique was used because we had limited *a priori* knowledge of the Parkway and a severely limited number of field-site observations per alliance.

Site Composition and Mapping Classification Confusion

Most of the field-site data were collected in forested areas. The relative percent occurrence of different species as well as the composition of species varied within an alliance. To more correctly map these classification mixtures, the mean photographic response (hue, intensity, and saturation) and spectral variance per alliance must be well estimated. The more field sites collected per alliance, the better the photographic response can be defined. Increased definition of the photographic responses improves the classification detail

(types of alliances separable) and accuracy; however, better definition can result in a lower spectral separation between alliances defined through field-site observations. For example, forest alliances differing by dominant substory species often would not be spectrally separable. Similarly, variable composition mixtures within a class decrease mapping performance. For another example, herbaceous alliances (mixtures of different grasses, ferns, and weeds) are often inseparable unless associated with highly different biomass contents (portending highly different near-infrared responses).

Methods

Photographic Image Data Collection

The CIR aerial data were collected during leaf-on conditions with no visible senescence onset, as was required by NPS to accomplish their ground-based vegetation classification (which followed NVC protocols). The CIR aerial data was collected at a 1:24,000 photographic scale to obtain a ground resolution of 1 m or better. The 1-m spatial resolution provided a compromise between the exceedingly high resolution needed to visually discern road markers on the CIR photography and the need to moderate the spectral variability for the mapping classification. A total of 388 photographic frames, including 9 frames over the Vicksburg National Military Park, were collected September 29–30 and October 6–15, 2004 (see app. 1 for CIR photography centers). The aerial photographic frames were scanned, and DOQQs were produced (a detailed description of the collection and processing of the photographic data is in app. 2). The orthophotographic production created precise terrain-corrected images that were projected to a World Geodetic System of 1984 (WGS 84), Universal Transverse Mercator (UTM) coordinate system. The images were cut to match existent DOQQs (table 1, fig. 2). The DOQQs are compliant with the DOQQ standards defined by the USGS Rocky Mountain Mapping Center (2000). The 235 DOQQs created from the 388 aerial frames were mosaiced to create full coverage of the Parkway graphic (fig. 3). Ground resolution of the DOQQs was 1 by 1 m.

Table 1. Digital orthophoto quarter quadrangles covering the Natchez Trace Parkway. See figure 3 for mosaic locations.

[UTM, Universal Transverse Mercator; NW, northwest; SE, southeast; NE, northeast]

UTM Zone 15			UTM Zone 16						
Mississippi			Mississippi			Alabama		Tennessee	
Mosaic 1	Mosaic 2	Mosaic 3 south	Mosaic 3 north	Mosaic 4 south	Mosaic 4 north	Mosaic 5 south	Mosaic 5 north	Mosaic 6	Mosaic 7
Natchez	Carlisle	Goshen Springs	French Camp	Houston East	Tupelo	Bishop	Cypress Inn	Riverside	Primm Springs
Washington	Utica West	Shoccoe	Weir	Troy	Guntown	Margerum	Westpoint	Henryville	Theta
Pine Ridge	Big Black	Sharon SE	Tomnolen	Troy SE	Ratliff	Barton	Whitten	Gordonsburg	Fairview
Cranfield	Cayuga	Farmhaven	Reform	Bissell	Kirkville	Cherokee	Three Churches	Sunrise	Leipers Fork
Church Hill	Learned	Ofahoma	Sapa	Verona	Marietta	Wright	Collinwood	Mount Joy	Kingston Springs
Rodney	Edwards	Thomastown	Maben	Sherman	Fulton NE	Sinking Creek	Waynesboro East	Greensfield Bend	Bellevue
Lorman	Terry NW	Conway	Mantee	Tupleo	Paden SE	Threet	Ovilla	Williamsport	
Red Lick	Raymond	Joseph	Montpelier		Belmont	Pleasant Site			
Widows Creek	Clinton	Singleton	Woodland		Tishomingo				
Port Gibson	Pocahontas	Kosciusko	Sparta						
Willows	Jackson	McAdams							
Hermanville	Ridgeland	Ethel South							
	Madison	Kosciusko NE							
	Canton								

Figure 2.   Example of a section of the photographic coverage of the National Park Service Natchez Trace Parkway transformed into a two-digital orthophoto quarter quadrangle (DOQQ) format. The spatial resolution is 1 m. The red boundary outlines the full frame of the DOQQ. (See table 1 for the list of DOQQs used in this study.)

Figure 3.   Graphic overview of the National Park Service Natchez Trace Parkway (the "Parkway"). Photography of the Parkway was divided into 11 mosaic tiles (sections 1 to 7) for processing. The location and extent of the 11 mosaic tiles are illustrated. The inset shows a small section from mosaic "2 north."

Creation of the Roadway Vector for the Natchez Trace Parkway

A vector representation of the Parkway roadway was constructed before the CIR photographic data collections (details are in app. 3). Although created to locate the centers of aerial photographic frames along the Parkway, the most important outcome of creating the roadway vector was associated with the Parkway boundary file received from NPS. Overlay of the newly created roadway vector on the Parkway boundary uncovered a substantial misalignment. The misalignment was due to an incorrectly projected Parkway boundary. A corrected Parkway boundary polygon was subsequently supplied by NPS.

Parkway Coverage Extracted from the CIR DOQQ Mosaic

For backup and analysis to be practical, the Parkway was divided into 11 DOQQ mosaic sections (fig. 3). In addition, a spatial buffer was added to the park boundary in order to provide mapping continuity of the Parkway landcover to the adjacent landscape.

The final park boundary polygon provided by NPS was extended by 100 m, and the extended polygon was used as a mask to extract the area of the DOQQ mosaic that would be mapped on the basis of the site-specific NVC landcover classification (fig. 4). Even with the 100-m extension, there are some places where the extracted polygon barely includes the Parkway roadway vector (fig. 5). These misalignments are probably due to persistent inconsistencies in the Parkway boundary polygon provided by NPS. In these instances, USGS scientists adjusted coverage by further increasing the Parkway boundary buffer. As seen in figure 4, the DOQQ mosaics (centered on the Parkway roadway) are about 4,500-m wide, whereas the Parkway boundary is only about 480-m wide. Depictions of the different mosaic sections of the extracted Parkway mosaic are shown in figures 5, 6 and 7.

A CIR Rendition Appropriate for Mapping Forest Stands

The 1-m spatial resolution CIR-based DOQQs provided good spectral discrimination of boundaries, such as between forest and grassland and between grassland and road, and the 1-m resolution was appropriate for mapping most features, including grasslands, developments (for example, buildings and roads) and agriculture on the Parkway and the Vicksburg National Military Park (unpublished data). The 1-m resolution, however, was too fine for mapping the forests because it resulted in direct mapping of the highly illuminated side and the shadowed side of each tree crown, thus diminishing the ability to discriminate differences at the forest stand level. To alleviate this over sampling, we applied a premapping averaging filter to the image data. Different preclassification

transforms were tested on a section of the Parkway imagery to discover the best method to relate the 1- by 1-m DOQQ to the ground-based observations from the 20- by 50-m ground plots used by NPS in the 2004 field reconnaissance. The testing involved application of spatial filters of different sizes.

Spatial filtering is a "local" operation in which the picture element (pixel) values (digital numbers [DN]) in the original image are modified on the basis of the intensity levels of the neighboring pixels. For example a 9- by 9-m pixel filter (window) may be implemented by passing a moving window throughout an original image and creating a second image where the DN at each central pixel corresponds to the local average within the moving window at each of its positions in the original image. In preparing the CIR-based DOQQs of the Parkway for the mapping classification, the filter size and dimensions were selected to accommodate both the need to reduce the spatial variability of the forest CIR spectral rendition and the size and dimension of the 2004 NPS field landcover classifications.

During a coordinated USGS-NPS field trip during September 8–11, 2004, NPS field-site classifications in the forested areas were based on 20- by 50-m plots. To enhance compatibility with the NPS field-site plots and improve forest mapping effectiveness, USGS simulated the 20- by 50-m plots by using spatial filters. In our analyses, the best results were obtained by using an average 11- by 25-pixel (or 11- by 25-m) spatial filter. The 11- by 25-m filter dimension produced a scale comparable to the 20- by 50-m ground-plot size used by NPS and was, thus, applied to each of the 11 mosaic sections of the Parkway imagery (comparison of fig. 7*A* [nonaveraged] and fig. 7*B* [averaged]).

Mapping "Irregular" Classes

In the field-site classifications received from NPS, we grouped 30 of the 331 total field sites into an "irregular occurrence" class. Twelve of the 15 alliances included in this group were observed at one to a few sites along the entire Parkway and were often of limited spatial extent. From a mapping perspective, it was highly unlikely these sites would be identified by using the unsupervised classification strategy. For these isolated and comparatively rarely occurring alliances, we formed a spectral key for each and subsequently used a supervised classification strategy to locate other occurrences of that alliance throughout the Parkway. These targeted, supervised classifications were not successful. No spectral key created for these individual alliances provided a unique signature, which is necessary for successful mapping. The high spectral variability and common features of these alliances on CIR image data prevented determination of unique spectral keys. Although these alliances could not be mapped throughout the Parkway, they were manually classified (visual detection and "heads-up" digitization) wherever the alliance extent could be spectrally discerned at the NPS field sites (table 2).
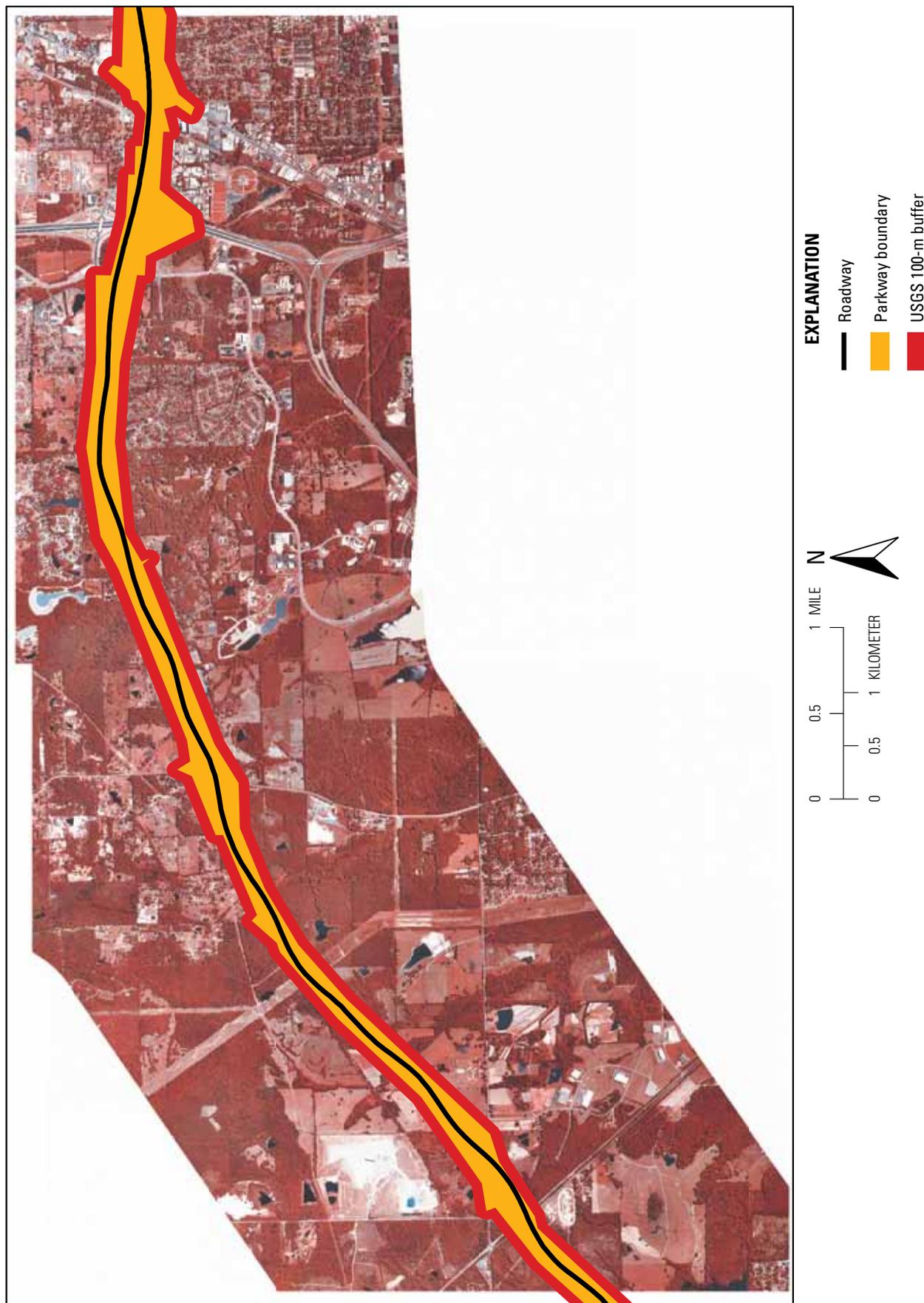
Figure 4. The roadway vector, the National Park Service Natchez Trace Parkway (the "Parkway") boundary, and the extended 100-m buffer applied by the U.S. Geological Survey (USGS) to produce the Parkway map (the extracted Parkway area is shown in fig. 5). The digital orthophoto quarter quadrangle from a section of mosaic 1 illustrates the width of total photographic coverage (about 3.5 km), whereas the Parkway boundary is often less than 0.5 km in width.
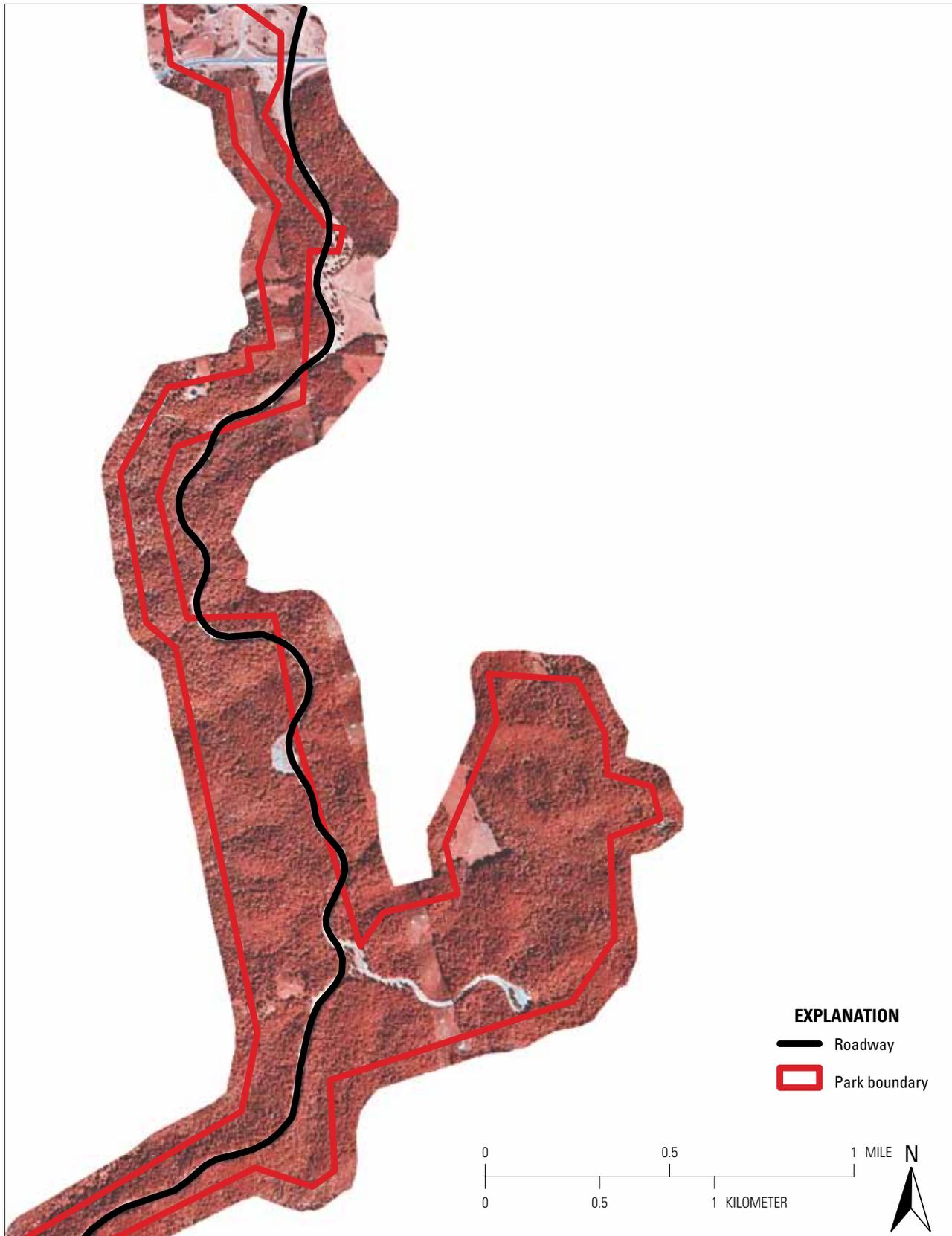
Figure 5.   This color infrared (CIR) image illustrates the misalignment between the road vector generated by the U.S. Geological Survey (USGS) and the National Park Service Natchez Trace Parkway boundary. These anomalies were rectified by the 100-m buffer applied by USGS, as shown on the extracted CIR digital orthophoto quarter quadrangle mosaic.
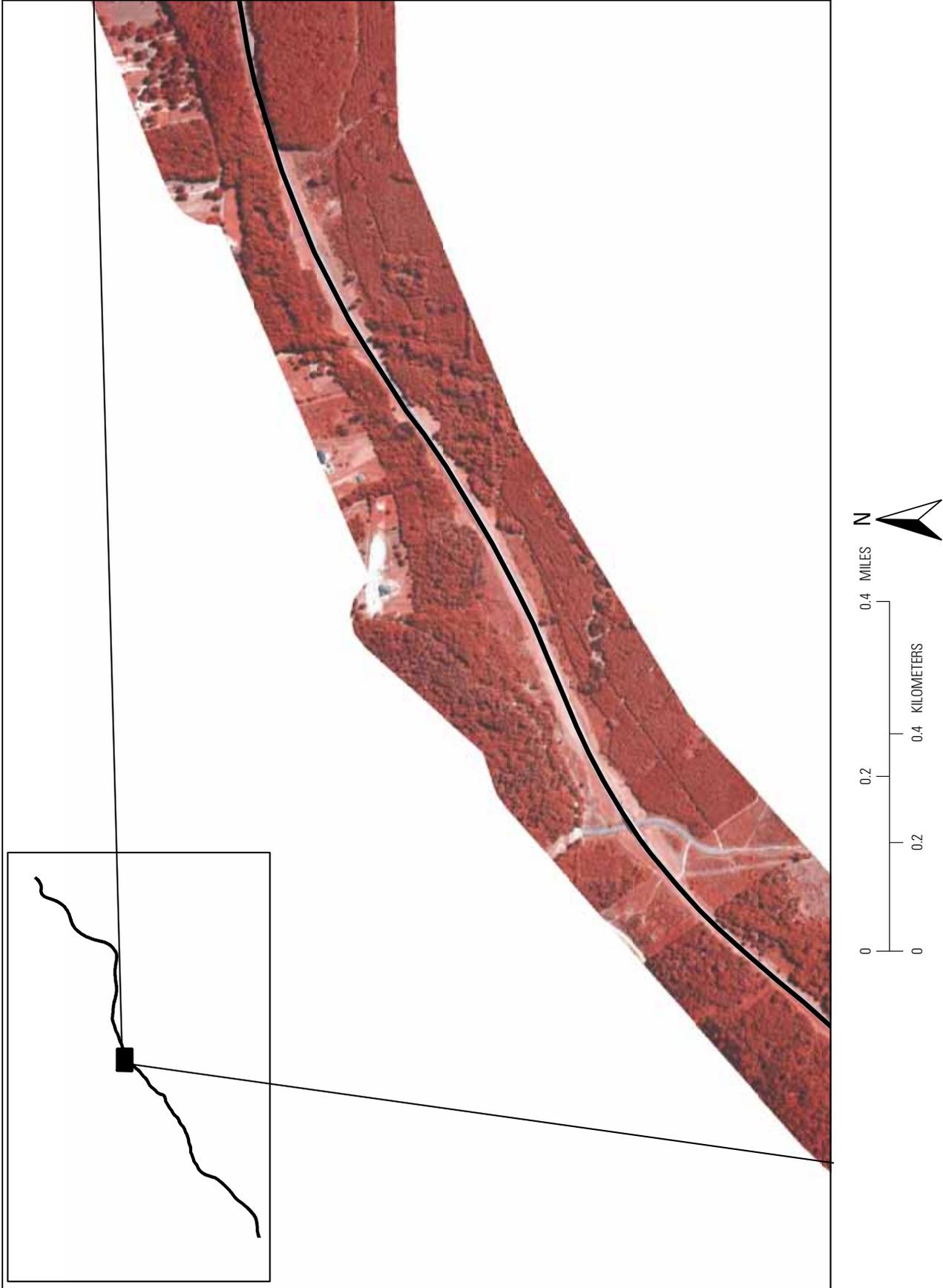
Figure 6.   Extracted from the "2 north" mosaic (see fig. 3), an image showing the width of the National Park Service Natchez Trace Parkway plus a 100-m buffer with the overlay of the roadway vector (in black) created by the U.S. Geological Survey. (Inset map shows the spatial extent of "2 north" mosaic.)
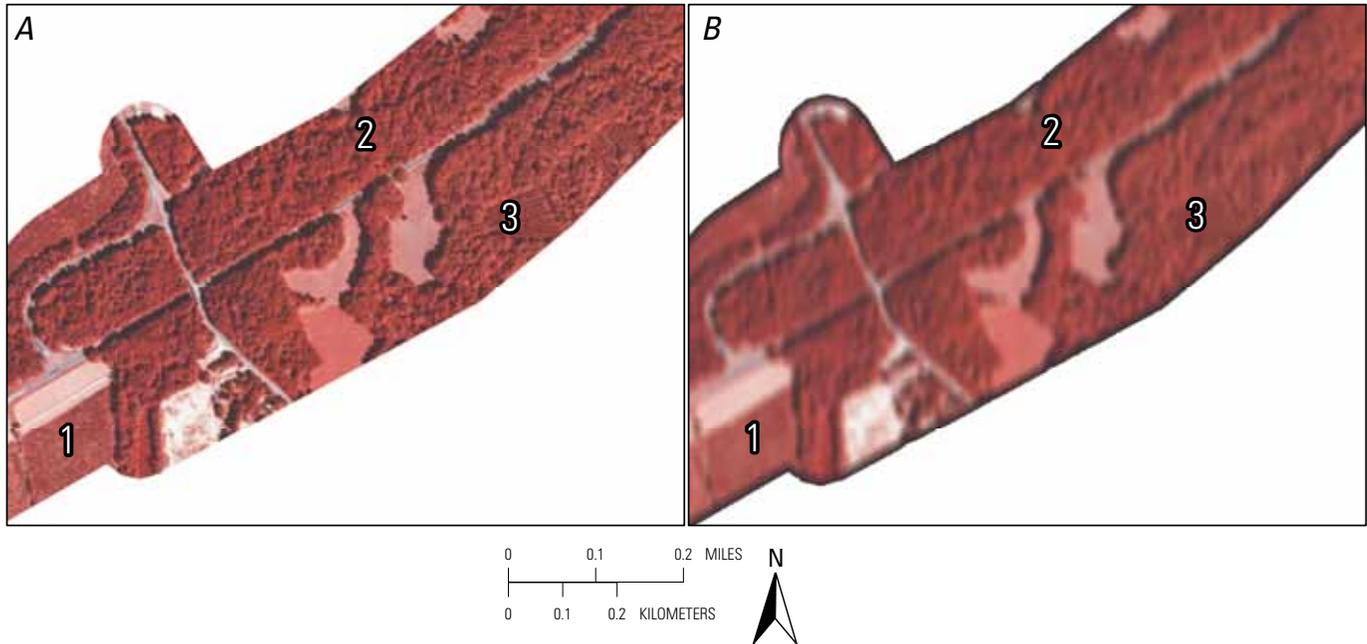
Figure 7.   Images of the National Park Service Natchez Trace Parkway plus a 100-m buffer extracted from the section 2 mosaic (see fig. 3). Images include three classes of vegetation cover, including (1) scrub-shrub and shrubland, (2) mature forest, and (3) tree plantation sites. Note the differences in color infrared tone (hue, intensity, and saturation) and texture among the three different vegetation covers. *A*, Image before application of the 11- by 25-m average filter. *B*, Image after application of the 11- by 25-m average filter.

Table 2.   Initial landcover classification of field sites in the Natchez Trace Parkway that were mapped as "irregular" classes. The initial classification was produced by National Park Service personnel in 2004. Classification codes are from the National Vegetation Classification. Frequency of observations per landcover class is provided.

[NVC, National Vegetation Classification; No., number]

NVC alliance code	NVC association	No. of field-site observations
A.214	Upper East Gulf Calcareous Bluff Forest	1
A.227	Beech - Maple Unglaciated Forest	8
A.227	Southern Mesic Beech - Tuliptree Slopes	1
A.232	Interior Low Plateau Sugarberry, Northern Hackberry Successional Forest	2
A.236	Mid- to Late-Successional Tuliptree - Hardwood Upland Forest (Acid Type)	1
A.236	Successional Tuliptree Forest (Circumneutral Type)	2
A.278	Box-elder Floodplain Forest	2
A.279	Silver Maple-Sugarberry-Pecan Floodplain Forest	1
A.280	River Birch Levee Forest	2
A.284	East Gulf Coastal Plain Beech Floodplain Forest	2
A.286	Southern Green Ash - Elm - Sugarberry Forest	3
A.288	Gulf Coastal Plain Sycamore - Sweetgum Floodplain Forest	2
A.288	Sycamore - Silver Maple Calcareous Floodplain Forest	1
A.316	Red Maple - Green Ash Seasonally Flooded Swamp	1
A.369	East Gulf Coastal Plain Calcareous Bluff Beech - Magnolia Forest	1

Mapping Kudzu (*Pueraria*) Vine

The one kudzu (*Pueraria*) site identified by NPS in the southern Parkway was located under edge shadows in the CIR photography. The occurrence of only a single kudzu site and the associated shadows prevented the ability to create a kudzu spectral key from the CIR photographic data.

In 2009, NPS requested USGS to provide as much information as possible concerning the distribution of kudzu in the Parkway. Even though we could not map kudzu in the Parkway based on a single occurrence, we used experience gained in mapping the various forms of kudzu in Vicksburg Military Park (unpublished data) to manually map likely occurrences in the Parkway. The visual detection was based solely on recognized hue and texture patterns on the CIR photography that suggested the occurrence of kudzu.

During mapping of kudzu in the Vicksburg National Military Park (unpublished data), USGS scientists found that kudzu was visible in a variety of hues and spectral textures on the CIR photography. The various spectral textural differences were associated broadly with two landcover subclasses of kudzu. The first subclass was associated with lush, green-vine ground covers (fig. 8*A, C*). A second subclass was often located adjacent to the ground kudzu but occurred as a high-to-moderate cover of scattered canopy trees, shrubs, and ground cover. By the time of kudzu mapping in the military park, much of the kudzu had been treated with herbicides as part of an invasive species eradication campaign (figs. 8*A, C*). Depending on the elapsed time since herbicide treatment and the collection of CIR photography, kudzu in the Vicksburg National Military Park (unpublished data) exhibited a range of CIR hues from bright red (healthy) to slightly brown to gray. Also based on field reconnaissance in the military park, USGS scientists found that although grapevines were visually distinguishable from kudzu vines, the two canopy-type vines were not distinguishable in the CIR photography.

Transference of knowledge learned from mapping kudzu in the Vicksburg National Military Park (unpublished data) allowed qualitative mapping of occurrences in the Parkway. Because of the lack of kudzu field sites and the highly variable spectral character of kudzu, mapping was accomplished by manual classification (example shown in fig. 8*B, D*). Accuracy assessment of the manual mapping of kudzu could not be performed because of the lack of kudzu field sites visited by NPS personnel.

2004 Field-based Reconnaissance and Mapping Classification

In September 2004, USGS scientists accompanied by NPS personnel visited 30 field sites within the Parkway. The purpose of having USGS scientists accompany NPS personnel was to document environmental features important to the image-based mapping classification that may have been missed by NPS personnel unfamiliar with image processing.

The number of field-site observations per alliance initially received by USGS scientists in 2004 (table 3) was less than that requested. Of the 83 field sites located along the entire Parkway, the maximum number of field-site observations for any given alliance or association was 12, representing the white oak (*Quercus alba*) alliance. Twelve alliances represented by 14 total field-site observations were associated with the herbaceous class, and 3 alliances of the shrubland physiognomic class were represented by 4 total field-site observations. Of the other 19 forest alliances, most were supported by 1 or 2 field-site observations, except for 2 alliances that were observed at 7 and 9 sites, respectively, and 4 alliances that were observed at 4 or 5 sites. The number of field-site observations per alliance was far less than statistically required (for instance with a Chi Square criteria) (for example, Grenier and others, 2008).

Formation of Spectrally Distinct Mapping Classes

The number and types of field sites for which USGS scientists received data from NPS in 2004 were not sufficient to generate spectral attributes (spectral key based on the class means and variance) for the landcover classes of interest in order to apply a supervised classification strategy. To overcome the lack of sufficient field-site observations, an unsupervised classification strategy was initially applied. Inputs into the unsupervised method were the three green, red, and near-infrared image planes making up mosaic sections created by mosaicing individual DOQQ frames.

In unsupervised classification, we used a minimum spectral distance formula to form clusters that were subsequently assigned class memberships. The algorithm began with arbitrary spectral means. For each iteration, the cluster centroid position was recalculated to reflect changes in the cluster-class memberships. The new cluster means were then applied in the subsequent iteration. Iteration continued until either the maximum iteration number defined by the user was reached or a maximum percentage of unchanged pixels remained below a user-specified threshold between two sequential iterations.

The unsupervised mapping algorithm was applied separately to each of the 11 mosaics (see fig. 3 for mosaic graphics). The unsupervised classifications included 100 initial arbitrary clusters. By using image analysis software, the classified image was visually compared with the original CIR image. On the basis of communality in spectral color, tone, and texture the 100 clusters were merged into 10 to 12 clusters and each merged cluster assigned a class value based on its physical association with a NVC class from the 2004 NPS landcover classification. Examples of the initial unsupervised classification produced in anticipation of the field reconnaissance during September 20–25, 2005, are shown in figures 9*A* and 10*C, D*.
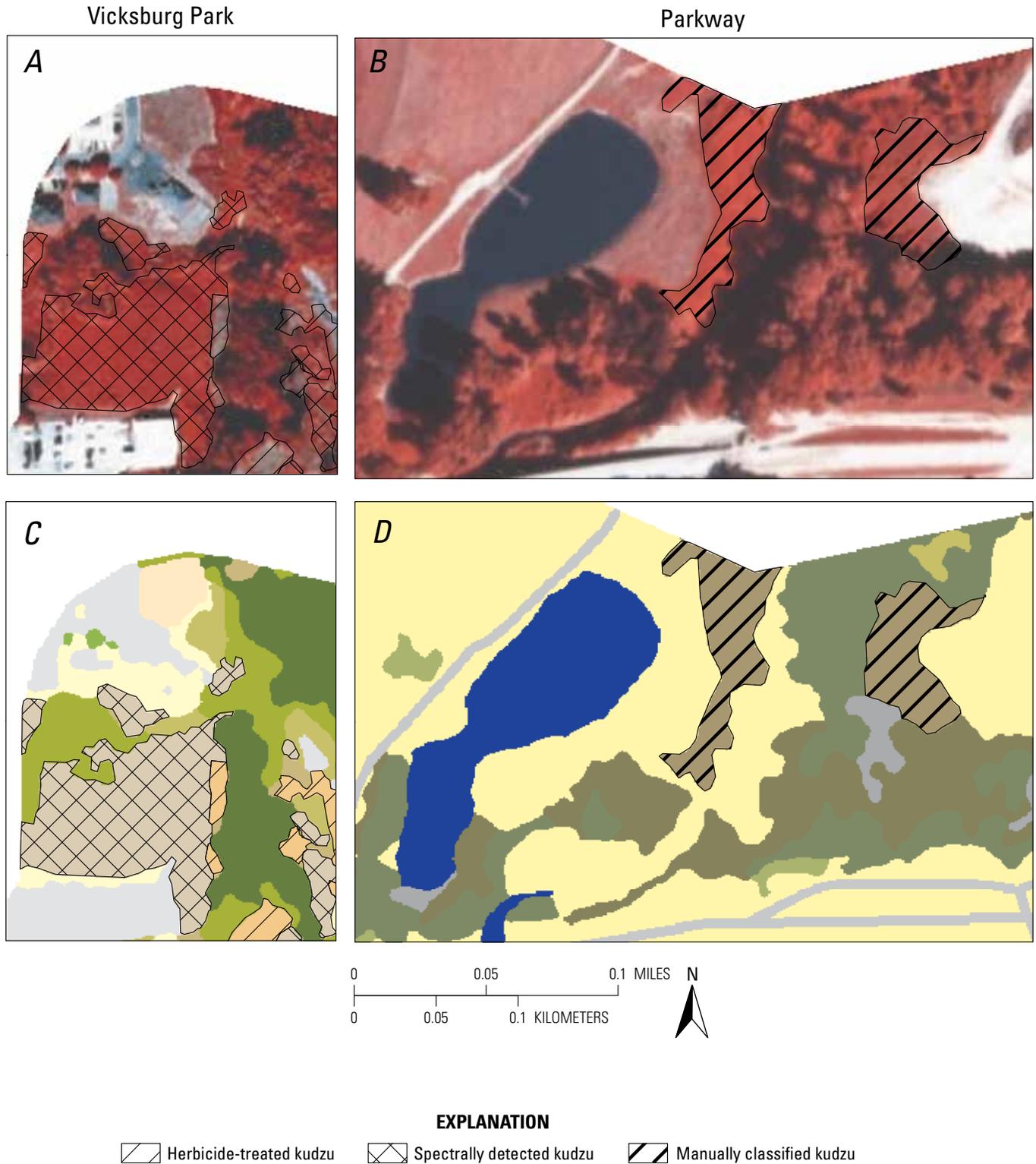
Figure 8. Variations of kudzu vine shrubland. *A*, *C*, Examples from the Vicksburg National Military Park ("Vicksburg Park"; unpublished data). *B*, *D*, Examples from the Natchez Trace Parkway (the "Parkway"). Kudzu vine was distinctly visible by its tone and texture on the color-infrared images (parts *A* and *B*), and parts C and D show the vegetation as mapped by U.S. Geological Survey scientists. Both examples show "ground" kudzu vine. Also shown in part *C* (example from the Vicksburg Park) is a small area of herbicide-treated kudzu.

Table 3.   Initial landcover classification of field sites in the Natchez Trace Parkway by National Park Service personnel in 2004. Classification codes are from the National Vegetation Classification. Frequency of observations per landcover class is provided.

[NVC, National Vegetation Classification; No., number]

Physiognomic class	NVC alliance code	NVC association	No. of field-site observations
Dry forest	A.241	White Oak - (Southern Red Oak, Post Oak)	12
	A.130	Loblolly Pine	9
	A.395	Shortleaf Pine - (Scarlet Oak, Rock Chestnut Oak)	5
	A.229	American Beech - Northern Red Oak - White Oak	7
	A.249	Rock Chestnut Oak - (White Oak, Southern Red Oak, Northern Red Oak)	2
	A.243	Southern Red Oak	1
	A.137	Eastern Red-cedar	2
	A.221	Tree-of-Heaven	1
	A.1912	Chinquapin Oak - (Sugar Maple)	1
	A.131	Virginia Pine	1
	A.242	Shumard Oak - Cherrybark Oak	2
	A.280	River Birch - (Sycamore)	1
Temporarily flooded forest	A.286	Green Ash - American Elm - (Northern Hackberry, Sugarberry)	4
	A.287	Sweetgum - (Tuliptree, Red Maple)	5
	A.292	(Willow Oak, Water Oak, Diamondleaf Oak)	4
	A.279	Silver Maple	1
Seasonally flooded forest	A.316	Red Maple - Green Ash	1
Permanently flooded forest	A.345	Water Tupelo - (Bald-cypress)	2
Seasonally flooded woodland	A.652	Bald-cypress - (Pond-cypress) Flooded Lakeshore	3
Shrubland	A.904	Kudzu Vine-Shrubland Alliance	1
	A.1101	Buttonbush Semipermanently Flooded Shrubland Alliance	1
	A.994	Smooth Alder Seasonally Flooded Shrubland Alliance	2
Herbaceous	A.1219	Bahia Grass	1
	A.2020	Johnson Grass	1
	A.1386	Woolgrass Bulrush Seasonally Flooded	1
	A.1669	Pickerelweed - Green Arrow-arum Semipermanently Flooded	1
	A.1696	Appalachian Shoestring Fern - Cave Alumroot Saturated	2
	A.1198	Little Bluestem - Yellow Indiangrass	1
	A.1881	Smartweed species Seasonally Flooded	2
	A.1213	Tall Fescue, Meadow Fescue, Alligator weed	1
	A.1754	Pondweed - Coontail - Waterweed species Permanently Flooded	1
	A.1716	Common Water-hyacinth Permanently Flooded	1
	A.1375	Soft Rush Seasonally Flooded	1
	A.1984	Water-lily Aquatic Wetland	1
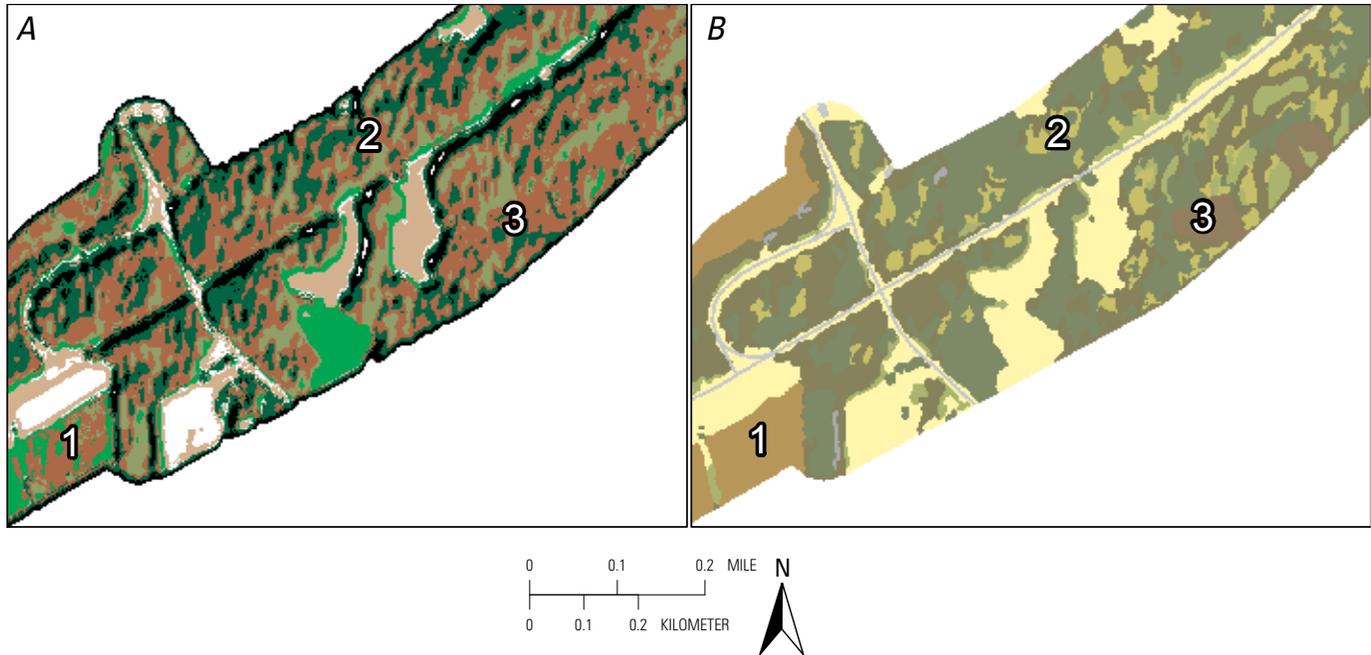
Figure 9.   Mapped landcover corresponding to the color-infrared image shown in figure 7. *A,* The initial unsupervised classification wherein scrub-shrub, shrubland (area A1), some mature forest stands (area A2), and plantations (area A3) were being represented by the same spectral signature. *B,* The final mapped classification of the area after applying different image processing techniques as discussed in the "Final Mapping Classification" section of the current report (areas B1–3 correspond to areas A1–3 in part *A*).

In the initial unsupervised classifications, it became apparent that the mapping classification of each mosaic was dependent to some extent on the interpretation of the analyst. In other words, consistency among analysts from mosaic to mosaic was not assured. At times, this variability resulted in inconsistent class mapping across mosaics. To diminish analyst-dependent variability and help maintain classification consistency, we applied the migration of signatures procedure (class centroid migration) from one mosaic to the next. The classes delineated in one mosaic were used as the cluster seeds (or *a priori* knowledge) for mapping of the next mosaic. At this point, the mapping became a supervised classification. Migration of cluster means from one mosaic to an adjacent mosaic relied on a majority of the landcover classes remaining spectrally similar from mosaic to adjacent mosaic. Minor spectral changes among the same landcover classes could exist, however, and a small number of new classes could appear in a newly classified mosaic. In the latter case, any signature that was not spectrally close to spectral classes of any of the previous mosaics was assigned to a new class. Before implementation of the migration of the means, testing indicated that the technique produced reasonable results.

Second NPS Field Classification

During September 22–30, 2005, a second field trip was conducted to add additional field-site observations for the initial NPS landcover classification of the Parkway. The USGS team accompanied classification representatives on one of the three NPS teams.

2005 NPS Field-Site Sampling Strategy

At the request of USGS, the number of field sites was increased in a coordinated USGS and NPS field exercise that occurred about 1 year after the CIR image data collection. In this second USGS-NPS coordinated field trip during September 22–30, 2005, the 20- by 50-m plot size that was used in the first field classification was changed. These new "quick plots" were limited to a boundary defined by an 11.3-m radius (400 m²), and the minimum separation distance among the field plots was set at 50 m. This change in plot size created a discrepancy with the image classification method already established by USGS scientists, which was generated
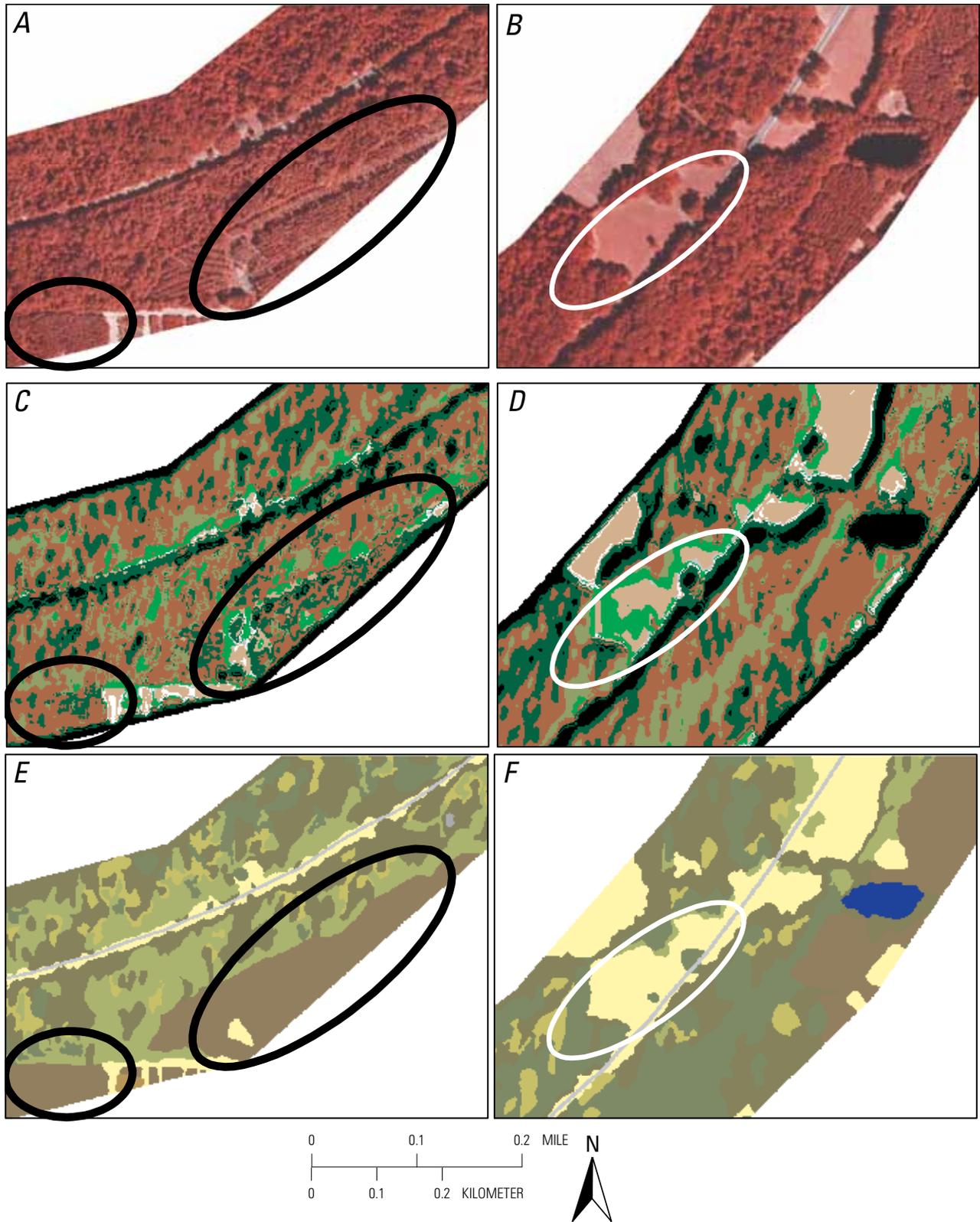
Figure 10.   Process for classifying color-infrared (CIR) digital orthophoto quarter quandrangles (DOQQs) of different areas in the "2 south" mosaic (see fig. 3). *A, B,* Source DOQQs. *C, D,* The initial unsupervised classification wherein confusion exists between forests and planted forests (shown within black ovals in parts *A, C,* and *E*) and between grasslands and edge trees (depicted within white ovals in parts *B, D,* and *F*). *E, F,* Final landcover maps created after applying a number of image processing and geographic information system (GIS) techniques and manually mapping the planted forests.

to best reproduce the initial 20- by 50-m plot dimension. Although decreasing the plot size for expediency did decrease the amount of time spent per plot, it also spatially limited plot sampling, thus limiting information concerning the spatial extensiveness of any given landcover class identified within the circle or surrounding the circle. Where spatially extensive, homogeneous compositions existed, the quick-plot sampling method was appropriate; however, where more heterogeneous patterns existed, this sampling method did not sufficiently indicate landcover composition outside the spatially restricted observations. This lack of information was pertinent to assessing mapping accuracy.

Field-Site Selection for the Second NPS Landcover Classification

For the 2005 NPS-field reconnaissance, about 60 field sites (located by UTM coordinates) exhibiting sets of unique CIR hues and spatial textures were selected by USGS scientists from areas within each of the 11 mosaics (mosaics 1 to 11, fig. 3) as candidates of ground-based landcover classification by NPS personnel. In mosaics 1 to 5, a minimum of five or six field-site locations were selected from each of the 11 to 12 spectral classes delineated in the initial USGS mapping effort (table 3). Field sites selected from mosaics 6 and 7 were based on the nonclassified CIR photography. The UTM coordinates for all selected field sites were transferred to NPS teams for field-site landcover classifications, and then NPS teams selected the field sites that were visited. Most USGS field sites were not visited by NPS classification specialists and therefore were not used in the USGS mapping of the Parkway; however, numerous USGS selected field sites used and classified by NPS classification specialists were discovered to contain landcover alliances (as defined in the NVC) that had not been identified in the previous 2004 field reconnaissance.

During the second field reconnaissance, the number of field sites was increased by 263, and 27 new NVC alliances were added to the 2004 catalogue. Out of the total 346 field sites, 6 had no classified NVC alliances or associations, 7 were outside the Parkway boundary, and the coordinates of 2 forest sites were mislocated in the roadway. These 15 sites were not included in the final mapping effort. In total, the final landcover classification reference sites included 61 alliances across 331 field sites. Although increased field landcover classifications were advantageous, the alliances were still significantly under-represented by field landcover classification data. Even excluding the "irregular" class (discussed in the "Mapping 'Irregular' Classes" section), only one NVC alliance was represented by an adequate number of field-site observations.

Mapping Limitations

Composition Gradients

A source of confusion concerning the mapping classification was related to assigning distinct class values along a continuum of spatial-vegetation gradient. This confusion occurred where one landcover class (for example, an alliance comprising a variable mixture of vegetation types) grades into another class over some distance. The necessity to assign each pixel along the gradient to a single class creates an unwanted but unavoidable level of classification confusion within the gradient (fig. 11). This problem is further complicated when compositions defining a class vary, as well as when many compositions of vegetation are shared among differently assigned classes.

Varying Class Compositions

Where landcover classes are spatially variable, as observed in the Parkway, spatial-vegetation continuums and mixed-variable compositions increase spectral confusion and tend to lower the expected mapping detail (number of identifiable landcover classes) and lower the mapping accuracy per class. In the case of mixed-variable compositions, increased field-site observations per landcover class increase the ability to determine whether or not assigned classes can be spectrally separated with the photographic data. For example, field sites classified in the white oak alliance were dominated by white oak at some percentage level; however, a variety of species co-occurred with white oak, including hickory (*Carya* sp.), southern red oak *(Quercus falcata)*, tuliptree *(Liriodendron tulipifera)*, water oak *(Quercus nigra)*, and diamond leaf oak *(Quercus laurifolia)*. One field site containing white oak might also include northern red oak and hickory, whereas another might only include water oak as the co-occurring species. Conversely, alliances dominated by other tree species could include white oak and other co-occurring species; for example, a pine alliance that included white oak, southern red oak, post oak, and oak. In figure 12, six different white oak alliance field landcover classification sites are shown as they appear on the CIR photography including four that are the same alliance and same association but exhibit highly different spectral hues and tones.

In addition to variable compositions within classes, the percent occurrences and dominant substory species could vary within an alliance. Where substory species are detected within the photographic response, they would influence the photographic hue (color), intensity, and saturation (color purity) and thereby would influence the mapping classification.
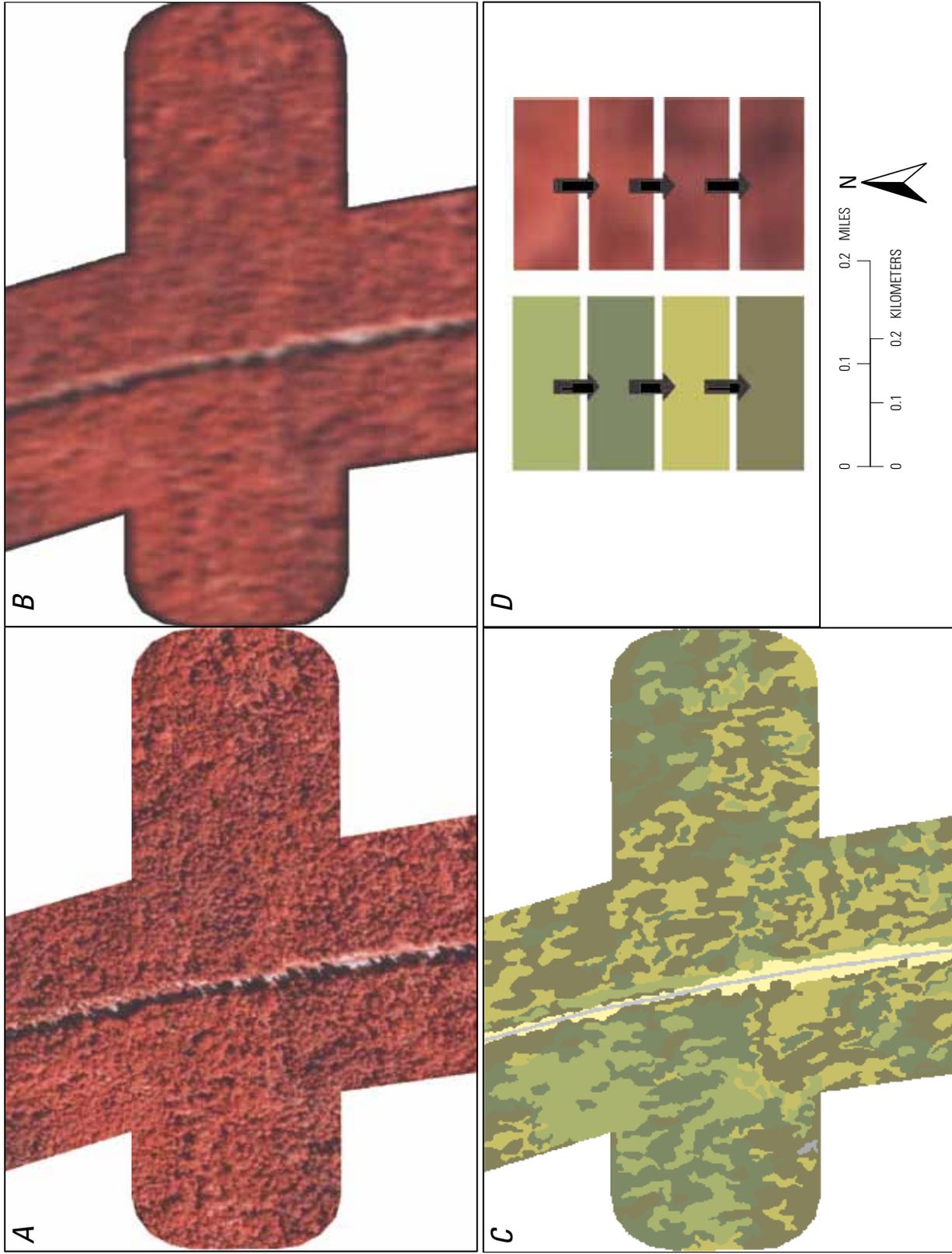
Figure 11. Examples of the spatial-vegetation continuum (as indicated by spectral qualities). *A,* The color-infrared (CIR) digital orthophoto quarter quadrangle from the "4 north" mosaic (see fig. 3). *B,* The spatially filtered CIR. *C,* Mapped landcover. *D,* The classification continuum from tree canopies having a lighter tone in the imagery to those with canopies having a darker tone. In part *C,* the brightest tones in the imagery depict grasses (shown in yellow) and bare areas (shown in gray; road in this example).
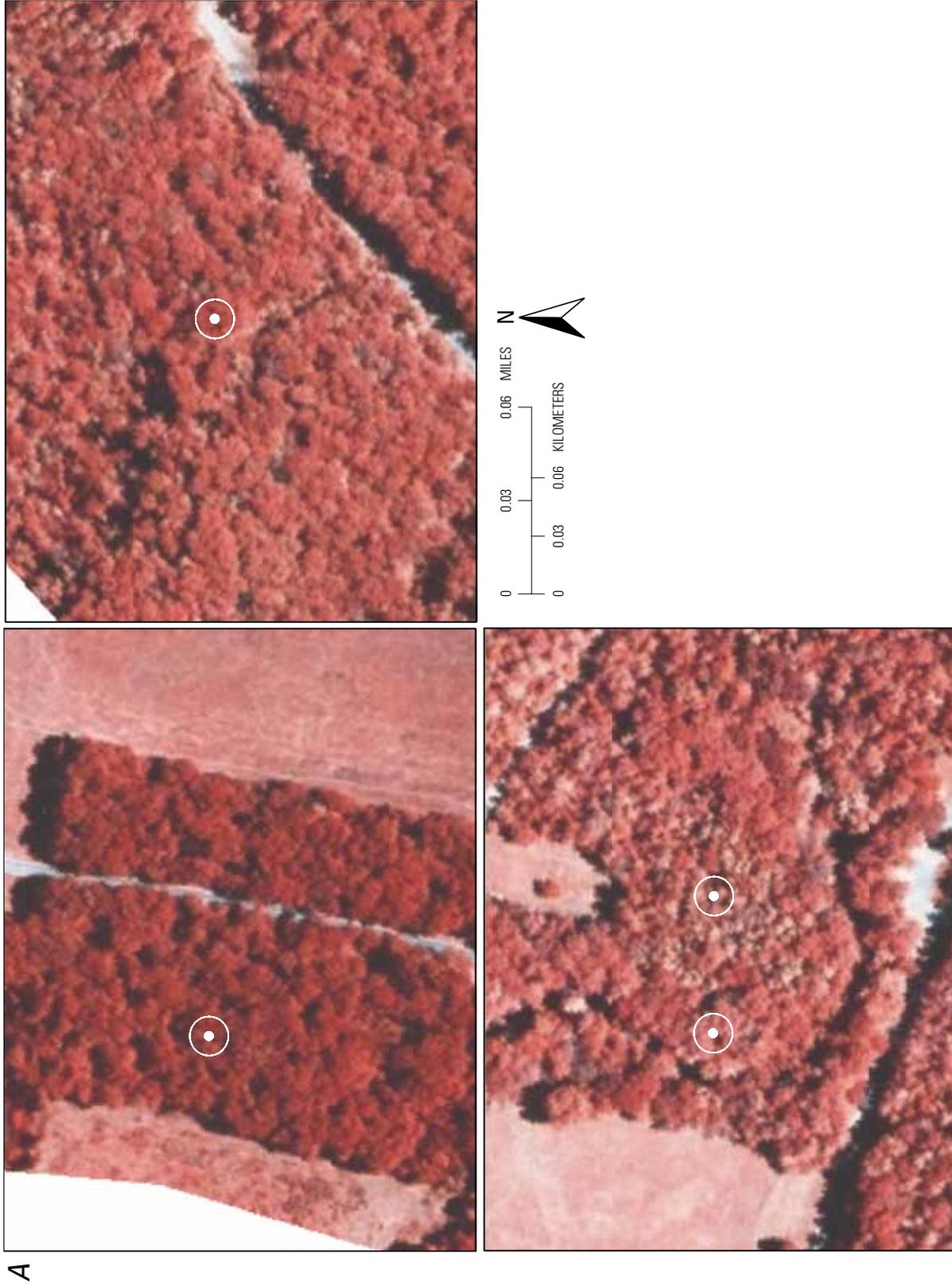
Figure 12.   Examples of white oak forest alliances mixed with different white oak associations. *A*, Color-infrared digital orthophoto quarter quadrangles wherein the white oak is the major class, but because of mixed variables with other forest compositions, the spectral confusion increases and lowers the ability to map the white oak class. These three examples are from the same section of the mosaic with no cutline. *B*, Example of four field sites classified by the Natural Park Service as white oak with the same alliance and same association; however, because of varying canopy composition, spectral tone varies.
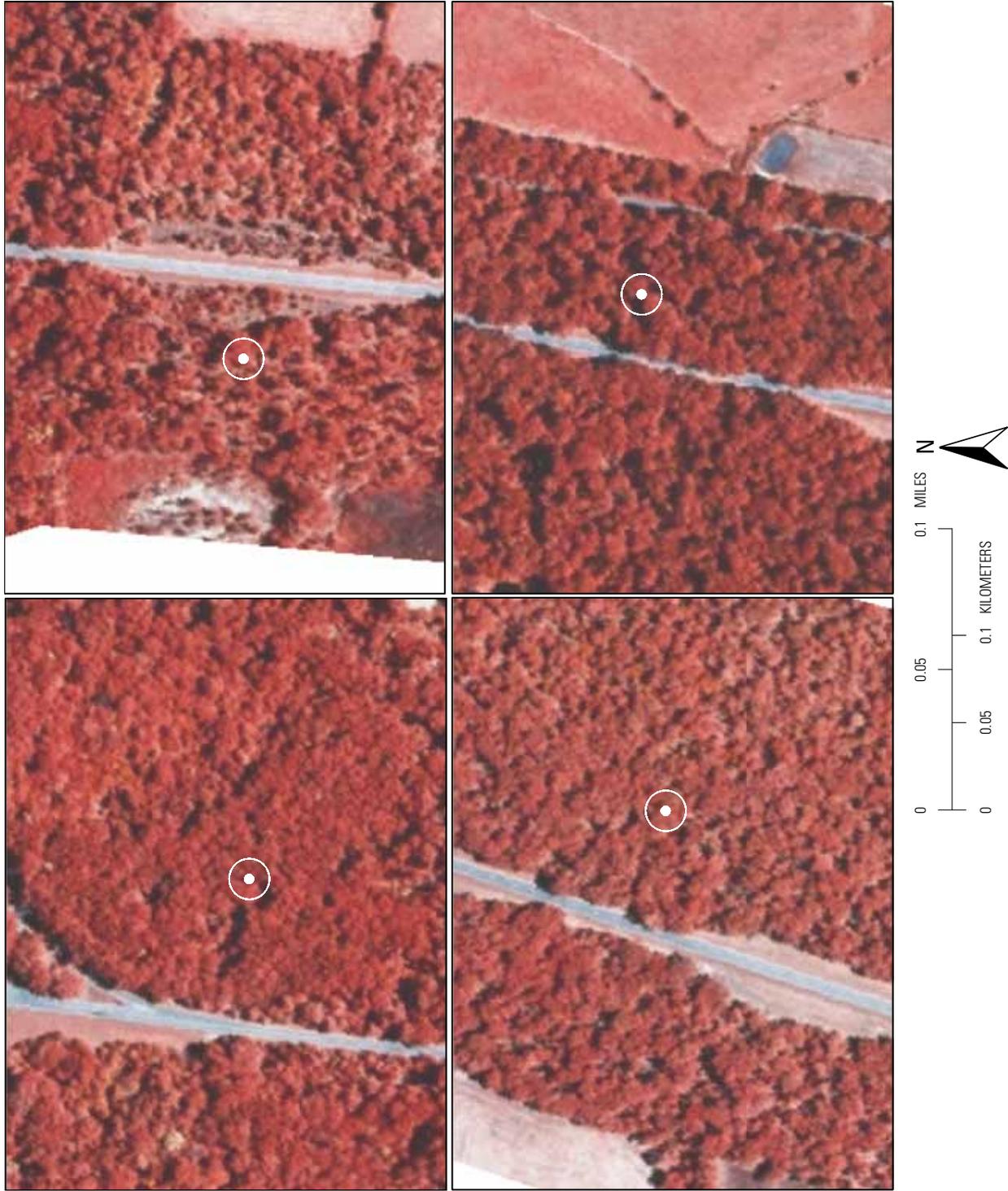
B

Figure 12.—Continued   Examples of white oak forest alliances mixed with different white oak associations. *A*, Color-infrared digital orthophoto quarter quadrangles wherein the white oak is the major class, but because of mixed variables with other forest compositions, the spectral confusion increases and lowers the ability to map the white oak class. These three examples are from the same section of the mosaic with no cutline. *B*, Example of four field sites classified by the Natural Park Service as white oak with the same alliance and same association; however, because of varying canopy cover, spectral tone varies.

In the case of the spatial-vegetation continuums, postprocessing procedures were used to minimize many ribbon type features in the mapping classification that resulted from a discrete classifier (one class per pixel) placed on a spatial continuum. Although minimized, these features were not totally eliminated from the mapping classification.

Spatial Filtering and Mapping Classification

Application of the spatial filter (discussed in the "A CIR Rendition Appropriate for Mapping Forest Stands" section) conformed to the 20- by 50-m field landcover classification sites while minimizing unwanted canopy variability (irregularly illuminated tree crowns and canopy gaps and associated shadowing) and maximizing forest-stand identification. The drawback was the loss of spectral detail and blurring of edges resulting in loss of definition of individual trees (for example, fig. 13). The image smoothing at one-quarter of the field site extent provided a spatially enhanced forest mapping classification and accounted for and minimized canopy variability and maximized canopy-stand texture within a landcover class.

Canopy Structure

An often overlooked variance in mapping classification is associated with canopy structure. The greatest influences on photographic classifications (manual and image processing) are crown type and canopy closure or openness. At times, canopy structure can help identify different species compositions. At other times, canopy structure variability masks spectral differences that define two or more alliances, thus increasing misclassifications among alliances. Smoothing filters and contextual filters (texture) were used to help alleviate some canopy-structure variability while enhancing selected canopy structure patterns to improve mapping classification performance (fig. 14).

Final Mapping Classification

In the final mapping strategy, the first expectation was that the initial USGS mapping effort had identified all the major spectral classes in the Parkway. The second expectation was that unsupervised mapping would not produce an acceptable classification because of (1) the ubiquitous edge and gap shadows in the DOQQ image data and (2) other noted complexities, such as site-location error, limited site extent, and mosaiced DOQQ cutlines (changing spectral renditions of the landscape), (3) varying compositions and varying canopy structures within the alliances (and thus the lack of a consistent spectral key) (figs. 12 and 15), and (4) inadequate number of field-site classifications per NVC alliance throughout the Parkway.

To determine spectral distinctiveness in the combined 2004 and 2005 landcover classification, the initial mapping based on the 2004 classification had to be refined. The final mapping of the entire Parkway per the NPS landcover classification included the following steps:

- The isolation and replacement of edge shadows (primarily along the roadway) and gap shadows (under a selected size) in forest areas,

- The detection and isolation of cutlines in the DOQQ mosaic in preparation for segmentation of mapping from cutline to cutline,

- Determination and formation of spectrally distinct classes, including the reiteration and refinement of class mapping in cases where there was significant confusion within one or more classes,

- Postclassification procedures that were carried out to minimize ribbons and maximize contiguous spatial coverages of the mapped classes, and

- An assessment of mapping accuracy.

Removal and Replacement of Edge and Gap Shadows

Canopy shadows are a considerable hindrance to producing accurate mapping classifications. Some problems were eliminated with the averaging filters. In these cases, the shadows were considered part of the forest structure and included in the progressive classification. In the case of extensive edge shadows and shadows within the forest associated with large canopy gaps, the shadows had to be classified independent from the progressive classification.

For the most part, edge shadows were limited to the area adjacent to the Parkway; however, edge shadows also occurred at any abrupt changes in vegetation. Multiple combinations of image processing techniques were applied to isolate the edge shadows. These combinations primarily included spectral texture and hue combinations, adjacency (to a roadway or forest cut for instance), and in some cases, spectral thresholds. Once edge shadows were isolated, replacement of the shadowed area by an appropriate landcover class was undertaken. Replacement again involved multiple image processing techniques. Many replacements combined some intelligence through GIS applications, for instance the distance to known features and class adjacency and distance, to decide which class would be used to replace the shadowed area. Consistency of the assigned landcover class with the surrounding vegetation was verified by visual comparison to the CIR photography.

The image processing steps taken to isolate the edge shadows also included forest gaps by their associated shadows. As stated previously, the average filter had integrated many forest canopy gaps into the mapping classification; however, in some cases the integration of the forest gaps reduced mapping effectiveness. In these cases,
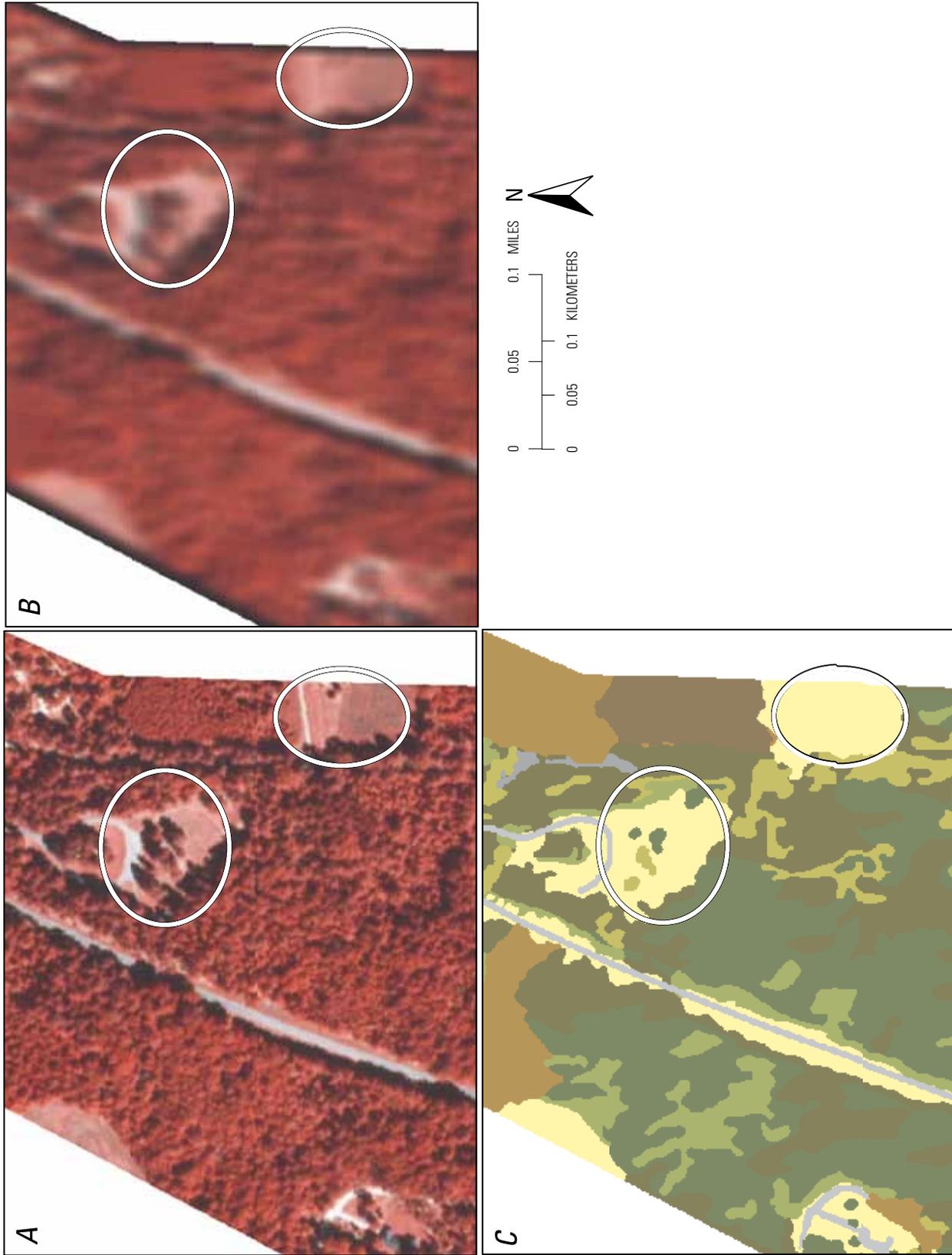
Figure 13.   Example of classification confusion resulting from spatial filtering. The image is from mosaic "4 south" in figure 3. By comparing the images, note the loss of single-tree definition (the trees highlighted by black circles) within a fairly large bare area. *A*, Color-infrared digital orthophoto quarter quadrangle (DOQQ). *B*, The spatially filtered DOQQ. *C*, The final mapped image.
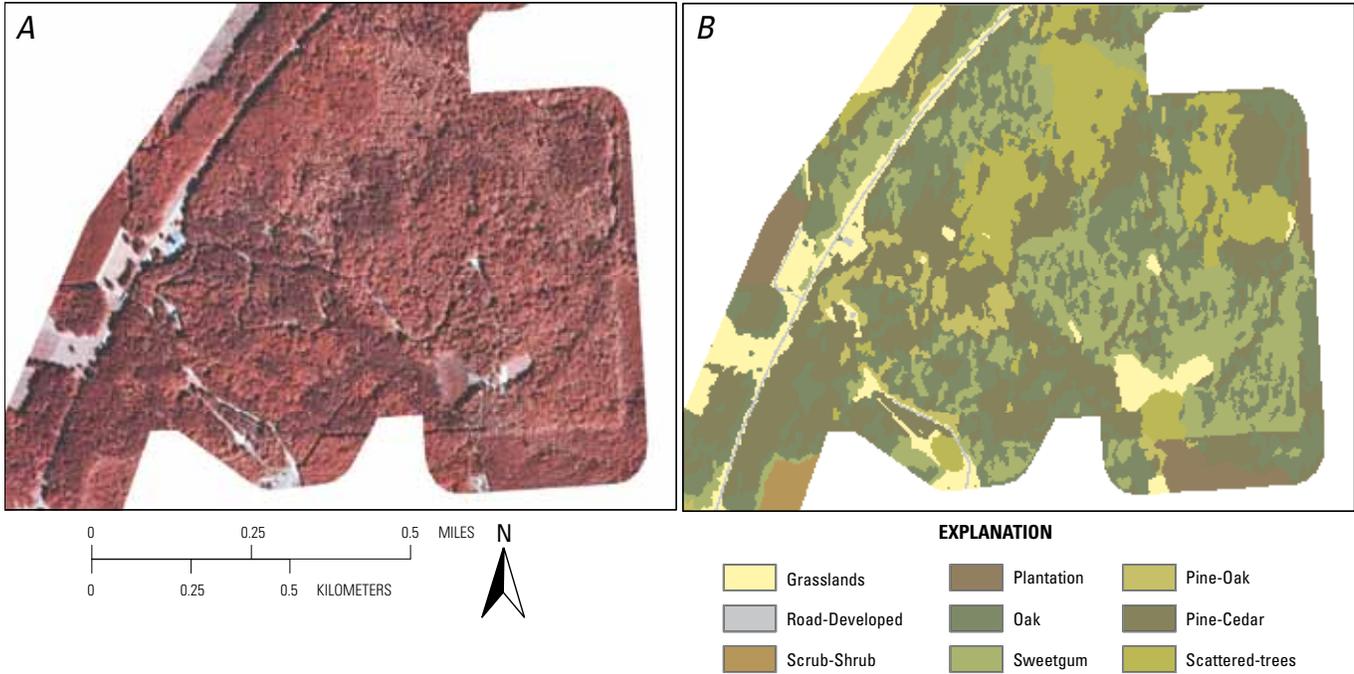
Figure 14.   An example of forest types featuring different crown sizes and percentages of canopy closure. *A*, Color-infrared digital orthophoto quarter quandrangle (DOQQ). *B*, Mapped area after applying smoothing and contextual filters to the DOQQ.
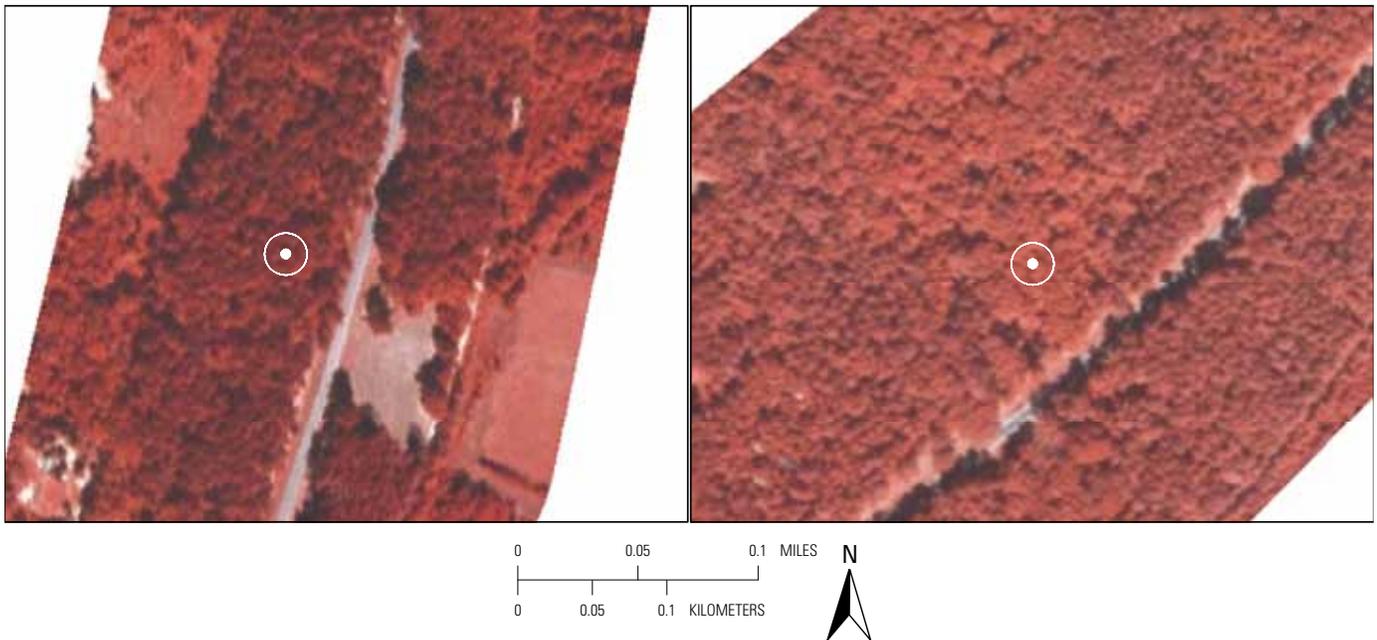
Figure 15.   An example of field sites where landcover was classified by National Park Service personnel. The data points are located in an area of mosaic "3 south" (see fig. 3) and both correspond to pine-oak forest (as defined in the National Vegetation Classification). In this case, both sites are classified within the same alliance and association. The variation of spectral tone is very distinct. No cutline occurs between these two examples.

gaps were removed and separately reintegrated into mapped forest classes. The integration was performed by using GIS functions to effectively partition the gap into the surrounding forest classes. Correctness of the gap reassignment into a landcover class was ascertained by visual examination, and the results were incorporated within the overall class accuracy assessment with respect to class continuity and field assessments (fig. 16). In addition, even though smaller gaps could be considered integral components of the forest class structure, gaps of considerable spatial extent in the forest landscapes may provide an important function that is important for forest management. For that purpose, forest gaps of less than or equal to 200 m^2 were integrated into the surrounding forest classes during one of the postmapping GIS procedures while larger gaps were retained.

Detection and Isolation of the Mosaiced DOQQ Cutlines

Orthophoto cutlines are a direct impediment to producing continuous and consistent classes extending throughout the spatially extensive Parkway. As discussed, the mapping procedure of using the migration of spectral means allowed for the incorporation of changes in landcover class dominance throughout the southern to northern extent of the Parkway. This mapping technique is appropriate and advantageous when spectral consistency is maintained or changes progressively or when there are a limited number of abrupt changes related to the introduction of new classes. Cutlines in the orthophoto image, however, can introduce abrupt spectral changes in all classes, at times exceeding the ability of the progressive mapping strategy to maintain spectral-class consistency (fig. 17).

Although cutlines were anticipated at the project onset, the high number of cutlines in the orthophoto mosaic intensified the complexity of the progressive mapping procedure. In addition, although the sensitivity was not apparent in the initial mapping effort, the application of the progressive mapping strategy to detect fairly subtle spectral changes led to an unexpectedly high sensitivity of the mapping procedure to the occurrence of cutlines. In most cases, cutline influences were circumvented by adding visually determined cutline regions to produce a consistent map product.

Landscape Mapping Classification Logistics

To compensate for some of the mapping challenges, USGS scientists applied a widely used spectral classification technique based on progressive narrowing of the spectral variance per mapped class (for example, Ramsey and Laine, 1997). The 2004 landcover mapping contained excessive areas of confusion; however, the initial spectral grouping provided an effective starting point for implementation of a refined mapping methodology (for example, Ramsey and Laine, 1997), excluding the manually classified categories. The refined classification procedure was operated on each of

the classes initially mapped in the unsupervised classification. USGS scientists used this technique and attempted to map all classes identified in the NPS landcover classification of the Parkway whether or not the class was properly represented with an adequate number of field-site observations (table 4). Inputs into the modified unsupervised mapping procedure were the three green, red, and near-infrared image planes making up mosaic sections, and in addition, the 2004 initial mapping classification.

The refinement of the initial unsupervised mapping classification still applied the unsupervised K-means clustering algorithm but within a progressive clustering technique (PCI Geomatics, 1998; Ramsey and others, 1998; Ramsey and others, 2001a and b; Ramsey and others, 2002). In the progressive classifications, the spectral values associated with each image element (pixel) are combined into spectrally similar clusters and each cluster then associated with identifiable landscape features (for example, NVC-defined alliances or associations). Clusters that exhibited mixed combinations of landcovers (alliances or associations) were separated and grouped with other clusters that also exhibited mixed identities. The progressive clustering technique was reiterated until no clusters exhibited mixed identities or until the composition of the remaining mixed clusters became constant. This regrouping and reassignment of image values progressively narrowed the spectral variance until it represented undefined noise. The final set of clusters identified the spectrally separable and inseparable classes (alliances and associations). Figure 9 and figures 10*C–F* illustrate the transformation from the initial mapping based solely on K-Means clustering and the K-Means clustering results modified by the progressive mapping classification strategy.

The final set of classes were then migrated to the next adjacent mosaic section. When cutlines were present within mosaic sections, the signature migration was from one cutline section to the adjacent cutline section. A single signature migration was not applied from one end of the Parkway to the other; however, a mixture of progressive mapping classifications and signature migrations were applied throughout the Parkway. Restarting the signature migration by initiating a new progression of mapping classification was at times beneficial in mapping the southern to northern extent of the Parkway.

Reduction of Mapping Artifacts after Mapping

In a continued effort to generate a map product conforming to requests by NPS personnel, filters and sieves were applied to the mapping output in order to reduce mapping artifacts. Many times these mapping artifacts result from application of a discrete class structure on a spectrally and physically continuous landscape. Most of these artifacts were manifest as (1) isolated single-to-multiple pixel groups that are widely distributed spatially and throughout all classes and (2) ribbons that result from mapping discrete classes on a spatially continuous landscape (fig. 18*A–D*).
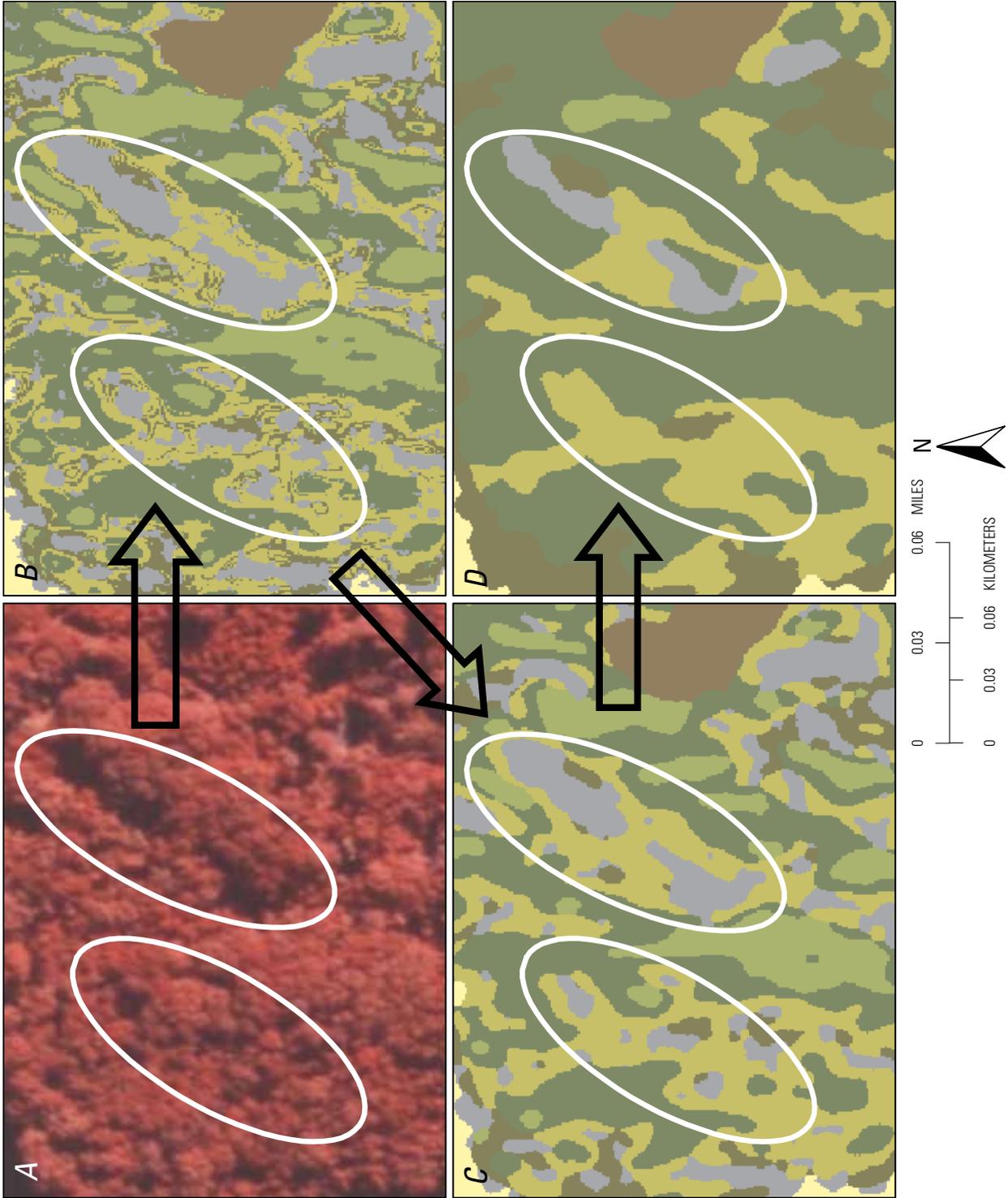
Figure 16. Process used to remove gaps and separately reintegrate them into mapped forest classes. *A*, Color-infrared (CIR) digital orthophoto quarter quadrangle. *B*, The CIR orthophoto after an unsupervised classification of landcover. *C*, The CIR orthophoto after applying a geographic information system procedure (nibble) to assign shadows of a defined size to the nearest forest class. *D*, The CIR orthophoto after filtering and merging clusters but before producing the final mapped landcover.
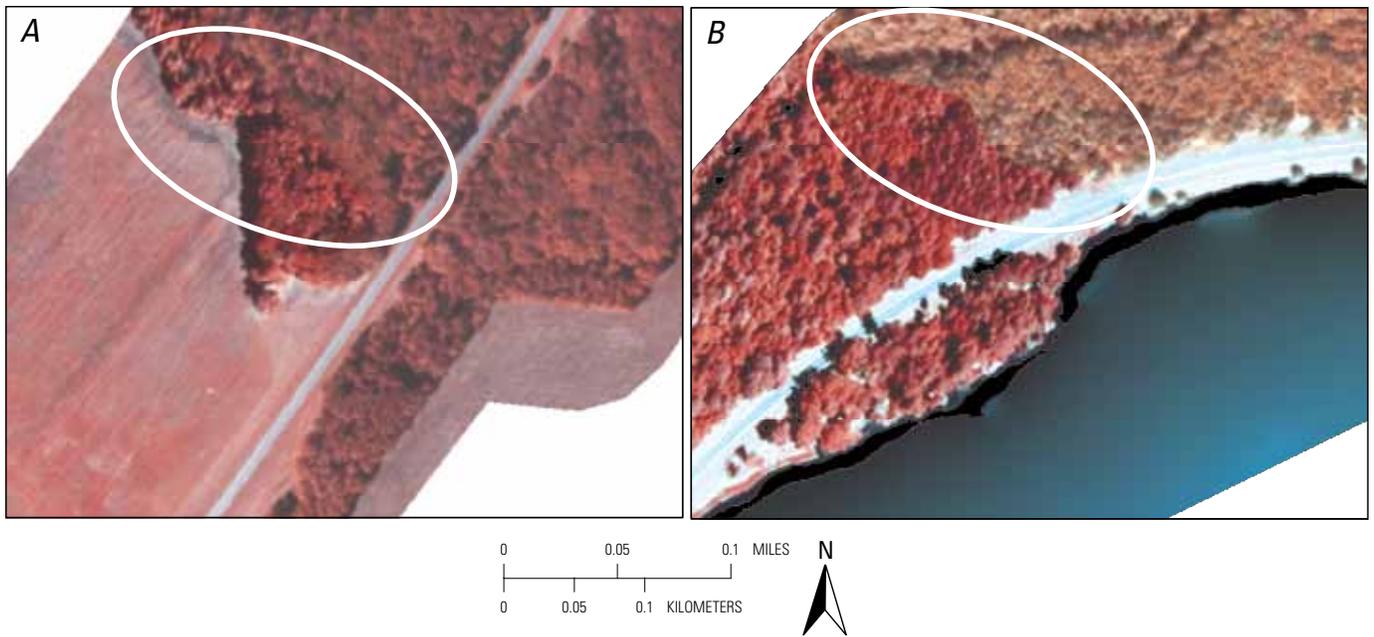
Figure 17. Examples of cutlines present in the different sections of the Natchez Trace Parkway mosaic. These cutlines were taken into account by creating masks and applying classification algorithms only under the masks. *A*, Cutline present on mosaic "3 north" (see fig. 3). *B*, Cutline present on mosaic "3 south" (see fig. 3).

Table 4. Landcover classifications defined by National Park Service (NPS) personnel (2004 and 2005) as they were mapped by U.S. Geological Survey (USGS) scientists (including how the classes were grouped in the USGS classification). Classification codes are from the National Vegetation Classification. Frequency of field-site observations per class by NPS personnel is provided.

[NVC, National Vegetation Classification; No., number; USGS, U.S. Geological Survey]

Physiognomic class	NVC alliance code	NVC association	No. of field-site observations	USGS classification
Herbaceous	A.1191	Highland Rim Wet-Mesic Prairie	1	Grasslands
	A.1198	Mississippi Jackson Calcareous Clay Prairie	2	
	A.1208	Successional Broomsedge Vegetation	2	
	A.1213	Cultivated Meadow	1	
	A.1219	Bahia Grass Pasture	1	
	A.1386	Highland Rim Pond (Woolgrass Bulrush - Threeway Sedge Type)	1	
	A.2020	Johnson grass vegetation	2	
	A.1657	Water-willow Rocky Bar and Shore	1	Aquatic vegetation
	A.1375	Rush Marsh	1	
	A.1669	Pickerelweed Marsh	1	
	A.1696	Cumberland Plateau Rockhouse	2	
	A.1881	Common duckweed-Swamp Smartweed-climbing vine	1	
	A.1881	Smartweed - Water-pepper Pond	1	
	A.1881	smartweed species - Savanna Panicgrass Seasonally Flooded Herbaceous Vegetation	1	
	A.1984	Water-lily Aquatic Wetland	1	
	A.1716	Water-hyacinth Aquatic Vegetation	2	Invasive species

Table 4.   Landcover classifications defined by National Park Service (NPS) personnel (2004 and 2005) as they were mapped by U.S. Geological Survey (USGS) scientists (including how the classes were grouped in the USGS classification). Classification codes are from the National Vegetation Classification. Frequency of field-site observations per class by NPS personnel is provided.—Continued

[NVC, National Vegetation Classification; No., number; USGS, U.S. Geological Survey]

Physiognomic class	NVC alliance code	NVC association	No. of field-site observations	USGS classification
Shrubland	A.1011	Southern Buttonbush Pond	1	Shrubland
	A.1905	Highland Rim Limestone Cliff/Talus Seep	1	
	A.993	Grapevine - Peppervine - Trumpetvine Thicket	1	
	A.994	Southeastern Smooth Alder Swamp	5	
	A.738	Chinese Privet Upland Shrubland	1	Invasive species
	A.904	Kudzu Vineland	1	
Planted Forest	A.99	Loblolly Pine Plantation	6	Plantation
Upland Deciduous Forests	A.221	Successional Tree-of-Heaven Forest	2	Invasive species
	A.229	Central Interior Beech - White Oak Forest	3	White oak
	A.239	Highland Rim White Oak - Tuliptree Mesic Lower Slope Forest	4	
	A.239	Interior Dry-Mesic White Oak - Hickory Forest	13	
	A.239	White Oak - Mixed Oak Dry-Mesic Alkaline Forest	9	
	A.239	White Oak - Red Oak Dry-Mesic Acid Forest	6	
	A.241	Southern Red Oak - White Oak Mixed Oak Forest	22	
	A.1912	Interior Plateau Chinquapin Oak - Shumard Oak Forest	2	Oak
	A.238	Basic Mesic Coastal Plain Oak-Hickory Forest	2	
	A.243	Dry Acid Eastern Coastal Plain Oak - Hickory Forest	17	
	A.243	Southern Red Oak Flatwoods Forest	3	
	A.247	Successional Water Oak Forest	2	
	A.249	Interior Low Plateau Chestnut Oak - Mixed Oak Forest	7	
	A.249	Lower Piedmont Chestnut Oak Forest	7	
	A.252	Cherrybark Oak û Water Oak Forest	7	
	A.286	Nuttall Oak - Sugarberry Bottomland Forest	1	
	A.330	Willow Oak Bottomland Flatwoods Forest	4	
	A.625	Western Highland Rim Blackjack Oak Barrens	1	
	A.625	Western Highland Rim Escarpment Post Oak Barrens	2	
Upland Evergreen Forests	A.234	Interior Mid- to Late-Successional Sweetgum - Oak Forest	2	Sweetgum
	A.234	Loess Bluff Sweetgum - Pecan - Water Oak Forest	3	
	A.234	Successional Sweetgum Forest	4	
	A.287	Successional Sweetgum Floodplain Forest	22	Sweetgum
	A.291	East Gulf Coastal Plain Calcareous Brownwater Terrace Forest	1	
	A.291	East Gulf Coastal Plain Small Oak Bottomland Forest	2	
	A.291	Swamp Chestnut Oak - Sweetgum Mesic Floodplain Forest	1	
	A.291	Sweetgum - Cherrybark Oak Floodplain Forest	8	
	A.292	East Gulf Coastal Plain Oak-Sweetgum Small Stream Floodplain Forest	12	

Table 4. Landcover classifications defined by National Park Service (NPS) personnel (2004 and 2005) as they were mapped by U.S. Geological Survey (USGS) scientists (including how the classes were grouped in the USGS classification). Classification codes are from the National Vegetation Classification. Frequency of field-site observations per class by NPS personnel is provided.—Continued

[NVC, National Vegetation Classification; No., number; USGS, U.S. Geological Survey]

Physiognomic class	NVC alliance code	NVC association	No. of field-site observations	USGS classification
Upland Evergreen Forests—Continued	A.130	Successional Loblolly Pine - Oak Forest	14	Pine-Oak
	A.369	Southern Loess Hills Hardwood - Pine Forest	2	
	A.394	East Gulf Coastal Plain Shortleaf Pine - Post Oak Forest	4	
	A.394	East Gulf Coastal Plain Shortleaf Pine - Southern Red Oak Forest	4	
	A.394	Upper East Gulf Coastal Plain Shortleaf Pine - Mesic Oak Forest	1	
	A.404	East Gulf Coastal Plain Loblolly-White Oak Forest	2	
	A.119	Shortleaf Pine Early-Successional Forest	1	Pine-Cedar
	A.130	Early- to Mid-Successional Loblolly Pine Forest	41	
	A.137	Black Belt Prairie Cedar Forest	6	
	A.137	Red-cedar Successional Forest	8	
	A.130	Mid- to Late-Successional Loblolly Pine - Sweetgum Forest	4	Pine-Sweetgum
Wetland forests	A.345	Water Tupelo Swamp Forest	3	Swamp Forest
	A.346	Bald Cypress Swamp	2	
	A.348	Interior Forested Acid Seep-CarolinaRedMaple, Blackgum	1	
	A.351	Swamp Blackgum - Sweetgum / Sweetbay / American Witch-hazel - Wild Raisin Forest	1	Swamp forest
	A.652	East Gulf Coastal Plain Bald-cypress Pondshore	1	
Total Number of Sites			301	
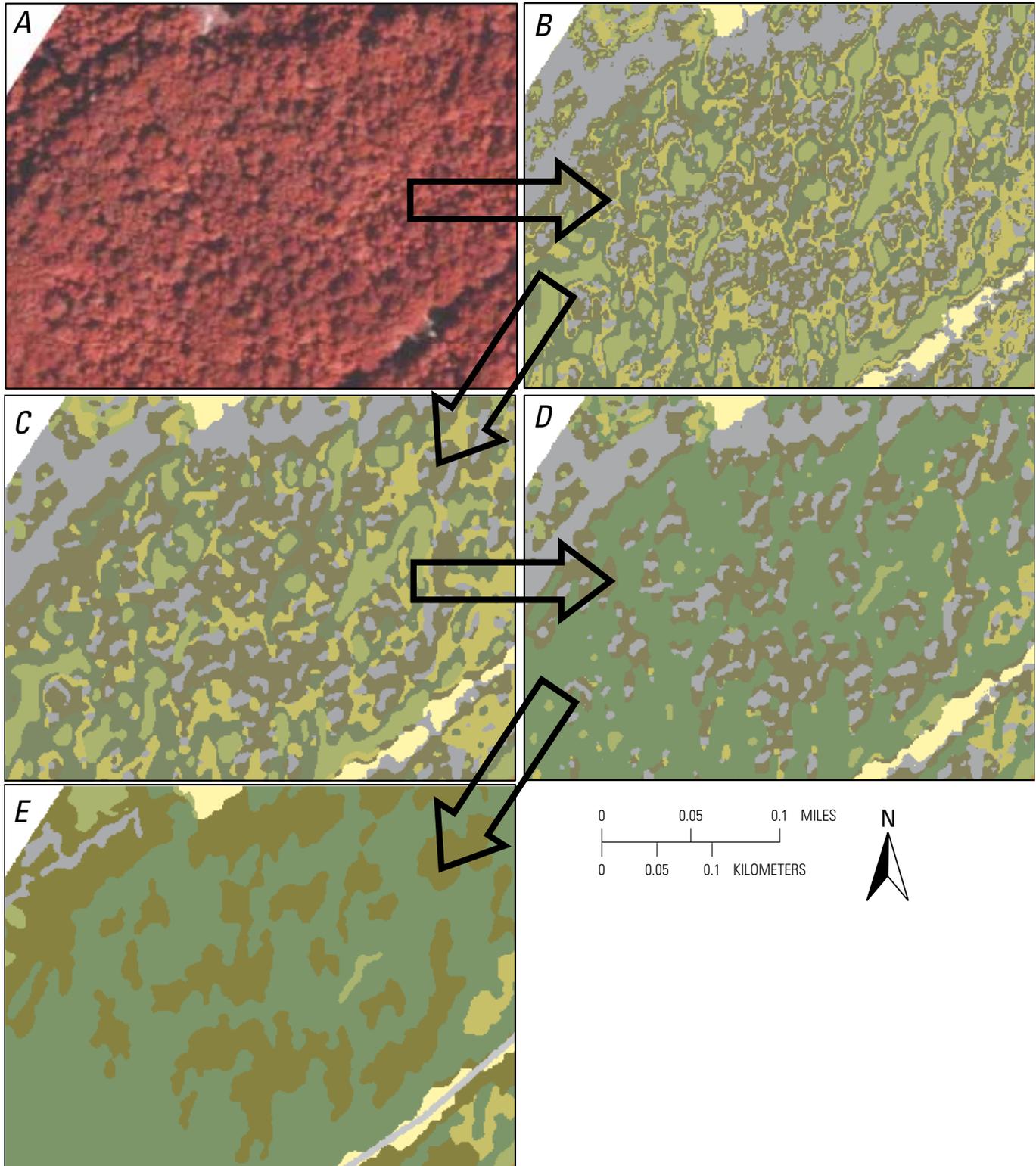
Figure 18.   Results of the process to reduce mapping artifacts from the final map product. *A,* Color-infrared digital orthophoto quarter quadrangle (DOQQ). *B,* Initial unsupervised classification of the DOQQ, which produced a lot of artifacts (as expected). *C,* Application of spatial mode filters. *D,* Merging of forest clusters within a defined threshold. *E,* Result of geographic information system (GIS) techniques to remove shadows and further image processing to merge small islands into the major forest classes.

Field-Site Location and Accuracy Assessment of Mapped Classes

During the 2005 field reconnaissance, the USGS team noted that in some instances field-site locations defined by GPS coordinates were not co-located with corresponding locations on the CIR photographic or mapped image (fig. 19). Partial alleviation of this discrepancy was provided by using the average of all satellite signals accumulated over the time taken to visit the field plot instead of using the initial GPS coordinate reading. Even with averaging the satellite signals, location errors associated with GPS units used in the 2005 (and most likely in the 2004) landcover classification were significant. Verbyla and Hammond (1995) showed that positional errors alone can lower mapping accuracy assessments by more than 50 percent.

Location errors associated with hand-held GPS units, the primary tool for specifying field-site locations, can vary dramatically under forest canopies, primarily in response to the varying canopy densities (Barette, 2000; Karsky and others, 2000; Mancebo and Chamberlain, 2000; Chamberlain, 2002a, b). Reported location errors between 5 and 30 m associated with time-averaged GPS recordings were typical of field reconnaissance. In response to the varying position error, the areal nature of the vegetation canopies (especially the forest canopies), and the spatially complex landscape, a 15-m positional tolerance buffer was attached to each GPS location received from NPS personnel by USGS scientists. If spatial concurrence between the NPS field landcover class location and the mapped location was within 15 m, correspondence was certified.

Mapping accuracy assessments are reported within contingency table formats (Congalton, 1991). The table matrix format lists the field-site classes observed by NPS personnel in the first column and the same classes as they were mapped by USGS scientists in the first row (tables 5–8). The entries within the table describe the correspondence between the field-based classification of sites and mapped classes. Entries along the matrix trace contain the number of correctly mapped field sites while entries off the trace denote misclassifications. Misclassifications are of two types—misclassifications along the column of any particular target class depict commission errors or user accuracy. These misclassifications define the number of times another class is incorrectly mapped as the target class; the target class has been incorrectly expanded into other observed classes. Misclassifications along the row of any target class define omission errors or producer accuracy. These misclassifications signify the number of times the target class has been incorrectly mapped as another class; the target class has been incorrectly decreased.
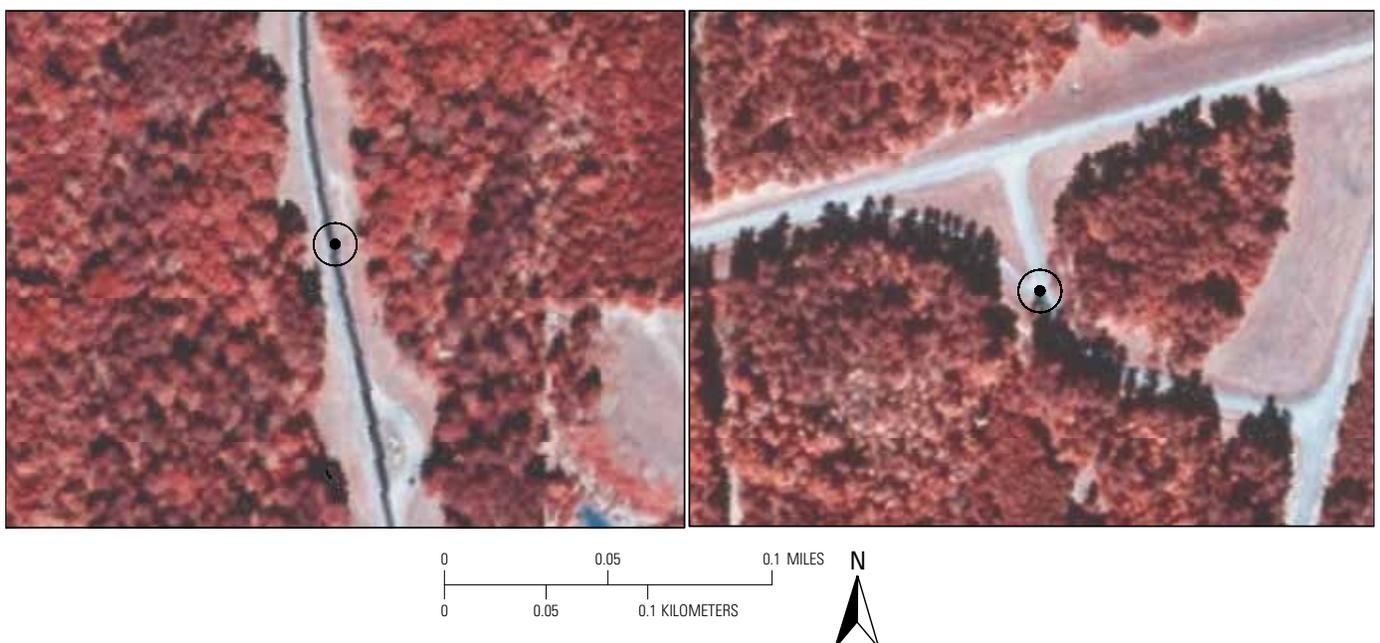
Figure 19. Example of two National Park Service forest sites mislocated outside the forested areas.

Table 5. Results from accuracy assessment of the landcover map of the Natchez Trace Parkway by U.S. Geological Survey scientists. The map was based upon a landcover classification provided by National Park Service (NPS) personnel. The "confusion matrix" indicates the divergence between the field-site classification (aggregated according to Table 4) and the USGS-produced map. The aggregated classes based on field sites are provided in the first column, and the same classes as they were mapped by USGS scientists are provided in the first row. Entries along the matrix trace (in gray shading) indicate the number of correctly mapped field sites, while entries off the trace denote misclassifications (errors of commission and omission). Overall user and producer accuracy rates are provided; the combined accuracy rate is estimated to be 65 percent.

[NPS, National Park Service; USGS, U.S. Geological Survey; no., number]

		Grass-lands	Oak	Pine-oak	Sweetgum	Pine	Sweetgum-oak	White oak	Cedar	Total no. of mapped instances	Producer accuracy	Omission error
NPS-defined classifications	Grasslands	10	0	0	0	0	0	0	0	**10**	100%	0
	Oak	0	42	7	1	0	0	5	0	**55**	76%	0.24
	Pine-oak	0	6	16	0	3	2	0	0	**27**	59%	0.41
	Sweetgum	0	8	0	9	5	8	0	0	**30**	30%	0.7
	Pine	0	0	2	0	40	0	0	0	**42**	95%	0.05
	Sweetgum-oak	0	7	1	0	0	17	0	0	**25**	68%	0.32
	White oak	0	21	1	0	2	2	31	0	**57**	54%	0.46
	Cedar	0	3	0	0	6	1	0	4	**14**	29%	0.71
	Total	**10**	**87**	**27**	**10**	**56**	**30**	**36**	**4**	**260**		
	User accuracy	100%	48%	59%	90%	71%	57%	86%	100%			
	Commission error	0	0.52	0.41	0.1	0.29	0.43	0.14	0			

Table 6. Results from accuracy assessment of the landcover map of the Natchez Trace Parkway by U.S. Geological Survey scientists (also see table 5). The map was based upon a landcover classification provided by National Park Service (NPS) personnel. The results presented here were derived after merging the "sweetgum" and "sweetgum-oak" classes into a "sweetgum" class and the "pine" and "cedar" classes into a "pine-cedar" class. The "confusion matrix" indicates the divergence between the field-site classification (aggregated according to table 4) and the USGS-produced map. The aggregated classes based on the field sites are provided in the first column, and the same classes as they were mapped by USGS scientists are provided in the first row. Entries along the matrix trace (in gray shading) indicate the number of correctly mapped field sites, while entries off the trace denote misclassifications (errors of commission and omission). Overall user and producer accuracy rates are provided; the combined accuracy rate is estimated to be 70 percent.

[NPS, National Park Service; USGS, U.S. Geological Survey; no., number]

		Grasslands	Oak	Pine-oak	Sweetgum	Pine-cedar	White oak	Total no. of mapped instances	Producer accuracy	Omission error
NPS-defined classifications	Grasslands	10	0	0	0	0	0	**10**	100%	0
	Oak	0	42	7	1	0	5	**55**	76%	0.24
	Pine-oak	0	6	16	2	3	0	**27**	59%	0.41
	Sweetgum	0	15	1	34	5	0	**55**	62%	0.38
	Pine-cedar	0	3	2	1	50	0	**56**	89%	0.11
	White oak	0	22	0	2	2	31	**57**	54%	0.46
	Total	10	**88**	**26**	**40**	**60**	**36**	**260**		
	User accuracy	100%	48%	62%	85%	83%	86%			
	Commission error	0	0.52	0.38	0.15	0.17	0.14			

Table 7.   Results from accuracy assessment of the landcover map of the Natchez Trace Parkway by U.S. Geological Survey scientists (also see table 6). The map was based upon a landcover classification provided by National Park Service (NPS) personnel. The results presented here were derived after merging the "Sweetgum" and "Sweetgum-Oak" classes as a Sweetgum class, the "Pine" and "Cedar"classes as a Pine-Cedar class, and the "White Oak" and "Oak" classes as a Oak class. The "confusion matrix" indicates the divergence between the field-site classification (aggregated according to table 4) and the USGS-produced map. The aggregated classes based on the field sites are provided in the first column, and the same classes as they were mapped by USGS scientists are provided in the first row. Entries along the matrix trace (in gray shading) indicate the number of correctly mapped field sites, while entries off the trace denote misclassifications (errors of commission and omission). Overall user and producer accuracy rates are provided; the combined accuracy rate is estimated to be 70 percent.

[NPS, National Park Service; USGS, U.S. Geological Survey; no., number]

		Confusion Matrix							
		Grasslands	Oak	Pine-oak	Sweetgum	Pine-cedar	Total no. of mapped instances	Producer accuracy	Omission error
NPS-defined classifications	Grasslands	10	0	0	0	0	**10**	100%	0
	Oak	0	100	7	3	2	**112**	89%	0.11
	Pine-oak	0	6	16	2	3	**27**	59%	0.41
	Sweetgum	0	15	1	34	5	**55**	62%	0.38
	Pine-cedar	0	3	2	1	50	**56**	89%	0.11
	Total	**10**	**124**	**26**	**40**	**60**	**260**		
	Users accuracy	100%	81%	62%	85%	83%			
	Commission error	0	0.19	0.38	0.15	0.17			

Table 8.   Results from accuracy assessment of the landcover map of the Natchez Trace Parkway by U.S. Geological Survey scientists (also see table 5). The map was based upon a landcover classification provided by National Park Service (NPS) personnel. The results presented here were derived after the "white oak" class was retained as a separate class in the north and merged with the "oak" class in the south. The "confusion matrix" indicates the divergence between the field-site classification (aggregated according to table 4) and the USGS-produced map. The aggregated classes based on the field sites are provided in the first column, and the same classes as they were mapped by USGS scientists are provided in the first row. Entries along the matrix trace (in gray shading) indicate the number of correctly mapped field sites, while entries off the trace denote misclassifications (errors of commission and omission). Overall user and producer accuracy rates are provided; the combined accuracy rate is estimated to be 74 percent.

[NPS, National Park Service; USGS, U.S. Geological Survey; no., number]

		Confusion Matrix								
		Grasslands	Oak	Pine-oak	Sweetgum	Pine-cedar	White oak	Total no. of mapped instances	Producer accuracy	Omission error
NPS-defined classifications	Grasslands	10	0	0	0	0	0	**10**	100%	0
	Oak	0	51	7	1	0	5	**64**	80%	0.2
	Pine-oak	0	6	16	2	3	0	**27**	59%	0.41
	Sweetgum	0	15	1	34	5	0	**55**	62%	0.38
	Pine-cedar	0	3	2	1	50	0	**56**	89%	0.11
	White oak	0	13	0	2	2	31	**48**	65%	0.35
	Total	**10**	**88**	**26**	**40**	**60**	**36**	**260**		
	User accuracy	100%	58%	62%	85%	83%	86%			
	Commission error	0	0.42	0.38	0.15	0.17	0.14			

The inadequate number of field-site observations (Van Genderen and Lock, 1977; Foody, 2002) resulted in two less than desirable outcomes. First, in the case of some NVC classes, the lack of an adequate number of field sites led to their elimination from the accuracy assessment (for example, swamp and pine-sweetgum) or to their being combined into one of the larger classes (for example, cedar with pine). Second, the field-site observations were used to both guide the mapping and produce accuracy assessments. The desired procedure would allow a set of field-site observations for mapping assessment and another independent set for accuracy assessment, but the number of field-site observations barely reached the minimum required for mapping assessment in the case of one alliance. Consequently, the ability to identify a separate set of field-site observations for accuracy assessment was not possible. However, the drawback of using the field-site observations for mapping and assessment may have been minimized by the logistics of the field classification site selections and the image processing employed.

According to Verbyla and Hammond (1995) and Hammond and Verbyla (1996), the problems using field-based classifications for both mapping and assessment is that typically field sites chosen for mapping are located in relatively homogeneous areas. If instead of homogeneous, the actual landscape was more of a heterogeneous mixture of vegetation types with variable canopy structure, the typical field sites would be inappropriate for accuracy assessment. In the field landcover classifications, the NPS classification teams did not consider extended spatial homogeneity of the landcover when choosing the field-site locations. This lack of association to homogeneous landscapes was highlighted by the limited spatial extents and the random selection of field sites used in the 2005 field trip but was also apparent in the 2004 field-site selections. The spatial heterogeneity of the Parkway was noted in the 2004 field reconnaissance. Consequently, the lack of consideration of field-site homogeneity and the spatial heterogeneity of the Parkway may have somewhat alleviated the problems in using the field-based classifications for both mapping and assessment.

In the Parkway mapping the lack of an adequate number of field-site observations and the spectral complexity of the Parkway prevented creation of spectral signatures corresponding to field-based landcover classes. The spectral signatures were created during unsupervised classifications and these migrated from one region of the Parkway to the next. Finally, in spatially heterogeneous landscapes, spatial aggregation into polygons can lower classification accuracy estimates (Verbyla and Hammond, 1995). Decreased accuracy results when polygons are created by incorporating similar classes and dissimilar classes of relatively small size in order to decrease the spatial complexity of the final mapping classification. The smaller polygons may have correctly identified a different landcover, but this landcover feature was eliminated when it was aggregated into a larger polygon representing a different landcover class (Fassnacht and others, 2006). This type of bias can lower accuracy estimates by

greater than 50 percent (Verbyla and Hammond, 1995). Post-processing to eliminate small, discrete class occurrences in order to create a more spatially continuous map classification may have inadvertently and unaccountably altered the actual class heterogeneity in some locations.

To provide an overall estimate of mapping performance, the same set of field-site observations were used in the mapping and in the accuracy assessments. Where multiple field sites were classified with a single landcover class, correspondences of 65 to 85 percent between the field-based classification and the map classification were considered fully successful (base-goal standard, Schwind and others, 2004).

Results and Discussion

Initial Image Mapping Classification

Each of the 100 clusters generated during the initial unsupervised cluster procedure was assigned a class value based on its spatial association with a spectral feature in the original nonspatially averaged CIR photography. On average, at the end of assigning each of the 100 original clusters, about 11 or 12 spectrally distinct CIR hues, intensities, and saturation features were identified and associated (examples shown in fig. 9*A* and figs. 18*C* and *D*) with the initial landcover classes received in 2004 from NPS (table 3).

Even though spectrally distinct, not all designated classes were distinctly associated with a single landscape feature. The most common cases of spectral confusion among obviously different landcover classes were between the "bright" forest and grassland classifications. In these cases, the classes were spectrally and at times texturally similar but visually distinguishable on the CIR photography. As discussed previously, application of texture filters alleviated some of this type of confusion and at times improved mapping accuracy.

Mapping classification confusion also existed between mature forests and tree plantations (fig. 10). These land covers are assigned separate alliances in the NVC. As with confusion between forest and grassland, texture information gained from filtering helped distinguish some plantations from forests; however, in most cases, texture was not a unique modifier. Primarily, plantations were manually classified throughout the Parkway.

General observations indicated broad groupings of photographic hue, intensity, and texture associated with different forests types. Darker CIR photographic features were often associated with pines (mostly loblolly, short- and long-leaf pines) and cedars. Younger pine stands with relatively open canopy showed a hummocky texture. Brighter CIR returns generally depicted hardwood forests, while bluish tones with some texture depicted cypress tupelo swamps and/or beaver-impounded sites with dead trees in very wet areas

or standing water. Even these broad groupings, however, were not consistent throughout the Parkway.

Undefined Landcover

In mapping the Parkway based on the NPS landcover classification, USGS scientists identified landscapes that were not spectrally aligned with any of the classes defined by NPS. As part of the migration of class means from section to section, a null class was retained for spectral outliers. The final mapping identified two landcover classes, one occurring throughout the Parkway and the other primarily occurring in the northern section of the Parkway that exhibited a unique spectral-textural pattern on the CIR photography. No field sites classified by NPS corresponded with these undefined landcover categories. Because of the close spatial association of one of the undefined classes and the sweetgum class, the undefined class was aggregated into the sweetgum class during the final mapping aggregations. A second undefined class did not spectrally align with any major NPS-defined class and was, therefore, retained as a class called "scattered trees" (fig. 20). Because NPS personnel were solely authorized

to designate NVC-based landcover classes, a separate GIS mask for the "undefined class" was included in final mapping products so that NPS personnel could locate and confirm this class designation during future field-site reconnaissance.

Kudzu Landcover

As discussed in the Methods section, there was only a single field site classified as kudzu by NPS personnel, and that site was hidden by shadows on the CIR photography. Responding to a request by NPS, USGS scientists performed manual detection and digitization of kudzu occurrences on the 2004 CIR DOQQs. The kudzu mapping included only the "ground-kudzu" vine that is described in Mapping Kudzu vine. The highest occurrences of kudzu were in the most southern sections of the Parkway that contained some of the most spatially extensive and relatively recently disturbed areas. Because of the lack of field observations and the application of manual mapping, the kudzu class was excluded from the mapping accuracy assessment. The kudzu distribution is contained as a polygon overlay in the final map products.
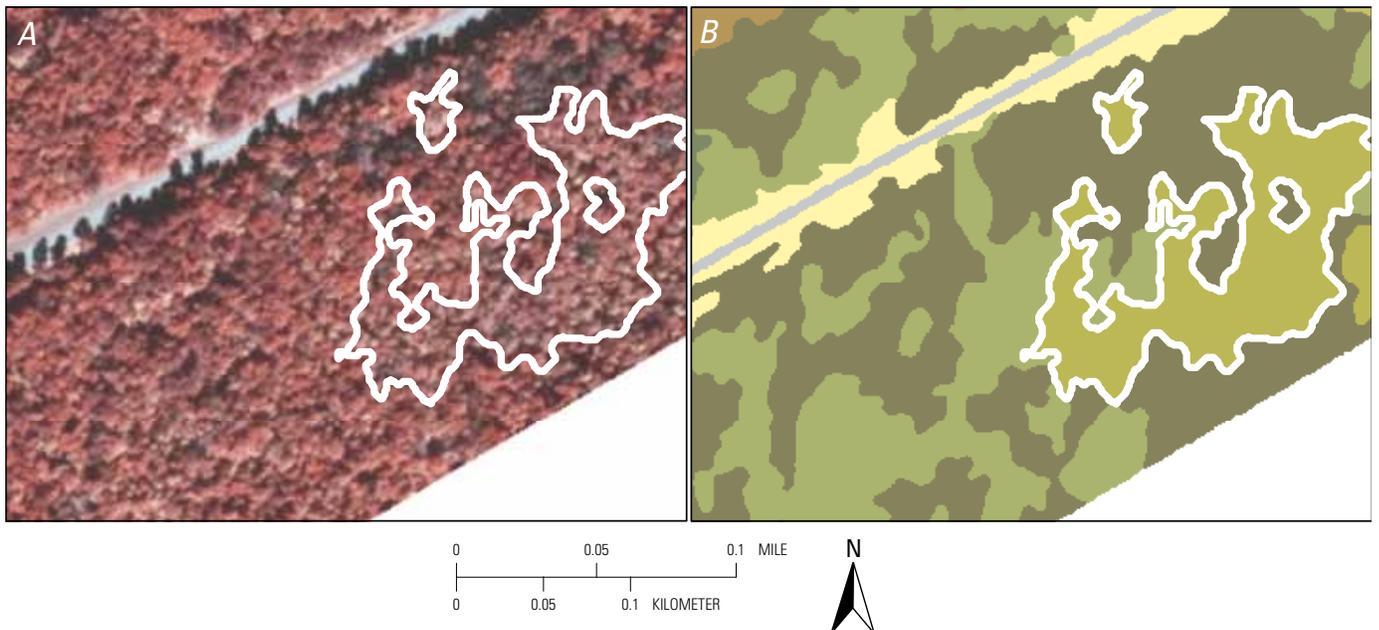
Figure 20. Example classification of the "scattered trees" class defined by U.S. Geological Survey scientists. *A,* Color-infrared digital orthophoto quarter quandrangle from an area of the "4 north" mosaic (see fig. 3). Indicated by the polygon (white) is a forest area with a distinct spectral and texture pattern. *B,* The polygon mapped as scattered trees because no field-site classification points were provided for this category of trees.

Plantation Landcover

Even though only four field sites were classified as plantation by NPS personnel, an attempt was made to map plantations based on the associated textural uniqueness observed on the CIR photography. Although many plantations exhibited unique textures, the textures differed from plantation to plantation. In addition, many of the texture patterns associated with relatively mature plantations were not as distinct as those exhibited by seemingly younger plantations. Even though visually observable on the CIR photography, most plantations were not consistently distinguishable (spectrally) from other forest classes with spectral-textural classifiers. In order to more thoroughly map pine plantations, manual mapping methods were employed. Because the mapping involved manual methods, the plantation class was not included in the accuracy assessments. The plantation classification was included as a class on the final map product.

Scrubland Landcover

As discussed in Mapping Kudzu vine, kudzu, an invasive shrubland, was manually mapped where visually identified. Chinese privet (*Ligustrum sinense*), a second invasive shrubland, was not mapped because even at the sole field site where this vegetation was classified by NPS personnel, it was not visually identifiable on the CIR photography; therefore, no spectral key could be created and tested. The four native shrubland alliances identified at eight field sites by NPS personnel (five sites were associated with one alliance) could not be mapped by using the progressive mapping technique. At five of the eight sites, spectral contrast surrounding the pertinent field sites that was visible on the CIR DOQQs was used to digitize spatial occurrence of the shrubland. At three of the shrubland field sites, the lack of spectral contrast did not allow determination of the the class extent; therefore, these sites were not classified as shrubland.

Addition of a USGS-defined Scrub-Shrub Class

Although no field site was classified as scrub-shrub by NPS personnel, USGS scientists created this class to describe and map highly disturbed areas containing mixed vegetations of variable age. The high composition variability (for example, shrubs, grasses, bare ground) and disturbed state of these areas resulted in nearly total confusion of the scrub-shrub class with almost all other classes when using supervised or unsupervised mapping techniques. The scrub-shrub class was mapped manually as was done for the shrubland class discussed above. The USGS-defined scrub-shrub class and NVC shrubland class were not included in the accuracy assessment because they were manually mapped.

Swamp and Water Landcovers

Although swamps and water bodies should be distinguishable spectrally, the mix of canopy densities within the swamps along the Parkway prevented consistent mapping of the swamp class and particularly its distinction from the water classes. The lack of an adequate number of field-site observations hindered the suitable development of a spectral method that provided mapping separation of the swamp class. In order to provide consistent mapping of these classes, manual mapping was conducted. Although swamp and water classes are included on the produced map, these classes are not included in the map accuracy assessment.

"Irregular" Landcovers

A list of the noncorresponding forest classes pertaining to 15 alliances with a total of 30 field sites is presented in table 2. As discussed in Mapping "Irregular" classes, these atypical or "irregular" forest alliances were represented most of the time by only one or two field sites. In addition, the forest alliances comprising the irregular classes did not align with any of the major forest classes (for example, oaks, sweetgum, and pine) and for the most part did not contain species that were common to other alliances. The combination of their composition uniqueness and the lack of field-site observations prevented successful application of progressive mapping for these alliances. Where a spectral hue or texture could be identified at the NPS-defined field-site location of the irregular class, manual mapping was performed; however, at 22 locations, the lack of a visually distinct spatial pattern prevented manual mapping of the irregular classes. In those cases, these alliances were not mapped and are not included on the final map product. Whether mapped manually or not, the overlay polygon depicting the irregular classes locates all nongrouped forest alliances. Where possible, the location is associated with a polygon estimated by visual interpretation.

Field-Site Classification Data from NPS

Field-Site Distribution

The combined 2004 and 2005 classification data received by USGS scientists from NPS personnel included a catalogue of 346 field sites within the Parkway that were classified into 83 NVC associations and 61 alliances. After some necessary exclusions, 301 field sites comprising 49 alliances and 68 associations remained (table 4). USGS scientists excluded 30 field sites in the irregular classes, along with 12 corresponding alliances and 15 associations; also excluded were 7 field sites incorrectly located outside photographic coverage, 6 field sites

for which there were missing alliance and association codes, and 2 forest-classified field sites that were outside the forest range.

The 301 field sites normalized by mapping-section length (the number of NVC plots per kilometer) showed an uneven distribution from south to north along the Parkway (fig. 21). The southern portion of the Parkway was not as well represented by field sites as were the more northern sections. In addition, 43.5 percent of the total number of field sites was located nearer the roadway than the Parkway boundary, even when excluding the grass buffer that runs along the roadway (fig. 22). In essence, field sites were on average more numerous in the northern portion of the Parkway and more likely representative of the front edge of the forest stands.

Physiognomic Class Descriptions for the NPS Landcover Classification

The upland evergreen physiognomic class included two cedar and two pine associations dominated by various pine species, six pine-oak associations dominated by various pine and oak species combinations, and one pine-sweetgum association. The upland deciduous physiognomic class included 19 oak associations dominated by various oak species, 6 white oak associations, 2 sweetgum associations, and 5 sweetgum-oak associations. The wetland-forest physiognomic class included five swamp associations that were composed of various dominant species. The planted forest physiognomic class included one pine plantation association. The herbaceous physiognomic class included 16 associations (table 4). Within the herbaceous class, USGS scientists grouped seven associations into the grassland class and eight associations into the aquatic vegetation class.

Water-hyacinth associated in the herbaceous physiognomic class and two associations, namely kudzu and Chinese privet, in the shrubland physiognomic class, and one upland deciduous physiognomic class association (the tree-of-heaven [*Ailanthus altissima*]) were defined as invasive species by NPS personnel. At the request of NPS personnel, USGS scientists separated the invasive species as a separate class. The invasive class is retained as a separate overlay in the USGS products.
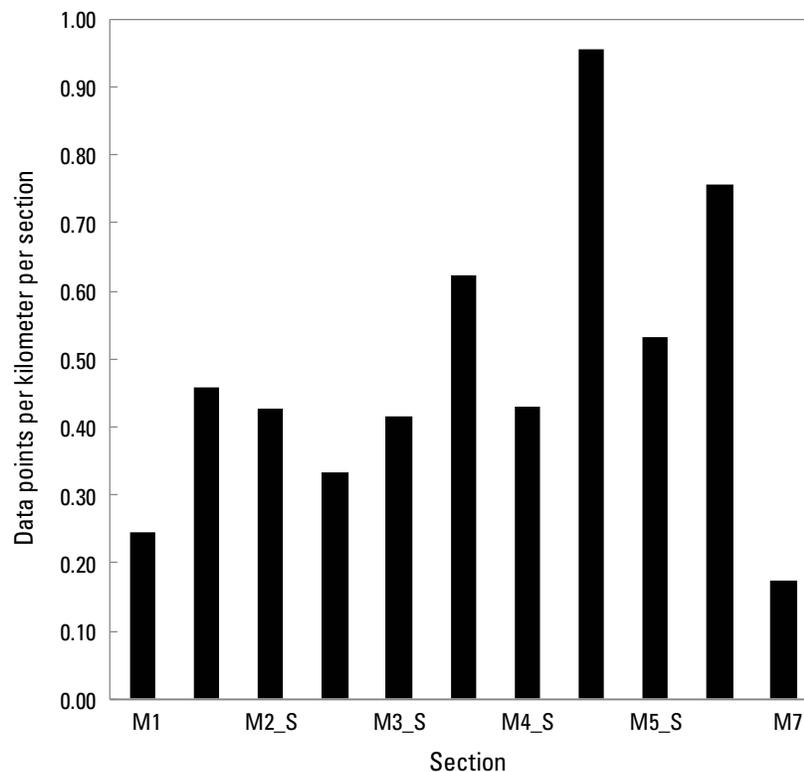
Figure 21. Distribution of field points (total of 331) for which data were provided by National Park Service personnel. The graph indicates that there were relatively more points per section as we moved from south (see mosaics 1 to 3 south) to north (see mosaic 4 north to mosaic 7). (See fig. 3 for locations of mosaic sections; in this figure mosaics are coded, for example, such that M2_S is the same as the "2 south" mosaic in fig. 3.)
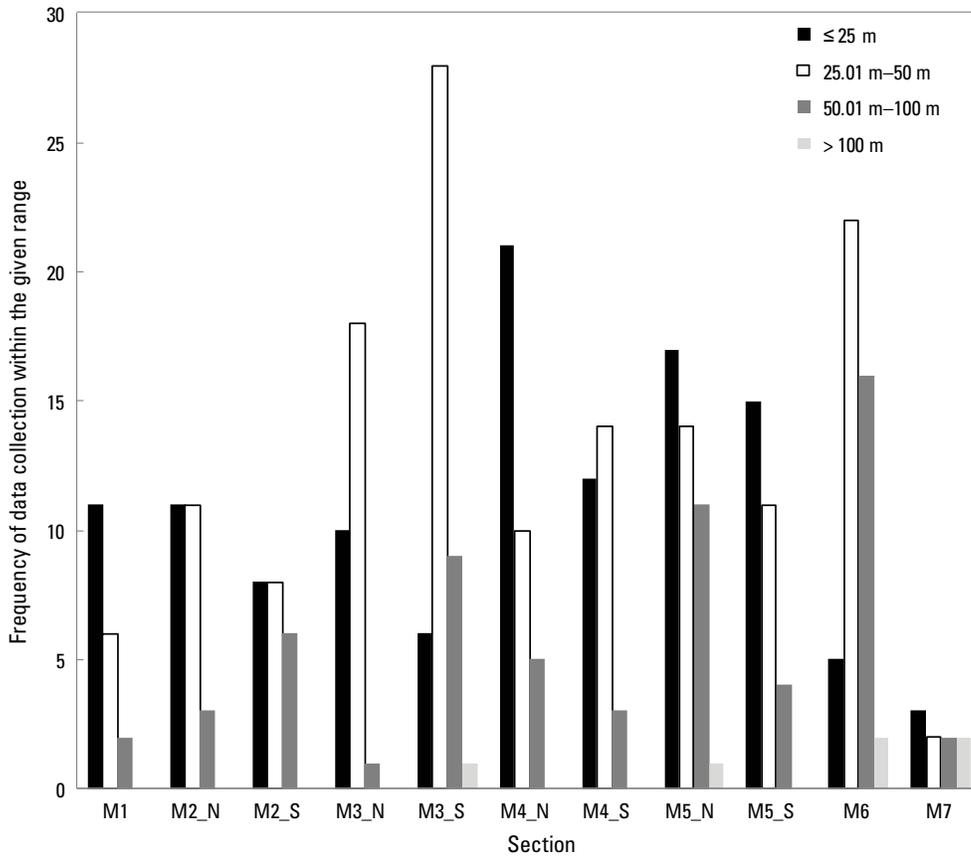
Figure 22.   Frequency of measurement ranges (in meters) indicating distance from the tree line to field sites where classification data were collected by National Park Service personnel. Most of the field sites were located at the front edge of forests within the range of 25 to 50 m. (Field-site locations are referenced to mosaic sections illustrated in fig. 3; in this figure mosaics are coded, for example, such that M2_S is the same as the "2 south" mosaic in fig. 3.)

Field Data for NPS Landcover Classification

A total of 301 field sites were visited for data collection, but only the Early- to Mid-Successional Loblolly Pine forest association was observed at more than 30 sites, while Southern Red Oak-White Oak-Mixed Oak and Successional Sweetgum Floodplain forest associations were observed at over 20 sites. Among other association classes, Dry Acid Eastern Coastal Plain Oak-Hickory forest was observed at 17 field sites; Successional Loblolly Pine-Oak forest was observed at 14 sites; Interior Dry-Mesic White Oak-Hickory forest was observed at 13 sites; and East Gulf Coastal Plain Oak-Sweetgum Small Stream Floodplain forest was observed at 12 sites. Of the remaining 61 association classes, only 16 were represented by 4 or more field sites.

Within alliance classes, the Pine forest alliance was observed at 59 field sites; the Oak (Red oak, Hickory) forest alliance was observed at 32 sites; the White Oak (Southern Red Oak) forest alliance was observed at 22 sites; the Sweetgum Floodplain forest alliance was as observed at 22 sites; and the Southern Red Oak forest alliance was observed at 20 sites. Only four additional forest alliances were observed at over 10 field sites (table 4).

Spectral Relationships Among NPS-Defined Alliance Classes

As discussed in the Final mapping classification, USGS scientists used a class-refinement strategy to include as many NPS-defined classes as possible in the mapping classification. A necessary restriction of class inclusion was that the spectral character of any given class be uniquely transferable throughout the Parkway. In other words, USGS scientists

attempted to select classes defined by a set of unique spectral features that could be fairly consistently migrated from any starting point out in either direction along the Parkway.

Numerous complexities existed that worked to reduce mapping performance; however, the lack of sufficient field-site observations per class at the association level was the most limiting factor. Where only a few field observations of associations existed and spectral-textural distinctiveness was lacking, the ability to map these classes throughout the Parkway could not be adequately tested. Another complexity was related to the limited 11.3-m radius field-observation used in the 2005 field plots. Where the landcover was spatially complex and changed relatively rapidly across small distances, the limited plot size increased difficulties associated with the lack of field samples. Mapping performance was also affected by the fact that aggregation of spectrally complex associations does not necessarily increase mapping performance; therefore, at each step in the progressive mapping, the aggregation of classes into a combined class had to be examined repeatedly in order to determine whether addition of certain classes into a large single class enhanced or degraded mapping performance. If the aggregation made sense and the mapping performance increased, the aggregation was accepted, but otherwise it was rejected.

Working within these constraints, extensive trial and error testing determined that eight aggregate classes was the maximum number that could be reliably mapped throughout the Parkway by using the progressive mapping strategy. The eight aggregated classes included (1) grasses (including weeds), (2) oaks, (3) white oak, (4) sweetgum, (5) sweetgum-oak, (6) pine-oak, (7) pine, and (8) cedar. As discussed in the Methods section, nine additional classes, including swamp forest, water, aquatic vegetation, plantation, invasive species, road and developed, and two unclassified landcovers—scrub-shrub and scattered trees—added by USGS scientists were manually mapped. Another category defined by USGS scientists termed "irregular classes" included forest alliances consisting of unique associations that could not be spectrally mapped. Within the irregular classes, only two associations were supported by more than one or two field observations. Even so, supervised classification was attempted with each irregular class, but none was successful; therefore, these manual classifications were not included in the calculation of mapping accuracy.

The combination of spectral migration of the means and progressive classification produced an organization of alliances that were highly internally consistent. The organization was not a function of mapper intervention; it was a result of the natural patterns or alignments of spectral variance and the focused definition of those spectral patterns. Even though availability of field-site data was severely limited, the spatial consistency generated by the migration of spectral means coupled with the progressive isolation of unique variances focused the highly mixed spectral variance cloud into related compositional groups. Those groups formed classes of NVC-defined alliances that were compositionally

similar within the dominant landcover species; that is, the oak class was dominated by oaks, the sweetgum class by sweetgums, the pine class by pines, and the pine-oak class by pines and oaks.

As discussed throughout this report, the simple fact that the classes were a composite of alliances that were themselves assigned to a composition of species challenged the success of any useful map production. Given the additional challenges posed by the spectral complexity of overlapping species and varying compositions within and among associations, along with numerous other complexities, the mapping strategy employed demonstrated a high performance level, as demonstrated by compositional similarity within classes.. One particular example highlights that high performance.

Even though alliances comprised a mixture of species and at times a mixture of associations, when the associations were compositionally similar, the mapping placed that alliance and its related associations in a single class (for example, the A.234 alliance comprised three associations; see table 4). In contrast, the three associations comprising the A.130 alliance were each placed in different classes with similar compositions, with the successional Loblolly Pine-Oak forest association in the Pine-Oak class, the early- to mid-successional Loblolly Pine forest association in the Pine class, and the mid- to late-successional Loblolly Pine-Sweetgum forest association in the Pine-Sweetgum class. Without mapper intervention, the mapping strategy produced a good representation of compositionally common classes. Inspection of these classes and their makeup may provide insight into the spectral and structural equivalences of these classes and the comprised alliances and associations.

The results of the mapping strategy revealed a number of classes that could not be consistently mapped even if aggregated. The plantation association at four sites, the four invasive-species associations (kudzu and Chinese Privet shrubland) at five sites, along with the Tree of Heaven (a forest alliance) and the Water hyacinth (an herbaceous alliance) classes, could not be consistently mapped with the progressive strategy. The four invasive-species alliances were manually mapped where they were visually detectable on the CIR photography. Similarly, the swamp class that included five associations with highly varying compositions was not amenable to automated mapping but could be mapped manually as a single aggregate class. Four native shrubland alliances identified at eight field sites by NPS personnel could not be mapped with automated processing but were manually classified. Although not identified by NPS personnel, a scrub-shrub class was manually mapped because of high variability in composition and canopy structure. Another class called "scattered trees" was introduced by USGS scientists to include all the single trees and forest areas that were spectrally distinct but not classified by NPS personnel. Also, upon the request of NPS personnel, six herbaceous aquatic alliances were manually mapped and aggregated as an aquatic vegetation class. Because of the lack of field observations and the

necessity to apply manual mapping to these classes, they were not included in the mapping accuracy assessments.

Correspondence of the USGS Landcover Map and the NPS Landcover Classification

Assessment of the mapping performance based on the eight aggregated classes and correspondence to the 301 NPS NVC field-site classifications determined 65 percent overall mapping classification accuracy (table 5). User accuracies per mapped forest class ranged from 100 percent to 48 percent. The lowest map accuracy of 48 percent was associated with the oak mix class. The next lowest user accuracies of 57 percent to 59 percent were associated with sweetgum-oak and pine-oak mix classes. Higher accuracies exhibited by single classes, such as sweetgum, white oak, pine, and cedar contrasted with the lower oak class accuracy. The oak mix class, however, contained 12 separate associations while sweetgum, pine, and cedar contained only two or three each. Although encompassing canopies dominated by oak species, the wide variety of included oak species resulted in the oak class resembling more mixed classes like pine-oak.

Producer-accuracy assessment results were not as high. Although the pine class had 95 percent and the oak class 76 percent producer accuracies, and the remaining classes had reasonable producer accuracies (54 percent), cedar and sweetgum-mix producer's accuracies were of concern. Sweetgum and cedar classes had producer accuracies of 30 percent and 29 percent, respectively. At the same time, the omission errors associated with these two classes were 70 percent and 71 percent. Over half of the time, sweetgum-mix was mistakenly mapped as primarily oak-mix and sweetgum-oak and cedar primarily as pine. Normally, user accuracies are used as the more appropriate evaluator of the map product usability. The very low producer accuracies associated with cedar and sweetgum classes, however, resulted in a decision to further aggregate the eight classes.

The sweetgum and sweetgum-oak classes were combined and the pine and cedar classes were combined (table 6). Combining these classes raised the overall mapping accuracy to 70 percent. The oak mix class had the lowest user accuracy at 48 percent and the pine-oak the next lowest at 62 percent. The remaining classes had user accuracies 83 percent and higher. All producer accuracies increased to acceptable levels with the white oak class having the lowest producer accuracy of 54 percent.

Further consolidation of the oak mix and white oak classes resulted in an overall mapping accuracy to 81 percent (table 7). User and producer accuracies of the five remaining classes, grasses, oak mix, pine-oak, sweetgum mix, and pine-cedar were reasonable at 59 percent or higher. The oak mix user and producer accuracies had increased to 81 percent and 89 percent, respectively. Combining the oak mix and white oak classes produced a reasonable mapping accuracy; however, the loss of the white oak class throughout the

Parkway eliminated the fairly high mapping performance related to these classes in the northern half of the Parkway.

Considering the white oak class as spectrally inseparable from the oak mix class in the southern half of the Parkway, the white oak and oak mix classes were combined into the oak mix class in the southern Parkway and considered as two separate classes in the northern Parkway. The separation is reasonable given the extensive south to north expanse of the Parkway. The enhanced mapping performance in the north versus the south with respect to these two oak classes may be related to the physical separation and increased expansiveness of the white oak class in the north or other unknown factors. In either case, the retainment of the white oak and mixed oak classes in the north and the combining of these oak classes in the south increased the useful landcover information available for resource management.

By using this reasoning to retain the white oak class in the northern Parkway, the overall mapping accuracy became 74 percent and resulted in user and producer accuracies above 58 percent (table 8). Even with the physical division, both sweetgum and white oak (limited to the northern Parkway) classes were most often mistakenly mapped as oak accounting for 27 percent of the total omission errors (38 percent and 35 percent, respectively) in these classes. On the other hand, oak exhibited a high commission error or lower user accuracy due to its mistaken replacement of pine-oak, sweetgum, and white oak. The only other substantial confusion was the oak mix class mapped as the pine-oak class. The spatial extensiveness of the oak class was too high and most of the mistaken expansion came at the expense of the pine-oak, sweetgum and white oak class occurrences. Conversely, the pine-oak expansion into the oak mix class offset the oak mix expansion into the pine-oak class.

Within the herbaceous landcover classes, the grassland class, comprising the nonaquatic and noninvasive major portion of the herbaceous physiognomic class, was mapped at 100 percent (tables 5 to 8). Even though the grassland class exhibited visibly different CIR hues throughout the Parkway, their spatial variation did not align with any defined NVC association. In contrast, the spectral distinctions seemed associated with grooming history or possibly soil water content.

Parkway Landscape Overview Based on the USGS Map

The spatial coverage of each mapped class was calculated for the Parkway including (1) the 100-m buffer and (2) solely within the Parkway boundary (table 9). Compared by spatial coverages, grasses, oaks, and pines (including the cedar class) made up the primary class covers, while sweetgums (including the sweetgum-oak class), pine-oaks, white oaks, and scrub-shrubs made up the secondary; plantations, water, developed areas, and canopy gaps made up the tertiary classes comprising the 100-m buffer of the Parkway. All other classes comprised minor portions of the Parkway buffer (fig. 23). The

Table 9. Total area of each class in the landcover map of the Natchez Trace Parkway produced by U.S. Geological Survey scientists.

	Landcover class	With 100-m buffer		Within park boundary	
		(km²)	%	(km²)	%
1	Grasslands	72.73	22%	41.15	22%
2	Road-developed	8.37	3%	6.03	3%
3	Scrub-shrub	16.84	5%	4.2	2%
4	Shrubland	0.0753	0.02%	0.0453	0.02%
5	Plantation	7.28	2%	1.29	1%
6	Water	3.06	1%	1.82	1%
7	White oak	14.21	4%	14.13	8%
8	Oak	80.3	24%	41.75	22%
9	Sweetgum	29.7	9%	17.9	10%
10	Pine-oak	32.91	10%	19.58	10%
11	Pine-cedar	61.69	19%	37.07	20%
12	Pine-sweetgum	0.76	0.23%	0.41	0.22%
13	Scattered trees	1.09	0.33%	0.593	0.32%
14	Swamp forest	0.921	0.28%	0.3608	0.19%
15	Irregular classes	0.06	0.02%	0.06	0.03%
16	Aquatic vegetation	0.121	0.04%	0.061	0.03%
17	Invasive species	0.21	0.06%	0.12	0.06%
18	Gaps	1.61	0.48%	0.84	0.45%
19	Clouds	0.17	0.05%	0.1	0.05%
	Total Area	332.11	100%	187.51	100%

landcover map of the Parkway (all mosaic sections as listed in fig. 3) is available on-line in PDF format on the Web page of USGS Open-File Report 2011-1276.

Forests dominate the Parkway, making up 66 percent of the landcover (table 9) and consisting of 24 percent oak (includes white oak in the southern sections), 19 percent pine-cedar, 10 percent pine-oak, 9 percent sweetgum, and 4 percent white oak (as mapped in mosaics 4 to 7; see fig. 3). Grass is the second largest Parkway cover at 22 percent (table 9). The USGS-defined scrub-shrub and the NVC-defined shrubland classes cover a sizeable portion (5 percent) of the Parkway. Pine plantations comprise 2 percent of the Parkway.

Oak classes, the dominant forests over the entire Parkway, also individually dominate the southern, middle, and northern sections (table 10) (refer to fig. 3 for spatial reference of the mosaic sections). Oak classes, including white oak, decrease somewhat from the southern to middle section and then increase dramatically in the northern-most section of the Parkway. Conversely, the pine-cedar class declines dramatically from the southern and middle sections to the northern-most section of the Parkway. Within these contrasting oak and pine-cedar cover trends, cover of the pine-oak class tended to progressively increase slightly from the southern to northern sections. Coverage of the USGS-defined scrub-shrub and NVC-defined shrubland classes decreased overall from the southern to northern sections, while the plantation occurrences dropped in the northern section.

EXPLANATION

- Grasslands
- Road-developed
- Scrub-shrub
- Shrubland
- Plantation
- Water
- White oak
- Oak
- Sweetgum
- Pine-oak
- Pine-cedar
- Pine-sweetgum
- Scattered trees
- Swamp forest
- Irregular classes
- Aquatic vegetation
- Invasive species
- Gaps
- Clouds
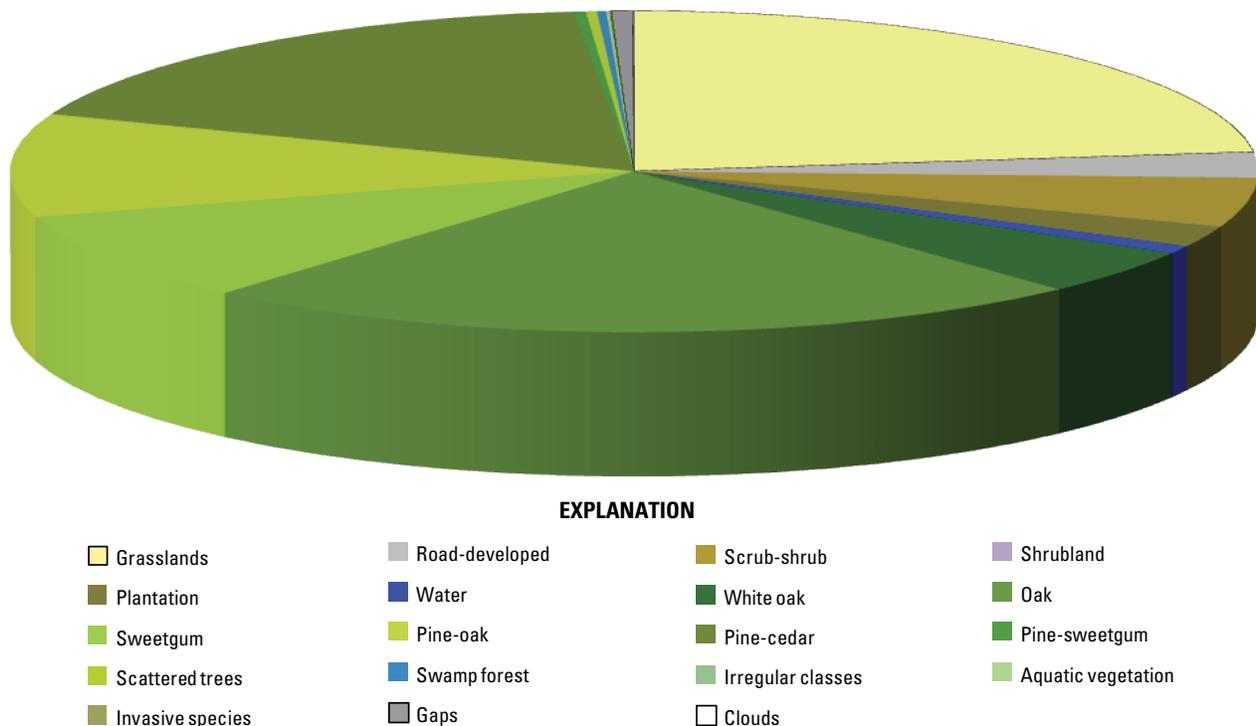
Figure 23. The graphic distribution of mapped classes within the Natchez Trace Parkway.

Table 10.   Landcover classes mapped for each of the southern, middle, and northern sections of the Natchez Trace Parkway by U.S. Geological Survey scientists.

[N, north; S, south]

	Landcover class	Southern (1–3N)	Middle (4S–4N)	Northern (5S–7)	Total
1	Grasslands	20%	27%	22%	22%
2	Road-Developed	2%	3%	2%	3%
3	Scrub Shrub	6%	5%	4%	5%
4	Shrubland	0.02%	0.01%	0.04%	0.02%
5	Plantation	3%	3%	1%	2%
6	Water	1%	1%	0%	1%
7	White Oak	0%	0.2%	14%	4%
8	Oak	26%	20%	24%	24%
9	Sweetgum	10%	11%	7%	9%
10	Pine-Oak	8%	10%	13%	10%
11	Pine-Cedar	23%	19%	11%	19%
12	Pine-Sweetgum	0.13%	0.82%	0.05%	0.23%
13	Scattered trees	0.40%	0.15%	0.32%	0.33%
14	Swamp Forest	0.44%	0.22%	0.04%	0.28%
15	Irregular Classes	0.00%	0.00%	0.06%	0.02%
16	Aquatic Vegetation	0.04%	0.08%	0.00%	0.04%
17	Invasive Species	0.05%	0.07%	0.08%	0.06%
18	Gaps	0.41%	0.89%	0.38%	0.48%
19	Clouds	0.10%	0.00%	0.00%	0.05%

Southern Section Map Description

As noted, the southern section exhibits the highest occurrences of oak and pine-cedars. Although representing much lower coverages, swamp forest occurrences are highest in the southern Parkway as well. Scrub-shrubs and shrubland occurrences are also highest in the southern section, exemplifying the higher and more recent disturbance observed in the most southern section of the Parkway. In contrast, grass and weed occurrences are lowest in the southern section.

Middle Section Map Description

From the southern to middle portions of the Parkway, grass and weed covers, including agricultural fields, increased to their highest cover proportions. The middle section is also the most developed portion of the Parkway (fig. 24 is an example from the section mosaic 4 south [see fig. 3]). With these increases in grass and weed covers, the overall forest cover declined. The forests in this section exhibited a higher proportion of canopy gaps, possibly suggesting more recent or more severe disturbance, and importantly, the smallest continuous forest stands (table 11). The sweetgum forest occurrence was highest in the middle section, and although a minor class, the pine-sweetgum class was observed and mapped only in this section. Again, although minor, the middle section contains the highest proportion of aquatic vegetation.

Northern Section Map Description

The northern section differed from the middle section in a number of ways and from the southern section in a few ways. The northern section was the most forested, with 69 percent compared to 67 percent forest cover in the southern section. As noted, the northern forested section contained the highest proportion of oaks when the oak and white oak classes were combined. It also contained the lowest proportion of pines and cedars. The northern section contained the only extensive stands of white oak. The increase in white oak contiguous extents may be the primary reason white oak could be separated from the oak mix class in the northern Parkway. The northern section exhibited slightly larger contiguous forest stands than those found in the southern forest. In addition, larger stands were more prevalent in the northern forests than in the southern forests (table 11). The northern section had the highest proportion of oaks, the largest and most numerous forest stands, and the fewest occurrences of scrub-shrub and shrubland covers and plantation occurrences.

Minimum Mapping Unit

The minimum mapping unit (MMU) defines the extent of the smallest spatial feature that can be consistently mapped as a discrete unit (for example, Fassnacht and others, 2006). The choice of an appropriate MMU is the subject of continuing and extensive research and discussion (for example, Fassnacht and others, 2006). As noted in the Introduction, the preferred and most appropriate MMUs in forested regions range from 25 to 900 m^2, most often dependent on the target forest species. In many cases, however, the MMU is chosen to match a selected need. For instance, the National Wetlands Inventory employs a MMU ranging from 1 to 3 acres (4,047 to 12,141 m^2) (National Oceanic & Atmospheric Administration Coastal Services Center, n.d)

Because of the high spatial resolution (1-m) of the base DOQQs, the MMU was not restricted to the base spatial resolution. In addition, the 1-m rendition was not desirable for mapping forest canopies of mixed species (with mixed crown shapes). The nature of the mapping, performed by combining various species with varying compositions, was
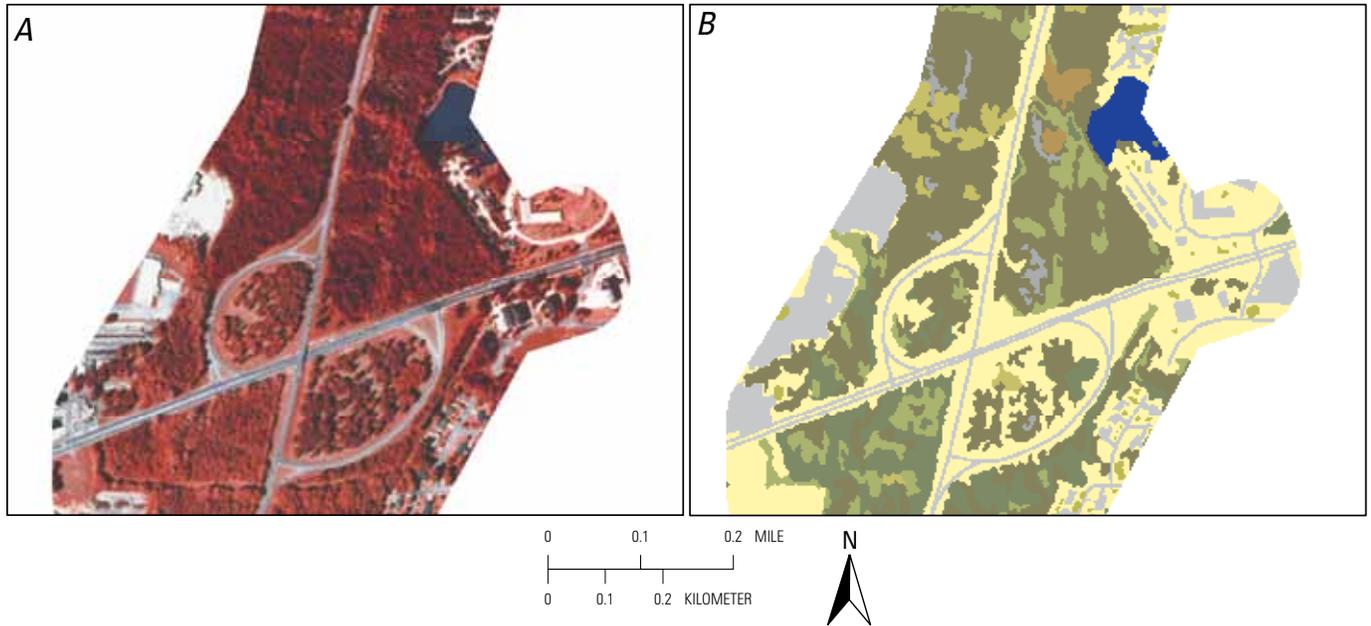
Figure 24.   Example of mapping landcover classification within an area of the Natchez Trace Parkway (the "Parkway"). *A*, Color-infrared digital orthophoto quarter quadrangle from the section 4 mosaic (see fig. 3). *B*, The final classes mapped by U.S. Geological Survey scientists based on the landcover classification of the Parkway by National Park Service personnel.

Table 11.   Size of the largest area of continuous forest stands within each mapped section (southern, middle, and northern) of the Natchez Trace Parkway, as mapped by U.S. Geological Survey scientists. See figure 3 for spatial location of mosaics.

[M, mosaic; N, north; S, south]

Section	Largest forest polygon (km²)	Section	Sum of the largest forest polygons (km²)
M1	2.56	Southern	9.41
M2_S	3.3		
M2_N	0.78		
M3_S	1.65		
M3_N	1.11		
M4_S	1.77	Middle	2.61
M4_N	0.84		
M5_S	1.4	Northern	9.59
M5_N	2.28		
M6	3.65		
M7	2.26		

not amenable to setting a fixed MMU before conducting the mapping. Our strategy was to use spatial filters to simulate the dimensions and orientation of the initial field-sites visited by NPS personnel and to dampen spectral variability due to uneven crown illumination. The postclassification aggregation of polygons was applied, in part, to accomplish more spatially contiguous mapped classes as desired by NPS personnel. The final map preparation minimized canopy gaps and shadows by dissolving these features into the surrounding forest and eliminated many smaller class polygons by again dissolving these into the surrounding larger contiguous class polygons. The accumulated effect of these premapping and postmapping procedures was not directly calculable. To provide an overall estimate of the MMU while avoiding classification artifacts, the smallest nondigitized forest polygon mapped consistently throughout Parkway was calculated. From this calculation, the forest MMU was defined as 300 m², and the grassland MMU was defined as 50 m².

Summary

Mapping challenges included limited availability of field observations, spatial and spectral complexity of the Parkway, and inherent composition variability contained in the NVC definitions. To accomplish high mapping performance with a limited set of calibration and verification data and inherently high spectral-texture variability, a mapping strategy was implemented based on the migration of class-related spectral-textural signatures and the congruent progressive refinement of the class signatures along the Parkway.

In order to maintain a consistent and quantifiable map product throughout the Parkway extent, mapping criteria were established. First, the spectral character of a selected class had to be uniquely transferable throughout the Parkway; that is, even though the class may have defined a compositional mixture, it should be recognized as the same class from one end of the Parkway to the other. Second, the map had to accurately portray the landcover types and distributions of the Parkway while maintaining a consistent conformity within created classes. Within the mapping process, the progressive aggregation of alliances into combined classes had to enhance mapping performance (or accuracy). If the aggregation was logical, was compositionally similar, and the mapping performance increased, the aggregation was accepted, but otherwise it was rejected. Along these same lines, alliance classes that lacked distinct spectral features and did not compositionally conform to any other alliance class were mapped manually (and termed "irregular" class). Third, the mapping procedure had to minimize bias and be reproducible and transferable. Excluding manual classifications, defined map classes were not to be based on interpretation but on quantifiable spectral processing.

Guided by the mapping criteria, the progressive classification strategy provided a method to evaluate the spectral-textural distinctiveness of the association classes and provided a consistent classification while incorporating dynamic spectral-textural patterns and the introduction of new classes along the 715-km Parkway. The combination of spectral migration of the means and progressive classification methods produced a map that conformed well to the Parkway landscape. Although some manual classifications were applied, they made up less than 8 percent of the mapped Parkway landcover. Even though important for NPS Parkway management, manual classifications were a minor contribution; the Parkway landcover map was an image-processing product based on methods and techniques only available within raster-based image processing (IP) and geographic information systems (GIS). By creating the map by using raster-based processing and limited mapper intervention, we produced an unbiased product rather than a subjective one. Furthermore, although the mapping strategy was complex, the processes applied are reproducible and are, therefore, transferable to other similar mapping projects or subsequent landcover classifications of the Parkway. Overall, the map-class composition indicated the existent spectral-textural patterns that defined and encompassed the complex variety of compositional alliances and associations of the Parkway. The map provides a good representation of the landcover patterns and their changes over the 715-km extent.

The implemented mapping strategy accommodated the limited field data and compositional class variability and produced a good landcover map of the Parkway. To provide some additional guidance for future mapping of similar landscapes with remote sensing and image processing techniques, we have added some summary insights gained in this and other similar mapping classifications. These summary insights are meant to provide information concerning issues that may arise in future mapping.

An additional factor influencing the mapping performance was the leaf-on timing of CIR photography acquisition. In most instances mapping during leaf-off conditions enhances the discernment between pines and broad-leaf forests; however the timing was selected by NPS personnel in order to conform to the NVC mapping criteria. If the Parkway mapping had been performed during leaf-off conditions discernment among the broad leaf forest species would have been severely diminished if not eliminated. Although USGS scientists were not able to separate alliances within the oak class, there was reasonable discernment among the oak, sweetgum, and pine-oak classes. This mapping classification provides a basis for continued separation of alliances contained within these aggregate classes.

Another issue was the spatial continuity of the mapped classification. One goal of the mapping classification was to produce as cohesive a map as possible while maintaining the highest class-cover detail as possible; however, some transitional artifacts remained in the final map product. Unless the mapping detail is at the tree level, these artifacts will always be present in natural environmental mapping. As pointed out in Verbyla and Hammond (1995) and stated previously in this report, in many cases these transitions and spatially smaller features actually exist; however, in interpretation of the aerial photography these features are not included. In image-based mapping, postprocessing can eliminate most of these features, as was done in this mapping. Other methods may use rules-based classifications that provide absolute limits of class inclusion, somewhat mimicking photointerpretation.

A final issue concerns consistency of field-site landcover classification. As pointed out by Congalton (1991) and Verbyla and Hammond (1995), no reference dataset is completely accurate. Errors or inconsistencies in the original classification directly change the mapping accuracy assessment. For instance, a 10 percent error in the landcover classification (or reference data) will result in a 10 percent error in the mapping accuracy assessment. A mapping classification that may have been 85 percent correct would be incorrectly reported as 75 percent correct given the 10 percent classification (or reference) error. As also stated in Congalton (1991), accuracy reference data should be considered in any mapping accuracy assessment.

Landscape Classification Protocols and Metadata

As mandated by the NPS, the landcover and landuse classification protocols followed the NVC (for example, Federal Geographic Data Committee, 1997; Ramsey and others, 2002). The NVC-based landcover classification of the Parkway was carried out by NPS personnel. Methods used to map the NPS classification to the Parkway area and interpret the accuracy of the classified map were developed in previous mapping projects conducted for the National Park Service and as described within this report (Ramsey and others, 2001a,b, 2002; Ramsey and Yan, 2006; Ramsey and Rangoonwala, 2007). Although map classes are composites of NVC-defined alliances and associations, each composite map class can be traced to the initial NVC-defined classes. Thus, the created map follows national protocols for landcover classification. Following Federal Geographic Data Committee geospatial guidelines (2010), a metadata record was created to capture the basic characteristics of pertinent data or information resources. The metadata record is available on-line on the Web page of USGS Open-File Report 2011-1276.

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Appendix 1. Color-infrared photograph centers.

Table. Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
1	027-001	-88	18	34	32	36	34.528556	-88.291944
2	027-002	-88	17	34	33	38	34.544417	-88.277750
3	027-003	-88	16	34	34	40	34.560194	-88.263389
4	027-004	-88	15	34	35	39	34.575528	-88.248472
5	027-005	-88	14	34	35	38	34.591417	-88.234306
6	027-006	-88	13	34	36	38	34.606944	-88.219472
7	028-001	-88	13	34	36	63	34.602750	-88.217889
8	028-002	-88	12	34	37	62	34.612028	-88.196778
9	028-003	-88	11	34	37	63	34.621250	-88.175639
10	028-004	-88	9	34	38	62	34.630528	-88.154667
11	028-005	-88	8	34	38	62	34.639750	-88.133556
12	028-006	-88	7	34	39	62	34.649028	-88.112500
13	028-007	-88	5	34	40	62	34.658556	-88.091611
14	029-001	-88	6	34	40	45	34.658444	-88.095611
15	029-002	-88	5	34	40	46	34.672333	-88.078694
16	029-003	-88	4	34	41	47	34.686167	-88.061556
17	029-004	-88	3	34	42	47	34.699750	-88.044250
18	029-005	-88	2	34	43	46	34.713556	-88.027250
19	018-001	-89	24	33	18	45	33.292528	-89.406722
20	018-002	-89	23	33	18	48	33.306111	-89.389722
21	018-003	-89	22	33	19	48	33.319444	-89.372333
22	018-004	-89	21	33	20	48	33.332722	-89.354944
23	018-005	-89	20	33	21	47	33.346306	-89.337833
24	018-006	-89	19	33	22	47	33.359583	-89.320472
25	018-007	-89	18	33	22	47	33.372972	-89.303278
26	018-008	-89	17	33	23	46	33.386528	-89.286139
27	018-009	-89	16	33	24	46	33.400194	-89.269139
28	019-001	-89	17	33	24	36	33.393667	-89.277472
29	019-002	-89	16	33	25	34	33.409778	-89.263889
30	019-003	-89	15	33	26	34	33.426194	-89.250778
31	019-004	-89	14	33	27	36	33.442250	-89.237083
32	019-005	-89	13	33	28	35	33.458389	-89.223500
33	019-006	-89	13	33	28	35	33.474667	-89.210139
34	019-007	-89	12	33	29	34	33.490944	-89.196861
35	019-008	-89	11	33	30	35	33.507222	-89.183583

Table.   Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
36	019-009	-89	10	33	31	36	33.523417	-89.170111
37	019-010	-89	9	33	32	35	33.539417	-89.156167
38	019-011	-89	9	33	33	36	33.555389	-89.142472
39	019-012	-89	8	33	34	34	33.571611	-89.129000
40	019-013	-89	7	33	35	34	33.587806	-89.115611
41	019-014	-89	6	33	36	34	33.604222	-89.102500
42	019-015	-89	5	33	37	36	33.620500	-89.089167
43	019-016	-89	5	33	38	34	33.636750	-89.075750
44	019-017	-89	4	33	39	35	33.653083	-89.062528
45	019-018	-89	3	33	40	35	33.669083	-89.048750
46	019-019	-89	2	33	41	36	33.685111	-89.035028
47	020-001	-89	3	33	41	17	33.679917	-89.047444
48	020-002	-89	2	33	42	20	33.698500	-89.039389
49	020-003	-89	2	33	43	20	33.717278	-89.032167
50	020-004	-89	1	33	44	17	33.736083	-89.024861
51	020-005	-89	1	33	45	17	33.754944	-89.018139
52	020-006	-89	1	33	46	17	33.773722	-89.010694
53	020-007	-89	0	33	48	14	33.792639	-89.004056
54	020-008	-88	60	33	49	19	33.811417	-88.996694
55	046-008	-86	58	36	2	193	36.041000	-86.971250
56	046-007	-86	59	36	1	193	36.021778	-86.976806
57	046-006	-86	59	36	0	196	36.002639	-86.982722
58	046-005	-86	59	35	59	193	35.983611	-86.988778
59	046-004	-86	60	35	58	194	35.964389	-86.994444
60	046-003	-87	0	35	57	194	35.945250	-87.000250
61	046-002	-87	0	35	56	195	35.926167	-87.006472
62	046-001	-87	1	35	54	194	35.907111	-87.012472
63	045-006	-87	0	35	55	209	35.917056	-87.007889
64	045-005	-87	1	35	54	207	35.899472	-87.019000
65	045-004	-87	2	35	53	209	35.882111	-87.030528
66	045-003	-87	3	35	52	209	35.864972	-87.042306
67	045-002	-87	3	35	51	208	35.847611	-87.053778
68	045-001	-87	4	35	50	208	35.830194	-87.065167
69	044-007	-87	3	35	50	252	35.839583	-87.050194
70	044-006	-87	4	35	50	257	35.834556	-87.073611
71	044-005	-87	6	35	50	256	35.829750	-87.097083
72	044-004	-87	7	35	49	255	35.824583	-87.120472
73	044-003	-87	9	35	49	255	35.819306	-87.143806
74	044-002	-87	10	35	49	255	35.814083	-87.167194
75	044-001	-87	11	35	49	255	35.808861	-87.190556
76	043-005	-87	11	35	49	200	35.818750	-87.179028
77	043-004	-87	11	35	48	200	35.800278	-87.187667
78	043-003	-87	12	35	47	198	35.781611	-87.195389
79	043-002	-87	12	35	46	198	35.762778	-87.202861

Table.   Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
80	043-001	-87	13	35	45	198	35.744111	-87.210472
81	042-006	-87	12	35	45	236	35.747556	-87.197472
82	042-005	-87	13	35	44	236	35.736556	-87.217667
83	042-004	-87	14	35	44	235	35.725306	-87.237444
84	042-003	-87	15	35	43	236	35.714167	-87.257444
85	042-002	-87	17	35	42	235	35.702972	-87.277361
86	042-001	-87	18	35	42	236	35.691722	-87.297250
87	041-004	-87	18	35	43	207	35.709417	-87.294250
88	041-003	-87	18	35	42	207	35.691833	-87.305306
89	041-002	-87	19	35	40	209	35.674639	-87.317139
90	041-001	-87	20	35	39	209	35.657361	-87.328722
91	040-003	-87	19	35	39	269	35.657944	-87.316583
92	040-002	-87	20	35	39	268	35.657500	-87.340806
93	040-001	-87	22	35	39	268	35.656722	-87.364944
94	039-007	-87	21	35	40	217	35.666222	-87.346917
95	039-006	-87	22	35	39	217	35.650472	-87.361528
96	039-005	-87	23	35	38	218	35.634833	-87.376167
97	039-004	-87	23	35	37	218	35.619167	-87.390972
98	039-003	-87	24	35	36	218	35.603639	-87.405778
99	039-002	-87	25	35	35	217	35.587917	-87.420472
100	039-001	-87	26	35	34	217	35.572278	-87.435056
101	038-008	-87	26	35	35	196	35.584167	-87.425167
102	038-007	-87	26	35	34	196	35.565222	-87.431583
103	038-006	-87	26	35	33	194	35.546139	-87.437861
104	038-005	-87	27	35	32	195	35.527111	-87.444028
105	038-004	-87	27	35	30	195	35.508028	-87.450389
106	038-003	-87	27	35	29	196	35.489056	-87.456778
107	038-002	-87	28	35	28	195	35.470028	-87.463167
108	038-001	-87	28	35	27	196	35.451000	-87.469500
109	037-004	-87	28	35	27	223	35.451222	-87.462750
110	037-003	-87	29	35	26	225	35.437167	-87.479667
111	037-002	-87	30	35	25	226	35.423278	-87.496806
112	037-001	-87	31	35	25	226	35.409500	-87.514000
113	036-011	-87	31	35	25	210	35.417056	-87.513194
114	036-010	-87	32	35	24	209	35.399861	-87.525028
115	036-009	-87	32	35	23	211	35.382694	-87.536944
116	036-008	-87	33	35	22	212	35.365917	-87.549528
117	036-007	-87	34	35	21	211	35.349111	-87.562194
118	036-006	-87	34	35	20	209	35.331861	-87.573917
119	036-005	-87	35	35	19	210	35.314611	-87.585583
120	036-004	-87	36	35	18	211	35.297667	-87.597861
121	036-003	-87	37	35	17	210	35.280500	-87.609833
122	036-002	-87	37	35	16	210	35.263361	-87.621722
123	036-001	-87	38	35	15	210	35.246250	-87.633583

Table. Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
124	036-001	-87	38	35	15	210	35.246250	-87.633583
125	035-004	-87	38	35	15	260	35.251389	-87.629222
126	035-003	-87	39	35	15	259	35.247778	-87.652861
127	035-002	-87	41	35	15	262	35.244556	-87.676583
128	035-001	-87	42	35	14	260	35.241444	-87.700389
129	034-012	-87	42	35	15	206	35.244000	-87.696333
130	034-011	-87	42	35	14	205	35.226139	-87.706500
131	034-010	-87	43	35	12	206	35.208306	-87.716778
132	034-009	-87	44	35	11	207	35.190639	-87.727611
133	034-008	-87	44	35	10	205	35.172944	-87.738194
134	034-007	-87	45	35	9	205	35.155083	-87.748278
135	034-006	-87	45	35	8	205	35.137139	-87.758278
136	034-005	-87	46	35	7	206	35.119250	-87.768306
137	034-004	-87	47	35	6	206	35.101583	-87.779278
138	034-003	-87	47	35	5	205	35.083833	-87.789694
139	034-002	-87	48	35	4	205	35.066056	-87.799972
140	034-001	-87	49	35	3	206	35.048194	-87.810278
141	034-001	-87	49	35	3	206	35.048194	-87.810278
142	033-006	-87	49	35	3	185	35.054556	-87.815056
143	033-005	-87	49	35	2	183	35.034889	-87.816528
144	033-004	-87	49	35	1	184	35.015222	-87.818306
145	033-003	-87	49	34	60	185	34.995556	-87.820333
146	033-002	-87	49	34	59	183	34.975833	-87.822028
147	033-001	-87	49	34	57	183	34.956167	-87.823139
148	032-010	-87	49	34	58	215	34.964472	-87.813750
149	032-009	-87	50	34	57	217	34.948694	-87.828167
150	032-008	-87	51	34	56	216	34.932833	-87.842472
151	032-007	-87	51	34	55	218	34.917194	-87.857083
152	032-006	-87	52	34	54	217	34.901528	-87.871556
153	032-005	-87	53	34	53	217	34.885667	-87.885944
154	032-004	-87	54	34	52	217	34.870028	-87.900500
155	032-003	-87	55	34	51	217	34.854333	-87.914972
156	032-002	-87	56	34	50	218	34.838611	-87.929500
157	032-001	-87	57	34	49	218	34.823056	-87.944194
158	031-005	-87	56	34	51	216	34.843889	-87.938694
159	031-004	-87	57	34	50	217	34.828083	-87.953167
160	031-003	-87	58	34	49	216	34.812139	-87.967278
161	031-002	-87	59	34	48	217	34.796306	-87.981500
162	031-001	-87	60	34	47	216	34.780500	-87.995694
163	030-005	-87	60	34	47	206	34.786028	-87.998694
164	030-004	-88	1	34	46	206	34.768306	-88.009111
165	030-003	-88	1	34	45	206	34.750472	-88.019500
166	030-002	-88	2	34	44	205	34.732667	-88.029583
167	030-001	-88	2	34	43	205	34.714667	-88.039556

Table.   Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
168	047-001	-90	51	32	23	179	32.383472	-90.850833
169	047-002	-90	51	32	22	181	32.363722	-90.851000
170	047-003	-90	51	32	21	180	32.343972	-90.851167
171	047-004	-90	51	32	19	180	32.324250	-90.851028
172	048-005	-90	53	32	18	359	32.307250	-90.882250
173	048-004	-90	53	32	20	360	32.327000	-90.882361
174	048-003	-90	53	32	21	360	32.346750	-90.882194
175	048-002	-90	53	32	22	360	32.366444	-90.881944
176	048-001	-90	53	32	23	360	32.386167	-90.881833
177	021-001	-88	59	33	48	25	33.806417	-88.990750
178	021-002	-88	59	33	49	23	33.824528	-88.981250
179	021-003	-88	58	33	51	24	33.842528	-88.971861
180	021-004	-88	58	33	52	23	33.860667	-88.962472
181	021-005	-88	57	33	53	25	33.878667	-88.952778
182	021-006	-88	57	33	54	24	33.896722	-88.943111
183	021-007	-88	56	33	55	24	33.914694	-88.933500
184	021-008	-88	55	33	56	24	33.932639	-88.923639
185	022-001	-88	56	33	56	19	33.932694	-88.934139
186	022-002	-88	56	33	57	20	33.951222	-88.926000
187	022-003	-88	55	33	58	20	33.969694	-88.917750
188	022-004	-88	55	33	59	21	33.988139	-88.909194
189	022-005	-88	54	34	0	19	34.006667	-88.901167
190	022-006	-88	54	34	2	20	34.025278	-88.893250
191	022-007	-88	53	34	3	20	34.043944	-88.885361
192	022-008	-88	53	34	4	20	34.062444	-88.877333
193	022-009	-88	52	34	5	21	34.080972	-88.868917
194	022-010	-88	52	34	6	20	34.099444	-88.860694
195	022-011	-88	51	34	7	20	34.118028	-88.852694
196	023-001	-88	51	34	7	30	34.114944	-88.846639
197	023-002	-88	50	34	8	28	34.132306	-88.835194
198	023-003	-88	49	34	9	28	34.149722	-88.824167
199	023-004	-88	49	34	10	28	34.167222	-88.813194
200	023-005	-88	48	34	11	27	34.184722	-88.802222
201	023-006	-88	47	34	12	28	34.202250	-88.791222
202	023-007	-88	47	34	13	28	34.219722	-88.780083
203	023-008	-88	46	34	14	29	34.237028	-88.768722
204	023-009	-88	45	34	15	29	34.254333	-88.757361
205	023-010	-88	45	34	16	29	34.271611	-88.746000
206	023-011	-88	44	34	17	29	34.288944	-88.734500
207	023-012	-88	43	34	18	28	34.306333	-88.723333
208	023-013	-88	43	34	19	28	34.323750	-88.712194
209	023-014	-88	42	34	20	28	34.341167	-88.701083
210	024-001	-88	43	34	20	47	34.337444	-88.709278
211	024-002	-88	42	34	21	46	34.351056	-88.692056

Table. Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
212	024-003	-88	40	34	22	47	34.364639	-88.674778
213	024-004	-88	39	34	23	45	34.378500	-88.657778
214	024-005	-88	38	34	24	48	34.392111	-88.640556
215	024-006	-88	37	34	24	47	34.405472	-88.622917
216	024-007	-88	36	34	25	47	34.418944	-88.605583
217	024-008	-88	35	34	26	46	34.432722	-88.588528
218	025-001	-88	36	34	25	70	34.421833	-88.595306
219	025-002	-88	34	34	26	72	34.428056	-88.572667
220	025-003	-88	33	34	26	72	34.434083	-88.550056
221	025-004	-88	32	34	26	71	34.440250	-88.527444
222	025-005	-88	30	34	27	71	34.446611	-88.504889
223	025-006	-88	29	34	27	71	34.453028	-88.482333
224	025-007	-88	28	34	28	71	34.459333	-88.459806
225	025-008	-88	26	34	28	71	34.465722	-88.437250
226	025-009	-88	25	34	28	71	34.472056	-88.414667
227	025-010	-88	24	34	29	71	34.478361	-88.392083
228	026-001	-88	24	34	29	66	34.481750	-88.404694
229	026-002	-88	23	34	29	67	34.489806	-88.382944
230	026-003	-88	22	34	30	69	34.496917	-88.360667
231	026-004	-88	20	34	30	68	34.504167	-88.338500
232	026-005	-88	19	34	31	68	34.511556	-88.316333
233	026-006	-88	18	34	31	68	34.519028	-88.294222
234	026-007	-88	16	34	32	68	34.526361	-88.272167
235	001-001	-91	22	31	33	63	31.547278	-91.373250
236	001-002	-91	21	31	33	61	31.556667	-91.353000
237	001-003	-91	20	31	34	64	31.565556	-91.332444
238	001-004	-91	19	31	34	63	31.574361	-91.311806
239	001-005	-91	17	31	35	63	31.583361	-91.291278
240	001-006	-91	16	31	36	63	31.592333	-91.270667
241	001-007	-91	15	31	36	63	31.601250	-91.250111
242	002-008	-91	17	31	35	41	31.591333	-91.277917
243	002-009	-91	16	31	36	42	31.606167	-91.262722
244	002-010	-91	15	31	37	42	31.620833	-91.247194
245	002-011	-91	14	31	38	42	31.635500	-91.231778
246	002-012	-91	13	31	39	42	31.650083	-91.216306
247	002-013	-91	12	31	40	42	31.664778	-91.200917
248	002-014	-91	11	31	41	41	31.679639	-91.185667
249	002-015	-91	10	31	42	42	31.694417	-91.170417
250	002-015	-91	10	31	42	42	31.694417	-91.170417
251	003-001	-91	11	31	42	19	31.692389	-91.190611
252	003-002	-91	11	31	43	16	31.711222	-91.183611
253	003-003	-91	11	31	44	16	31.730222	-91.177222
254	003-004	-91	10	31	45	16	31.749111	-91.170778
255	003-005	-91	10	31	46	16	31.768083	-91.164417

Table.   Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
256	003-006	-91	9	31	47	16	31.787139	-91.158056
257	004-001	-91	9	31	46	50	31.767778	-91.154778
258	004-002	-91	8	31	47	50	31.780333	-91.137028
259	004-003	-91	7	31	48	49	31.793222	-91.119528
260	004-004	-91	6	31	48	50	31.806028	-91.101917
261	004-005	-91	5	31	49	51	31.818583	-91.084111
262	004-006	-91	4	31	50	50	31.831194	-91.066250
263	004-007	-91	3	31	51	51	31.843722	-91.048417
264	005-001	-91	3	31	50	32	31.840639	-91.058139
265	005-002	-91	3	31	51	35	31.857139	-91.045417
266	005-003	-91	2	31	52	36	31.873111	-91.031778
267	005-004	-91	1	31	53	35	31.889222	-91.018417
268	005-005	-91	0	31	54	34	31.905528	-91.005472
269	005-006	-90	60	31	55	34	31.922028	-90.992556
270	005-007	-90	59	31	56	35	31.938222	-90.979500
271	005-008	-90	58	31	57	35	31.954361	-90.966056
272	005-009	-90	57	31	58	35	31.970500	-90.952694
273	005-010	-90	56	31	59	35	31.986611	-90.939417
274	005-011	-90	56	32	0	35	32.002806	-90.926222
275	006-001	-90	56	31	59	69	31.989056	-90.925611
276	006-002	-90	54	31	60	68	31.996333	-90.904056
277	006-003	-90	53	32	0	69	32.003556	-90.882556
278	006-004	-90	52	32	1	69	32.010639	-90.861000
279	006-005	-90	50	32	1	69	32.017750	-90.839306
280	006-005	-90	50	32	1	69	32.017750	-90.839306
281	007-001	-90	51	32	1	42	32.021361	-90.853972
282	007-002	-90	50	32	2	40	32.036361	-90.839028
283	007-003	-90	49	32	3	40	32.051611	-90.824278
284	007-004	-90	49	32	4	41	32.066722	-90.809333
285	007-005	-90	48	32	5	41	32.081611	-90.794111
286	007-006	-90	47	32	6	42	32.096444	-90.778833
287	007-007	-90	46	32	7	41	32.111278	-90.763500
288	007-008	-90	45	32	8	41	32.126167	-90.748194
289	007-009	-90	44	32	8	41	32.141167	-90.733167
290	007-010	-90	43	32	9	41	32.156111	-90.718111
291	008-001	-90	43	32	9	59	32.147528	-90.718389
292	008-002	-90	42	32	9	61	32.157361	-90.698306
293	008-003	-90	41	32	10	59	32.167556	-90.678417
294	008-004	-90	39	32	11	60	32.177500	-90.658333
295	008-005	-90	38	32	11	60	32.187333	-90.638222
296	008-006	-90	37	32	12	60	32.197139	-90.618083
297	008-007	-90	36	32	12	59	32.207000	-90.597917
298	008-008	-90	35	32	13	58	32.217389	-90.578222
299	008-009	-90	34	32	14	58	32.228000	-90.558556

Table. Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
300	008-010	-90	32	32	14	60	32.238111	-90.538611
301	008-011	-90	31	32	15	60	32.247972	-90.518528
302	008-012	-90	30	32	15	60	32.257861	-90.498417
303	008-013	-90	29	32	16	60	32.267722	-90.478361
304	008-014	-90	28	32	17	59	32.277806	-90.458417
305	008-015	-90	26	32	17	59	32.288083	-90.438500
306	008-016	-90	25	32	18	59	32.298278	-90.418639
307	009-001	-90	25	32	17	44	32.284972	-90.413333
308	009-002	-90	24	32	18	44	32.299083	-90.397056
309	009-003	-90	23	32	19	44	32.313333	-90.380972
310	009-004	-90	22	32	20	44	32.327556	-90.364889
311	009-005	-90	21	32	20	46	32.341500	-90.348361
312	009-006	-90	20	32	21	45	32.355361	-90.331806
313	010-001	-90	20	32	21	57	32.349083	-90.331694
314	010-002	-90	19	32	22	57	32.359889	-90.312222
315	010-003	-90	18	32	22	57	32.370667	-90.292806
316	010-004	-90	16	32	23	57	32.381500	-90.273250
317	010-005	-90	15	32	24	57	32.392222	-90.253750
318	010-006	-90	14	32	24	57	32.402944	-90.234306
319	010-007	-90	13	32	25	57	32.413667	-90.214750
320	010-008	-90	12	32	25	57	32.424389	-90.195167
321	011-001	-90	12	32	26	90	32.426806	-90.196444
322	011-002	-90	10	32	26	91	32.426639	-90.173194
323	011-003	-90	9	32	26	90	32.426389	-90.149861
324	011-004	-90	8	32	26	90	32.426444	-90.126583
325	011-005	-90	6	32	26	90	32.426417	-90.103361
326	011-006	-90	5	32	26	91	32.426250	-90.080056
327	012-001	-90	5	32	26	44	32.431361	-90.090444
328	012-002	-90	4	32	27	48	32.445083	-90.073583
329	012-003	-90	3	32	28	46	32.458500	-90.056583
330	012-004	-90	2	32	28	46	32.472167	-90.039833
331	012-005	-90	1	32	29	46	32.485833	-90.022889
332	012-006	-90	0	32	30	47	32.499389	-90.006083
333	012-007	-89	59	32	31	48	32.512639	-89.988833
334	012-008	-89	58	32	32	47	32.525944	-89.971583
335	012-009	-89	57	32	32	47	32.539417	-89.954528
336	012-010	-89	56	32	33	46	32.553111	-89.937694
337	013-001	-89	56	32	33	50	32.542167	-89.934472
338	013-002	-89	55	32	33	49	32.555333	-89.917028
339	013-003	-89	54	32	34	51	32.567889	-89.899056
340	013-004	-89	53	32	35	51	32.580306	-89.880833
341	013-005	-89	52	32	36	51	32.592611	-89.862722
342	013-006	-89	51	32	36	51	32.605000	-89.844528
343	013-007	-89	50	32	37	52	32.617278	-89.826306

Table. Locations of photograph centers from the Natchez Trace Parkway landcover mapping project.—Continued

[no., number; long, longitude; dec, decimal; min, minute; lat, latitude; deg, degree]

No. of frames	Frame no.	Long dec	Long min	Lat dec	Lat min	Direction of flight	Long dec deg	Lat dec deg
344	013-008	-89	49	32	38	50	32.629917	-89.808361
345	013-009	-89	47	32	39	50	32.642750	-89.790556
346	013-010	-89	46	32	39	51	32.655250	-89.772611
347	013-011	-89	45	32	40	51	32.667667	-89.754472
348	013-012	-89	44	32	41	51	32.680083	-89.736333
349	013-013	-89	43	32	42	51	32.692417	-89.718111
350	014-001	-89	43	32	41	13	32.688556	-89.711611
351	014-002	-89	42	32	42	13	32.707833	-89.706361
352	014-003	-89	42	32	44	13	32.727056	-89.701222
353	014-004	-89	42	32	45	13	32.746333	-89.696056
354	014-005	-89	41	32	46	14	32.765472	-89.690417
355	014-006	-89	41	32	47	14	32.784583	-89.684694
356	014-007	-89	41	32	48	14	32.803750	-89.678944
357	014-008	-89	40	32	49	13	32.822972	-89.673556
358	014-009	-89	40	32	51	13	32.842167	-89.668278
359	014-010	-89	40	32	52	13	32.861389	-89.662944
360	015-001	-89	39	32	51	16	32.851833	-89.653639
361	015-002	-89	39	32	52	18	32.870694	-89.646472
362	015-003	-89	38	32	53	18	32.889417	-89.639139
363	015-004	-89	38	32	54	19	32.908194	-89.631722
364	015-005	-89	37	32	56	17	32.926889	-89.624556
365	015-006	-89	37	32	57	17	32.945778	-89.617722
366	015-007	-89	37	32	58	17	32.964694	-89.610889
367	015-008	-89	36	32	59	17	32.983583	-89.604111
368	015-009	-89	36	33	0	18	33.002389	-89.597139
369	015-010	-89	35	33	1	19	33.021111	-89.589639
370	015-011	-89	35	33	2	19	33.039806	-89.582222
371	016-001	-89	35	33	2	36	33.030861	-89.576139
372	016-002	-89	34	33	3	36	33.046722	-89.562028
373	016-003	-89	33	33	4	35	33.062917	-89.548639
374	016-004	-89	32	33	5	35	33.079167	-89.535389
375	016-005	-89	31	33	6	35	33.095333	-89.521944
376	016-006	-89	31	33	7	35	33.111528	-89.508444
377	016-007	-89	30	33	8	35	33.127639	-89.494944
378	016-008	-89	29	33	9	35	33.143778	-89.481417
379	016-009	-89	28	33	10	36	33.159806	-89.467833
380	016-010	-89	27	33	11	35	33.175889	-89.454278
381	017-001	-89	28	33	10	23	33.172333	-89.466222
382	017-002	-89	27	33	11	23	33.190417	-89.457056
383	017-003	-89	27	33	13	23	33.208556	-89.447806
384	017-004	-89	26	33	14	23	33.226722	-89.438528
385	017-005	-89	26	33	15	22	33.245028	-89.429694
386	017-006	-89	25	33	16	23	33.263333	-89.420806
387	017-007	-89	25	33	17	24	33.281361	-89.411472

Appendix 2.   Photography collection and processing.

Aerial Photography of the Natchez Trace Parkway

The color infrared (CIR) aerial data were collected during leaf-on conditions with no visible senescence onset, as was required by NPS personnel to accomplish their ground-based landcover classification following the NVC protocols. For the study, 386 photographic frames, including 9 frames over the Vicksburg National Military Park, were collected on September 29 and 30 and on October 6 and 15, 2004. The CIR photography contains three spectral bands, including a green band, a red band, and a near-infrared band.

For testing, aerial photography of selected sections of the Parkway was collected on September 9, 2004. This exercise was conducted so that acquisition of the best color CIR film rendition was assured. To find the best camera settings, the film was developed at different exposures, and several test products were made with different contrast levels until optimal contrast, tone, and color was achieved. These camera settings were then used as a template for subsequent aerial coverage and film development of the entire area.

Equipment and Logistics for Collecting Aerial Photographs

Cessna 206 # N4803U fitted with Leica RC-30 precision camera (calibrated in September 2004) was used to collect the CIR photographic data.

Kodak Aerochrome 1443 color infrared film was used for the aerial photography.

Aerial sorties were conducted on September 29 and 30 and on October 6 and 15, 2004.

The 386 photographic frames acquired have a 60 percent end lap and a 30 percent side lap (side overlap is only relevant to the Vicksburg National Military Park coverage).

A 1:24,000 photographic scale was selected to obtain a ground resolution of 1 m or better.

During postprocessing, two sets of aerial film rolls were generated, one original and one duplicate roll. (Details provided in the interim report of January 24, 2005)

Orthophoto Production

Preprocessing—Original Film Roll

To determine the best photographic results for brightness, saturation, and hue, a number of frames were developed by using different photographic processing settings. We then selected frames having the correct contrast, color, and tone for different land cover categories (for example, harvested agriculture fields, forested lands, and plantations). Another set of test film frames was developed by using our indicated contrast and brightness levels. Final calibrations for the film development were set after re-examining several sets of test frames.

Photographic frame centers were calculated and converted to an ESRI ArcInfo format. The coordinate system is spherical. A representation in a Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83) coordinate system was produced from the photographic frames with referenced spherical coordinates.

Postprocessing—Duplicate Film Roll

Test film frames were also first created for the duplicate film roll. The best results for contrast and hue were selected, and this constant contrast and hue adjustment was then applied for developing the entire duplicate roll. The option of individual dodging of the duplicate film frames was not available.

Digital Orthophoto Quarter Quadrangles

In addition to the required products listed in the contract agreement with NPS, digital orthophoto quarter quadrangles (DOQQs) were produced from the aerial photographic frames. In orthophotographic production, the effects of tilt and relief were removed from the aerial photos by a mathematical process called rectification. The transformation of the photographic frames to DOQQ representation provided uniform scale. Uniform scale allowed the direct measure of true distance and direction. The DOQQs are terrain-corrected images that are used as precision base maps.

The 235 DOQQs created from the 386 aerial frames were mosaiced to create full coverage of the Parkway graphic (fig. 3). Production of DOQQs provided enhanced registration of the mosaiced frames. This allowed exact

alignment of the linear features that transverse multiple frames (for example, roads).

The Parkway crosses two UTM zones. Heading north, UTM zone 15 is replaced by UTM zone 16 at Canton, Mississippi. The quads from Goshen Springs, Mississippi, onwards to Bellevue, Tennessee, are in zone 16. All frames were projected in the correct UTM zone.

Scanning of the Aerial Photographic Frames

Scanning of the duplicate film roll was done at 25 microns by using a true color, true optics scanner to generate a 1,000-dot per inch (dpi) product. Analytical triangulation was performed by using controls from existing DOQQs. Elevation data was used to rectify, mosaic, and tone balance the tiles. The tiles were cut to match DOQQs in the UTM projection zones (fig. 2).

The DOQQs generated are compliant with the digital orthophoto standard as defined by the USGS Rocky Mountain Mapping Center (2000). (http://rockyweb.cr.usgs.gov/nmpstds/doqstds.html).

Color Balancing

Manipulation of the intensity per color in a frame was accomplished by selective shading or masking to match appearance of the frames for mosaic. Effort was made to eliminate frame line appearances (the point at which one frame ends and another frame starts).

USGS