

**National Park Service
U.S. Department of the Interior**

**Intermountain Region
Sonoran Desert Network
Tucson, Arizona**



Applicable Remote Sensing and Cultural Resources Monitoring Research

May 2006



ON THE COVER

Unauthorized off-road vehicle track at Organ Pipe Cactus National Monument.
Photograph by Sam Drake, University of Arizona.

Applicable Remote Sensing and Cultural Resources Monitoring Research

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U.S. Department of the Interior
National Park Service
Intermountain Region
Denver, Colorado

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May 2006

As the nation's primary conservation agency, the Department of Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historic places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

May 2006

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Acronyms

ADAR	Airborne Data Acquisition and Registration
APT	Apache Pass Transect
ARSC	Arizona Remote Sensing Center
ART	Administrative Road Transect
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BLM	Bureau of Land Management
BST	Bear Springs Trail
CASI	Digital Compact Airborne Spectrographic Imager
CE90	Circular Error, 90%
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
GB	Gigabytes
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
ISODATA	Iterative Self-Organizing Data Analysis Technique
MSAVI	Modified Soil Adjusted Vegetation Index
NAD83	North American Datum 1983
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NED	National Elevation Dataset
NFS	National Forest Service
NHS	National Historic Site
NIR	Near Infrared
NPS	National Park Service
NWSE	Ft. Bowie Northwest to Southeast transect
PCA	Principal Components Analysis
PCT	Principal Components Transform
QB	Quickbird
RGB	Red, Green, Blue
RMSE	Root Mean Square Error
RPC	Rational Polynomial Coefficients
SAVI	Soil Adjusted Vegetation Index
SMA	Spectral Mixture Analysis
SE	Southeast

SWIR	Short-wave Infrared
TIFF	Tagged Image File Format
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

Abstract

Parks located along the U.S./Mexico border have experienced dramatic increases in illegal cross-border traffic in recent years, with traffic typically utilizing backcountry areas to avoid detection. Most of this traffic is on foot, though off-road driving is not uncommon. The result is a spiderweb of unofficial trails and roads replete with discarded water bottles, clothing, food, and other refuse.

One methodology that holds promise for quantifying and monitoring numerous impacts to park resources is the examination and analysis of data from high-spatial resolution satellite imagery. This imagery allows large areas to be surveyed with full coverage. Newly developed, commercially available satellite imagery offers < 1m ground pixel resolution, in geo-rectified formats that can be directly integrated with existing GIS information.

For this project we acquired multispectral, high-spatial resolution Quickbird imagery to assess border-related impacts at three parks: Chiricahua Nat. Mon., Ft. Bowie NHS and Palo Alto Battlefield NHS. We quantified the use of various image processing methods for extracting information about trails and trash sites. A literature review on remote detection of disturbed areas was conducted and suggestions for alternate image processing techniques are provided.

APPLICABLE REMOTE SENSING AND CULTURAL RESOURCES MONITORING RESEARCH

Introduction

Project Background and Rationale

Parks located along the U.S./Mexico border have experienced dramatic increases in illegal cross-border traffic in recent years, with traffic typically utilizing backcountry areas to avoid detection. Most of this traffic is on foot, though off-road driving is not uncommon. The result is a spiderweb of unofficial trails and roads replete with discarded water bottles, clothing, food, and other refuse.

Efforts to control illegal activities have focused largely on the apprehension of illegal migrants and illegal drug traffickers. However, documentation and monitoring of cultural resource impacts in these areas have received very little attention. With the exception of one year of monitoring data that has been collected at Organ Pipe Cactus National Monument, none of the border parks have been successful in systematically collecting quantitative resource information specific to migrant and drug traffic impacts. Quantitative resource data are critical for designing and evaluating park resource management and protection in border parks, and could serve as the foundation for continued specific threat-based monitoring of migrant impacts in border parks.

None of the 11 parks located in the states of Arizona and Texas along the Mexican border has specific staff dedicated to monitoring illegal border activity, and it is difficult at this point to envision a single ground-based monitoring program that can readily yield the same amount of quality information that has been generated in one year's effort at Organ Pipe. It is also important to realize that even at Organ Pipe, there is no current long-term fiscal support for continued threat-based monitoring of this sort, and other means of supporting this crucial effort will have to be investigated.

One methodology that holds promise for quantifying and monitoring numerous impacts to cultural resources (and perhaps to natural resources as well) is the examination and analysis of data from high-spatial resolution satellite imagery. This imagery allows large areas to be surveyed with full coverage. Commercially available satellites currently offer < 1m ground pixel resolution, in geo-rectified formats that can be directly integrated with existing GIS information. This tool has been applied to vegetation mapping and land use studies in southern Arizona, including a recent joint effort between the NPS Sonoran Desert Network and the Arizona Remote Sensing Center (ARSC) to map plant communities at Coronado National Memorial. Preliminary examination of IKONOS imagery from that study clearly shows numerous cross-border trails present in remote areas of that park. While existing studies suggest that satellite remote sensing may provide an accurate, cost-effective means of quantifying border impacts, protocols and methodologies for this specific application must be developed, and its efficacy for monitoring must be evaluated.

Working Hypotheses and Project Objectives

Project hypotheses were:

- 1) a percentage of the trails visible on the ground will also be visible in the imagery (in particular the larger trails and vehicle tracks);
- 2) this percentage can be ascertained for a park or a landscape type within a park, with appropriately-collected ground data;
- 3) image processing algorithms and vegetation indexes can help extract trail networks in certain areas;
- 4) the trail density estimate obtained from image analysis and extrapolation will be more accurate, useful and spatially meaningful than one obtained from ground-based line transect data;
- 5) clothing and trash piles will be spectrally distinct from surrounding image elements and their locations can be extracted through automated processes.

Project objectives were to:

- 1) task the Quickbird (QB) satellite to acquire swaths of imagery at Fort Bowie National Historic Site/Chiricahua National Monument and Palo Alto Battlefield National Historic Site;
- 2) geo-register and enhance the imagery for trail and trash detection, then hand-digitize the visible trail network on it;
- 3) compare the field data with the digitized trails to determine the relationship between trails present on the ground and those visible in the imagery;
- 4) test the ability of image processing methods to detect simulated trash piles;
- 5) test the ability of image processing methods to distinguish active trails from surrounding bare ground;
- 6) evaluate the usefulness of these relationships for estimating trail network density in an imagery-based monitoring program;
- 7) conduct a search of and review recent research on remote sensing techniques for border impacts;
- 8) review existing and future multispectral and hyperspectral sensors and their potential application for border impacts monitoring.

Study Areas

Based on extensive reconnaissance of border parks from Arizona to Texas by J. McGovern, and on interviews with park staff, three areas were chosen for focused study including satellite imaging: Fort Bowie National Historic Site, Chiricahua National Monument, and Palo Alto Battlefield National Historic Site.

Chiricahua Nat. Mon. and Ft. Bowie Nat. Hist. Site

The Chiricahua Mountains are located in Southeastern Arizona, trending north from the US/Mexico border at Douglas up to Apache Pass, which separates the Chiricahua Mountains from the Dos Cabezas Mountain range. A large portion of the range is administered by the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM). The range contains two National Park units: Chiricahua Nat. Mon. and Fort Bowie NHS (Figure 1).

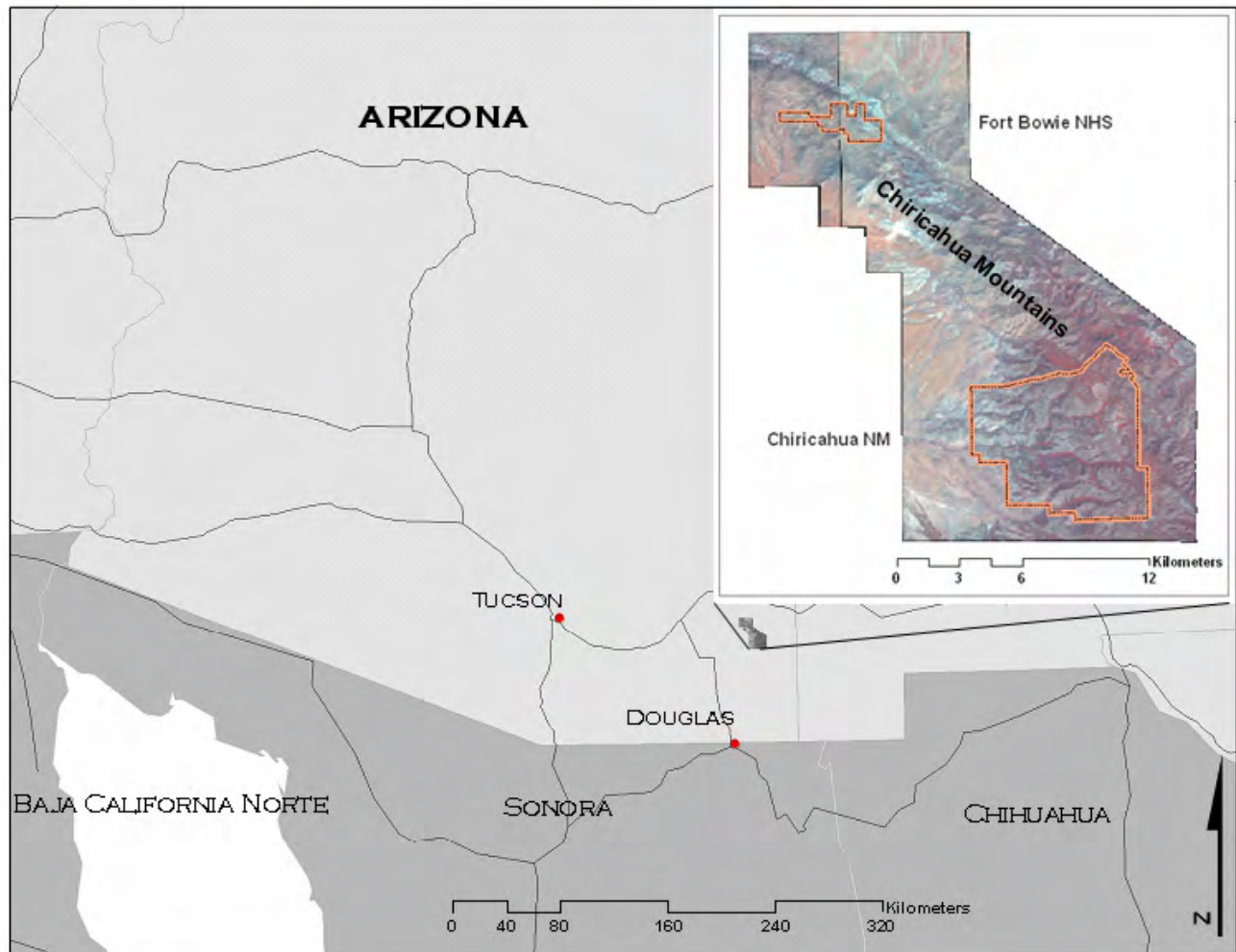


Figure 1. Location map and Quickbird imagery of Fort Bowie NHS and Chiricahua Nat. Mon.

Fort Bowie National Historic Site is a small park unit commemorating a history of conflict between the Chiricahua Apaches and United States military. Apache Spring attracted many different cultures throughout the ages, and served as a crossroads for emigrants, miners, soldiers and surveyors during the Euro-American settlement era. Fort Bowie was established to assist and protect Anglo settlers and their interests from the Chiricahua Apaches. Fighting between the U.S. military and the Apaches lasted for 25 years (1861-1886) and the fort was abandoned in 1894 (Warren et al. 1992).

The site consists of 1,000 acres centered on Apache Pass, which connects the Sulphur Springs Valley in the southwest to the San Simon Valley in the northeast. The historic site houses several ruins of the old military fort and several historic trails. The fort was formerly controlled by BLM, but was designated a National Historic Site in 1964.

Elevations at Fort Bowie range from 1,400 to 1,600 meters. The vegetation consists of a mixture of Chihuahuan desert, Madrean evergreen woodlands and semidesert grassland. Vegetation surveys found a total of 471 species and subspecies representing 75 families of vascular plants, a

number much higher than expected given the small area and site conditions (Warren et al. 1992). Researchers speculate that the high plant diversity at the site is related to existing riparian areas and the variety of geologic substrates: limestone, granitic and metamorphic rock (Warren et al. 1992). Three uncommon native species with limited range were detected in the area, and twenty-four introduced species.

Chiricahua National Monument, located ~15 km south of Fort Bowie, is renowned for its unusual formations of eroded rhyolitic tuff. The monument occupies ~5,260 hectares, with 4,165 designated as wilderness. Elevations range from 1,575 to 2,385 meters. The monument contains a variety of vegetation: approximately 680 species (30 tree species, 92 shrub and 317 herbaceous perennials) (Kunzmann et al. 1996). The monument is bounded by BLM land to the east and north, National Forest land to the south, and private ranch land to the west.

Palo Alto Battlefield NHS

Located near the southernmost tip of Texas, Palo Alto Battlefield NHS was established in 1992 to preserve the site of the opening battle of the two-year war between Mexico and the United States (Figure 2). The National Historic Site is comprised of 1,375 hectares. Vegetation communities include: Tamaulipan Brush, Mesquital Forest, Huisachal, *Borrchia frutescens* Prairie, *Spartina spartinae* Prairie, *Texal colubrine* Prairie, *Sonchus asper* Prairie, and Mesquital Prairie.

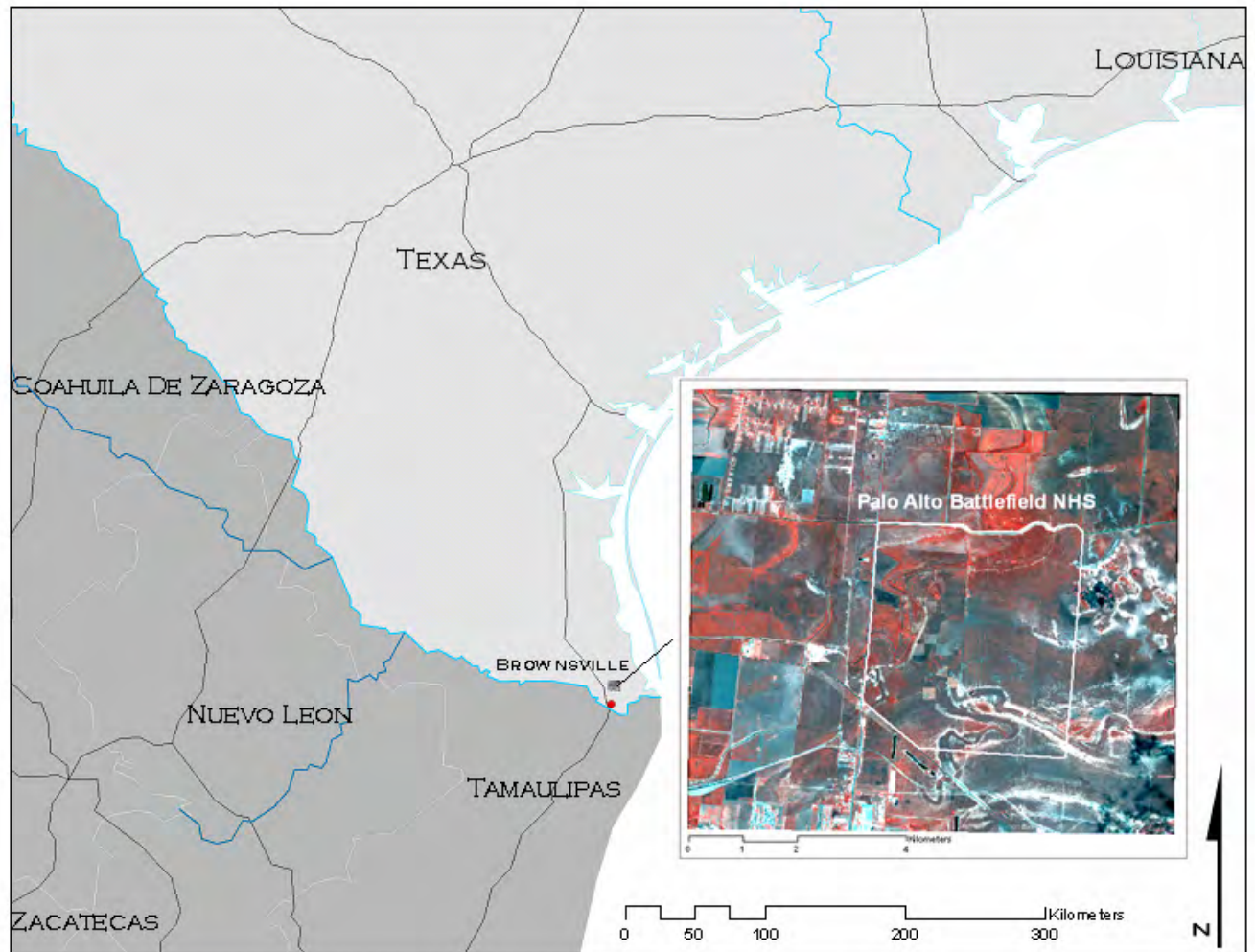


Figure 2. Location map and Quickbird image of Palo Alto Battlefield Nat. Hist. Site.

Park Imagery Acquisition

Imagery orders were planned for the early spring to maximize the ability to detect roads and trails against a vegetated background, before the senescence of grasses and forbs. Specifications for the image acquisitions were decided, and ArcView shapefiles were created to define the image areas. Orders were transmitted to DigitalGlobe, Inc. through Global Systems Modeling, LLC in January for image acquisition windows in April.

Imagery was acquired as scheduled, from April 1-April 20, 2005, and delivered in May. Initial inspection showed that the experimental garbage targets were somewhat visible, and all 5 of the pre-set fabric ground control points were visible. These ground control points were placed in areas of the Chiricahua-Ft. Bowie imagery lacking road intersections or other distinctive features. The Palo Alto Battlefield imagery contains a sufficient number and distribution of distinctive features that can serve as ground control points, and no additional GCPs or experimental targets were placed there. J. McGovern made two trips to the Palo Alto Battlefield

area to collect GPS coordinates for a set of control points, and to record any border-related impacts visible on the ground.

Field Methods

Field methods: Chiricahua Nat. Mon. and Ft. Bowie NHS

In February and March, before image acquisition, consultations were held with staff at Ft. Bowie and Chiricahua to plan and get permits for setting out experimental targets and ground control points. The experimental targets of interest were accumulations of garbage typically left by immigrants. While substantial amounts of such waste normally exist at certain places in and around Ft. Bowie NHS, staff had recently performed a thorough cleanup and no *in situ* targets were available. Redistribution of some of the collected garbage was rejected as an option due to concerns about sanitation in handling the material. Instead, a suitable number of empty plastic bottles were collected from personal household recycling, and about 3 cubic meters of unsalable donated clothing was obtained from thrift stores at almost no cost. With the assistance of Ft. Bowie-Chiricahua staff in arranging landowner permission and gate keys for necessary access, and using an NPS pickup truck, the simulated garbage was transported from Tucson and set out at a selected site near Chiricahua Nat. Mon. Targets were arranged against both a bare-soil background and a vegetated background (Figures 3 and 4).



Figure 3. Trash target located near Chiricahua Nat. Mon.



Figure 4. Water bottle target located near Chiricahua Nat. Mon.

For ground control points to be used in geo-registering the imagery, inexpensive cotton muslin fabric was purchased from a fabric store: 100 yards x 42 inches of white and about 20 yards x 42 inches of black (remnant). Grommets and large nails for securing the fabric in the field were purchased from a hardware store. One black and four white L-shaped targets were placed in portions of the proposed imagery lacking other features that might be used as ground control points, such as road intersections (Figures 5-8). GPS locations of the control points were recorded.

All but one of the fabric GCPs were used to geo-register the images; fabric targets proved more accurate when compared to GCP locations of road intersections and buildings. Fabric GCPs were especially helpful in wilderness areas with few, if any, hard-edged or high contrast features to use as GCPs. The fabric GCPs stood out well against the landscape (Figure 6). One GCP was disturbed by wind or animals prior to image acquisition, and was not used for geo-rectification (Figure 7). The black fabric target was placed in a light-colored sandy wash for contrast, but the fabric was still more reflective than the sandy soil and so appears *lighter* than the surrounding sand in the Quickbird panchromatic image (Figure 8). From our experience using these fabric targets for registration, we recommend the use of white targets, and suggest timing their placement in the field as close to the image acquisition window as possible to reduce the chance of disturbance.



Figure 5. Examples of white GCP targets on the ground.



Figure 6. Satellite view of a white GCP target as recorded by Quickbird.

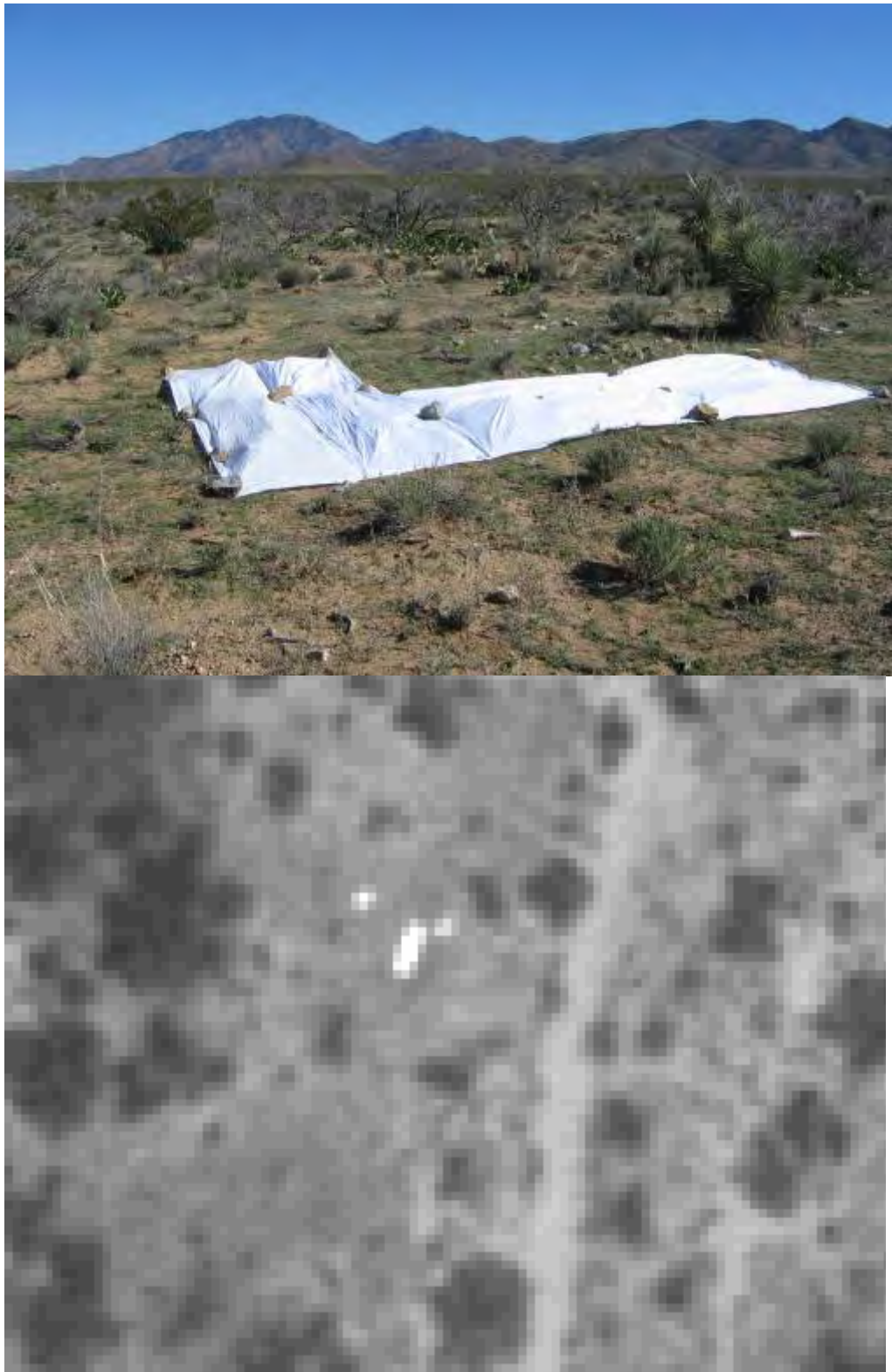


Figure 7. White target after construction (above) and during image acquisition (below).



Figure 8. Black GCP target on the ground and in the Quickbird imagery.

Field Methods: Ft. Bowie NHS

During the first week of April, as concurrent with image acquisition as possible (there is no way to know exactly which day(s) the imagery will be acquired during a window of several weeks), 4 ground transects totaling about 15 km were walked in selected areas of the Ft. Bowie-Chiricahua image to record the number and characteristics of foot trails and other possible border-related impacts. At Ft. Bowie, the basic field task was to walk transects on the ground and count the number of roads and trails that crossed the transects. The field-identified roads and trails were characterized by age class (old vs. active), size class (small, medium, large) and substrate type (bare, vegetated, or litter).

Four transects were walked at Ft. Bowie NHS:

- ~4 km along the south side of the park boundary in the grasslands at the foothill of Chiricahua Mountains. A portion of this transect was on private property owned by James Riggs.
- ~4 km along Apache Pass, south of the unpaved road used as an entrance to the fort. This transect was almost entirely within the park boundary.
- ~1.5 km along the park service entrance road, starting at the fort ruins (~100m above the road).
- ~4.5 km over Bear Springs Pass.

Observers included Sam Drake, Jeff McGovern, Miguel Villarreal and Keith Lombardo.

Tools were simple: GPS units, clipboards with data sheets, topographic and customized field maps and 8.5x11-inch prints of aerial photos (DOQQs) for orientation. The prints were annotated in the field with trail locations to supplement data recorded on the data sheets.

The procedure was to walk along a transect with a GPS unit constantly recording the field observer's track. The observer would record trail data on sheets and UTM coordinate information from the GPS. Each location was marked on the prints in relation to recognizable features. It was expected that the GPS-marked locations and measured trail distances could be imported onto the Quickbird imagery when it was delivered, using ArcGIS to produce a kind of ground-truth map of roads and trails observed in the field.

The criteria for classifying trails by age class and size class were difficult to define precisely. Or, rather, it was difficult to define criteria that could be applied with certainty in the field. Age class was considered to be "old" if the trail had not been used in the previous 9-12 months. This was judged primarily by new growth of grass over trampled grass, or by an absence of visible footprints or wheelprints on bare or sparsely vegetated ground. Presence of recent, unweathered trash was a good indicator of an active trail, but the absence of such trash was not a definitive indicator of an old trail. Size (width) class was considered "small" if the trail was a single-use or single-file footpath, "medium" if traversed by two or three people abreast (not necessarily coincident in time), and "large" if traversed by the equivalent of four or more people abreast.

Northwest to Southeast

The Ft. Bowie Northwest to Southeast (NWSE) transect began near the west park boundary, and traversed the south side of the Chiricahua mountains away from the fort (Figure 9). This transect was entirely on private land (ranching and mining), and most of the observations were related to ranching uses.

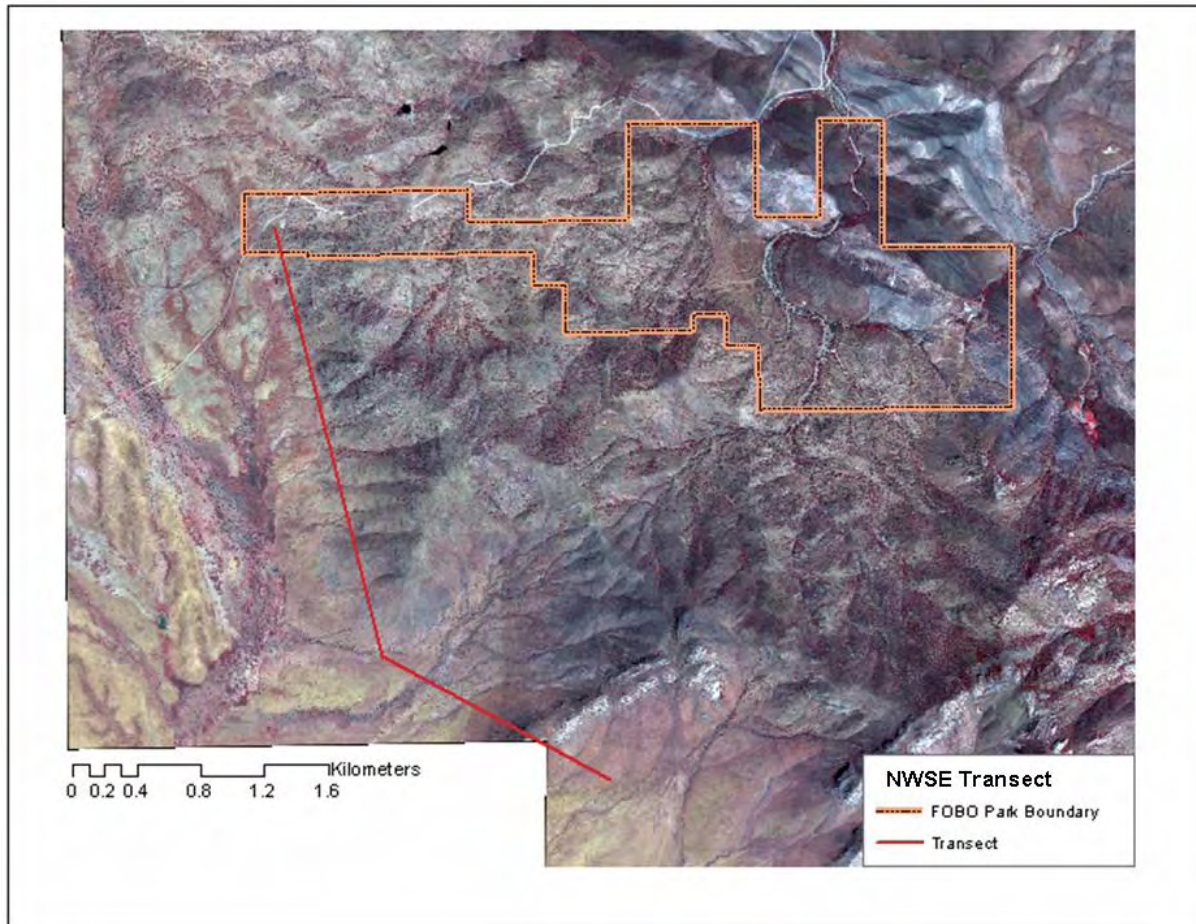


Figure 9. Location of Northwest to Southeast Transect.

Apache Pass

Apache Pass Road is the main entrance route to Ft. Bowie, connecting Hwy 186 in the west to Interstate 10 in the northeast. The Apache Pass transect (APT) began at the west park boundary and traversed the hillside south of Apache Pass Road, 4km towards the fort ruins (Figure 10). While walking the transect, the field observer noted only two signs of trails, one an active horse trail, and the other an old unused east-west trail. There were no signs of broken fences, trash or other migrant artifacts along this transect. The APT was walked on April 7, 2005.

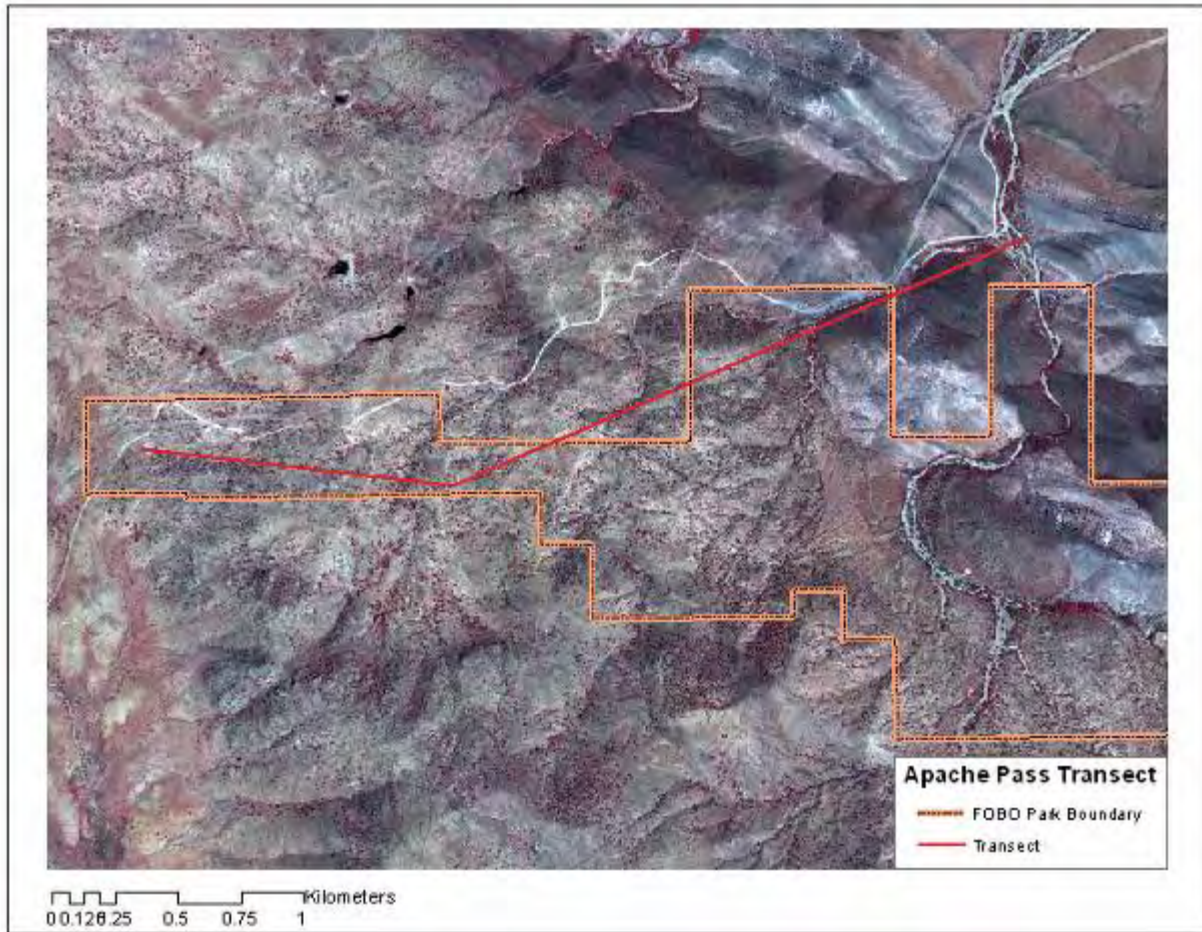


Figure 10. Location of Apache Pass Transect.

Administrative Road

The administrative road transect (ART) begins at the fort ruins and traverses the hill a few dozen meters above the administrative road (Figure 11). Nearly all of this transect is located on private property. Certain areas along the ART were without a doubt used by migrants: trash with Spanish-language labels was found at these areas, which were in drainages, under tree-canopy cover and close to the road. The trash points found in the area are likely located at places where individuals wait to receive rides. The ART was walked on April 7, 2005.

Bear Springs Trail

Bear Springs Trail (BST) traverses north-south over the spine of the Chiricahua Mountains, crossing private land to the east and southeast of Ft. Bowie NHS (Figure 11). The trail is an obvious candidate for migrant travel since it crosses the Chiricahua Mountains at a lower elevation pass, and it eventually meets up with a road that leads to the town of Bowie, AZ and Interstate 10. We were not expecting to see many migrant trails bisecting BST, but took careful note of areas that contained trash or other impacts. The BST transect was walked on June 3, 2005.

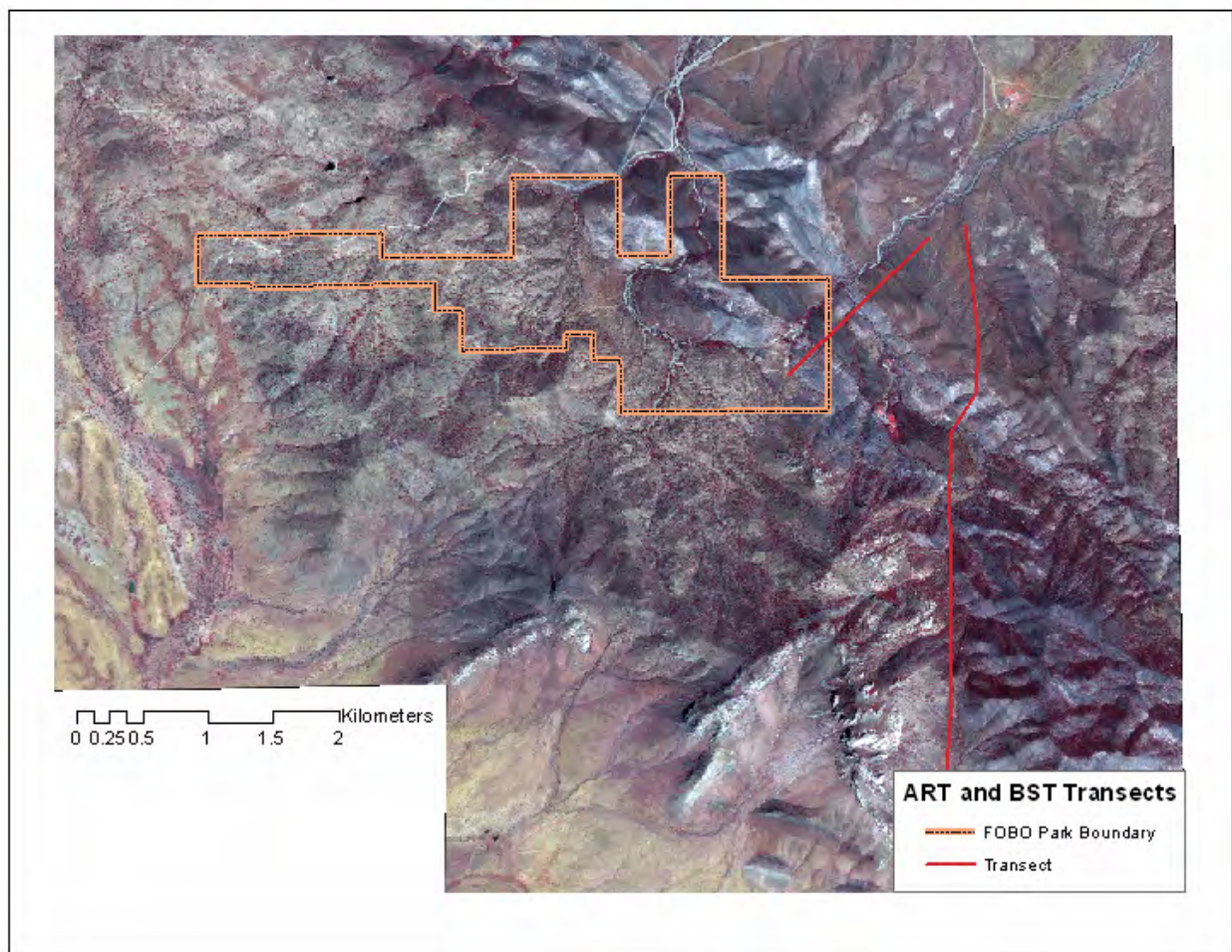


Figure 11. Administrative Road and Bear Springs Trail Transects.

After the imagery was collected, two trips were made to the Ft. Bowie-Chiricahua area in an NPS pickup, to retrieve the simulated garbage and the more easily accessible ground control point targets. On May 5, 2005 the trash locations were confirmed by another GPS fix and their general condition was documented with photographs to aid interpretation and reduce uncertainty possibly introduced by any changes occurring while they were in place. On May 5 and June 3, 2005 the remaining material GCP targets were collected and dozens more GPS coordinates were collected for features that were used as control points in the less accessible parts of the Ft. Bowie-Chiricahua area.

Field Methods: Palo Alto Battlefield NHS

Two visits to Palo Alto Battlefield NHS were conducted to gather ground data: the first in mid-March 2005, to collect transect data and some GCPs; and the second in early June 2005 to verify previously collected data and to record additional GCP coordinates of features visible in the Quickbird imagery.

Ground Transect Method of Assessment (as reported by Jeff McGovern):

March 2005

To complete the ground transect part of the analysis at Palo Alto Battlefield, I discussed with park staff their assessments of illegal border-related activities at the park, and developed a plan that involved walking various perimeters of the park itself and the (larger) congressionally designated boundary of the National Historical Site. Working by myself, I walked, over a three-day period, approximately 40 miles, all around the current, fenced NHS core boundary and the larger congressionally designated battlefield boundary surrounding it. This included two circuits for each boundary, one 5 to 10 meters inside and one a similar distance outside. Using a differential GPS unit, in combination with topographic maps and earlier satellite imagery (supplied by Rolando Garza, Palo Alto's GIS specialist), I collected electronically, marked on field maps, and recorded in my field notebook possible sites of resource-impacting illegal activities, GCPs, and general field notes.

June 2005

For this return trip, I drove to various existing and new GCP points (designated by Miguel Villarreal at the Arizona Remote Sensing Center before I left for Palo Alto). At each point I retook differential GPS coordinates, recording them electronically and in my field notebook.

During this period of field work, no evidence was found of any current or recent illegal cross-border related traffic or law enforcement counter-measures at Palo Alto Battlefield NHS. While there is some evidence of past illegal entry into the park (e.g. cut or displaced fence wire strands), there is no evidence to suggest that it is related to cross-border activity. Finding negative results during the conduct of the ground transects has the positive aspect that it indicates Palo Alto Battlefield is more than likely not receiving border-related impacts (though final assessment will come after the imagery analysis).

Remote Sensing Methods and Results

Imagery Description

The imagery used for this project was acquired by Digital Globe Inc.'s Quickbird (QB) satellite in the spring of 2005 as a new, tasked acquisition. Archive imagery was not considered due to the need to collect field data as nearly coincident in time with the image acquisition as possible in order to meet project objectives. The imagery product purchased was the "Ortho-ready Standard" bundle of 4 spectral bands (blue, green, red and near-infrared; Figure 12) at 2.4m spatial resolution, plus the broadband panchromatic data at 0.6m resolution. This imagery is intended to be orthorectified by the user and is only coarsely geo-registered with a nominal spatial accuracy of 23m CE90. This means that 90% of features in the imagery must be within 23 meters of their true location on the ground. More information about the general specifications of this imagery can be found at <http://www.digitalglobe.com/> , or more specifically at http://www.digitalglobe.com/product/standard_imagery.shtml.

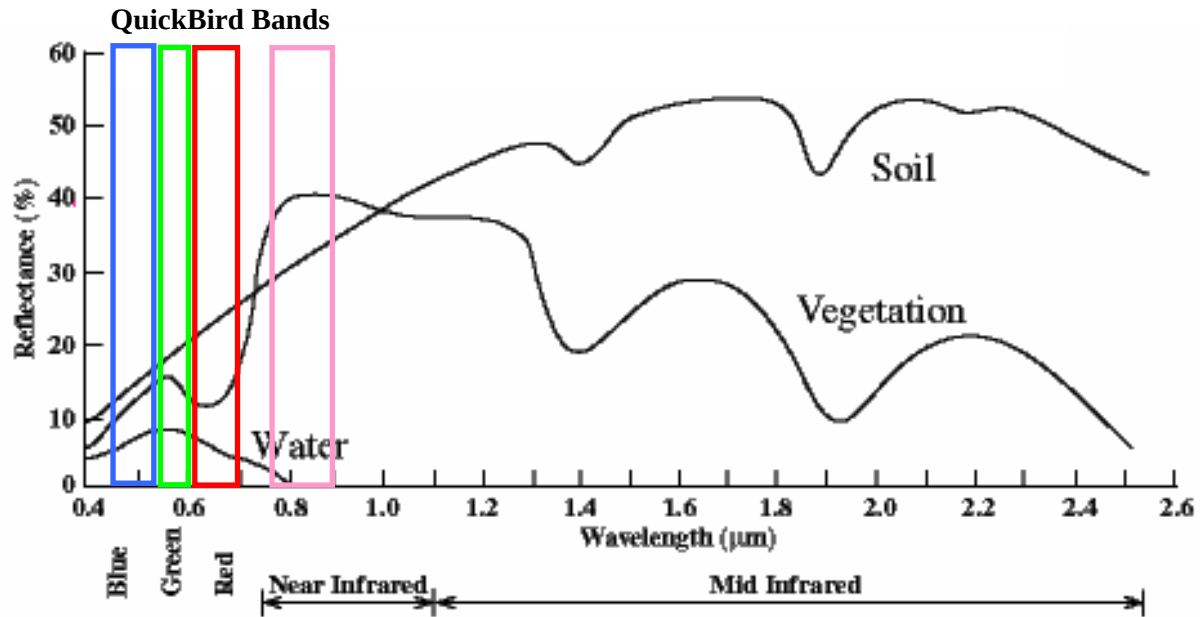


Figure 12. Quickbird spectral bands in the electromagnetic spectrum.

The geographic area of coverage for Chiricahua-Ft. Bowie includes the monument and the historic site, including the mountainous area between the two, and varying amounts of private land surrounding the parks (Figure 13). The NW corner of this image is located at 641620, 3562355 UTM NAD83 Zone 12, and the SE corner is at approximately 662799, 3538212. The imagery was acquired in two swaths on April 15 and 20, 2005. The larger of the two swaths of imagery was initially too big to work with in ERDAS Imagine v. 8.7 (> 2GB), so the image was subset in ENVI prior to geo-rectification and analysis.

The geographic area coverage of the Palo Alto Battlefield image contains the park and the congressionally designated boundary of the NHS, as well as considerable area of private land surrounding the park (Figure 14). The NW corner of this image is located at 649152, 2883854 UTM NAD83 Zone 14, and the SE corner is at approximately 657178, 2875815. The image was acquired in a single pass on April 1, 2005.

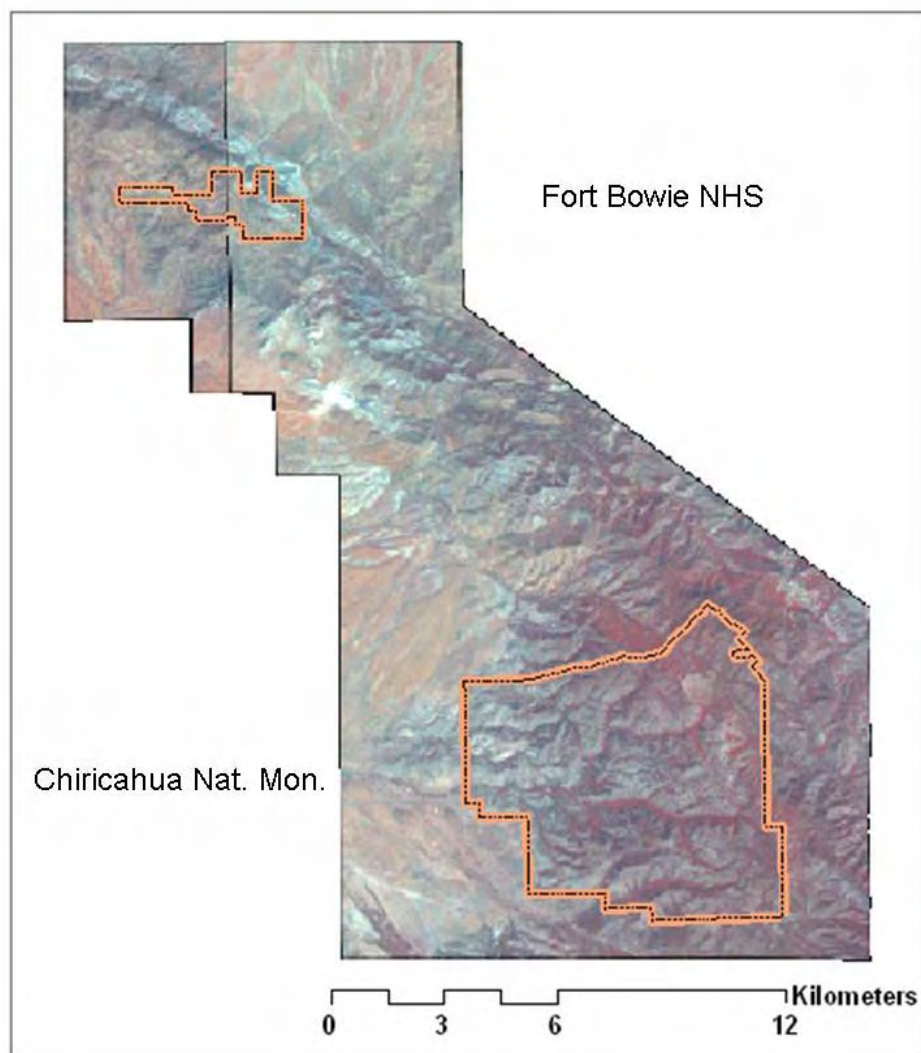


Figure 13. Quickbird imagery of the Chiricahua-Ft. Bowie area.



Figure 14. Quickbird image of Palo Alto Battlefield and surrounding area.

Image Processing

The images of Chiricahua-Ft. Bowie and Palo Alto Battlefield were orthorectified with ERDAS (Leica) OrthoBASE. Orthorectification employed a USGS National Elevation Dataset DEM, GPS coordinates of ground control points (GCPs) and Quickbird Rational Polynomial Coefficient (RPC) models. During the rectification process, field-based GPS coordinates of ground control point locations were entered into a table and compared to image coordinates for the same GCP locations. After all coordinates were entered and the GCPs located in the image, the images were rectified using a polynomial model with cubic convolution resampling. The 10-25 GCPs collected for each site were initially included in the rectification processes, but points causing high root mean square (RMS) registration error were iteratively removed to achieve optimal registration. The final number of GCPs used, and RMS errors (in pixels) are included in Table 1.

Table 1. RMS errors (pixels).

Image Name	Ch/Ft.Bowie Pan 1	Ch/Ft.Bowie Pan 2	Ch/Ft.Bowie Multi 1	Ch/Ft.Bowie Multi 2	Palo Alto Multi
Original Number of GCPs	9	7	15	7	16
GCPs used for rectification	6	5	9	3	5
RMS Error X	3.4848	3.2309	0.6149	0.4475	1.1123
RMS Error Y	2.6593	3.4802	0.7076	0.4356	1.4021
Total RMS Error	4.3835	4.7488	0.9374	0.6245	0.8536

Following orthorectification, the images were pan-sharpened for visual interpretation. Pan-sharpening is the process of merging the high resolution 0.6m panchromatic image with the 2.4m multispectral image to produce a multispectral image with 0.6 m resolution. This results in an almost 16-fold increase in the multispectral image file size. Difficulties pansharpening the Chiricahua-Ft. Bowie image were encountered due to the large file size and allocation of available hard drive space on lab computers at ARSC. A Seagate 200-gigabyte external hard drive was purchased to store temporary files during image processing, and is currently being used to back up NPS related satellite images and project data.

Digitization of Road and Trail Network

Identifying trails in the imagery is a subjective process, the results of which depend on the interpreter's experience and familiarity with the area, and on a set of intuitive, not easily articulated criteria for identifying a lineament as a trail rather than a drainage, a random alignment of shrubs, or another natural landscape feature that might look somewhat like a trail. For the purpose of this project, long continuous lines of lighter shade than their surroundings were considered trails.

Trails at Palo Alto Battlefield NHS

The orthorectified and pansharpened Quickbird images of Palo Alto Battlefield were imported into ArcGIS. Thirty 0.5x0.5 km blocks radiating away from the park boundary were created and within each block single trails and double-track vehicle roads were systematically digitized. Trails and roads that infiltrated the park boundary were digitized and later compared to field transect data. Most of the trails detected outside of the park boundary were on private ranch lands, and were likely created by livestock or recreational vehicles (Figure 15). These numerous trails and tracks were nevertheless delineated to refine our approach to satellite-based trail detection.

Variations in ground-cover brightness made it difficult to identify trails in some areas of the image (Figure 16). To help understand which land cover types presented difficulties for interpretation, we requested ancillary land cover information for the park. Three Compact Discs containing USGS vegetation maps of Palo Alto (2000) and associated documentation were sent by R. Garza.

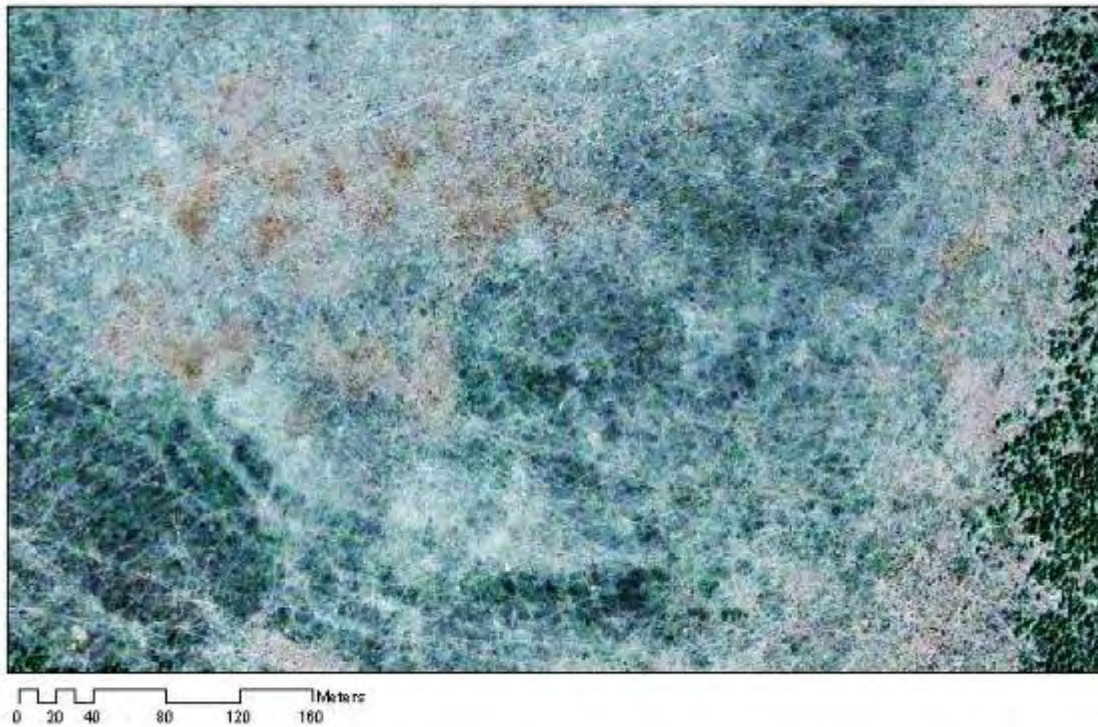


Figure 15. Area outside the Palo Alto Battlefield boundary with dense trail network.

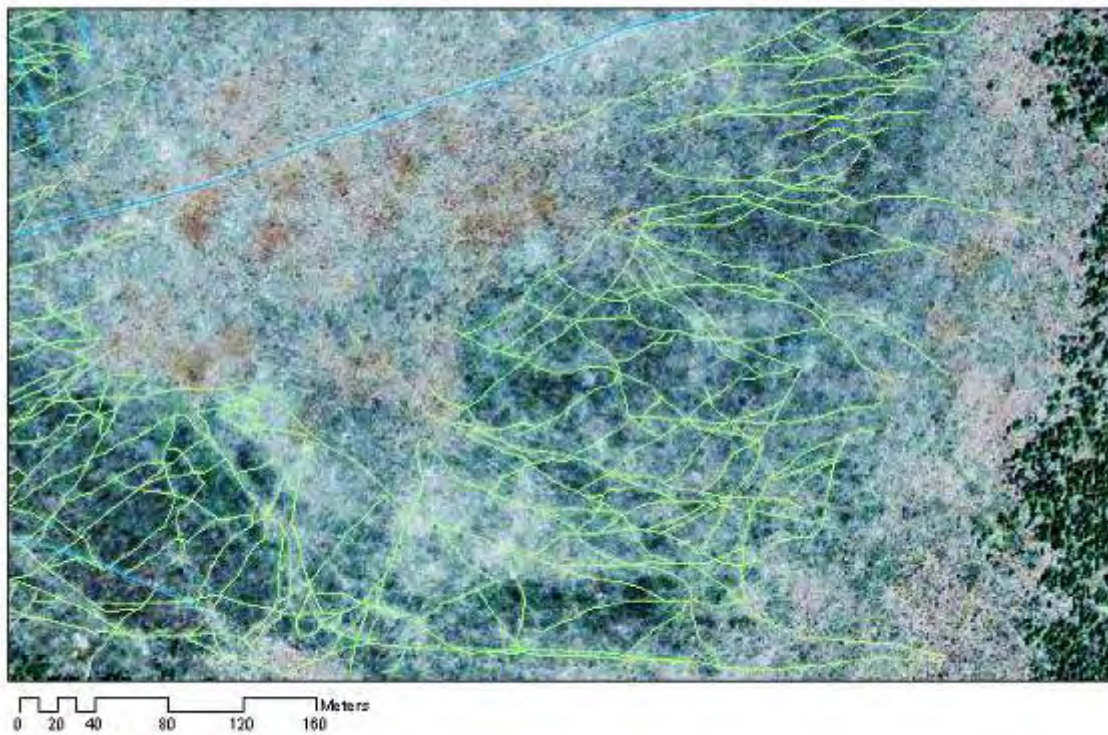


Figure 16. Digitized single and dual track trails. Note the difference in trail visibility over different vegetation types.

Vegetation polygons of the park area were imported into ArcGIS and used to relate the detectability of certain trails to various vegetation types. Vegetation/Land Cover types mapped at Palo Alto include: Tamaulipan Brush, Mesquital Forest, Huisachal, *Borrchia frutescens* Prairie, *Spartina spartinae* Prairie, Dead and Sparse Grasses, Bare Soils, *Texal colubrine* Prairie, *Sonchus asper* Prairie, and Mesquital Prairie.

Unfortunately, vegetation was only mapped inside the park boundary, and not outside of the boundary where the densest network of cattle trails and off-road tracks occurs. However, since we digitized trails adjacent to the park boundary, it was possible to extrapolate vegetation types for continuous patches that transcended the park boundary (Figure 17). Using this qualitative method we found that trails were the most detectable on Mesquital prairie and *Borrchia frutescens* Prairie. Roads were most detectable in dense Tamaulipan Brush. Land Cover/Vegetation types that created difficulties for trail detection were Dead and Sparse Grasses, Bare Soil and *Spartina spartinae* Prairie. In general, impacts on these cover types were difficult to distinguish because trails did not contrast sufficiently on a surface that was either too bright or too dark.

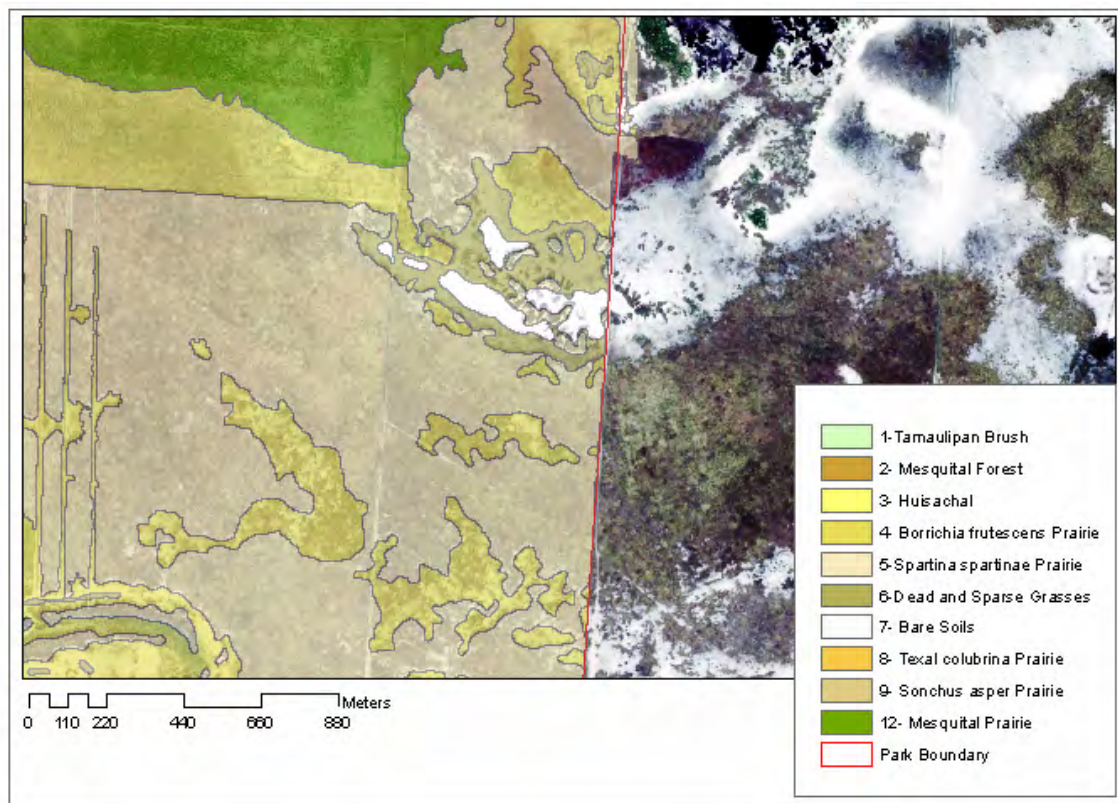


Figure 17. Vegetation map of Palo Alto Battlefield NHS.

A land cover brightness-based approach for histogram manipulation was implemented to improve visual interpretation of the panchromatic, multispectral and pansharpened imagery. This

contrast enhancement approach requires familiarity with basic properties of statistical pixel distributions for remotely sensed data, and requires the operator to manipulate the histogram according to changes in surface materials present on the ground at a particular location in the scene. In general, an image histogram displays the statistical distribution of image pixel brightness values from dark black (0) to light (255). Image processing software packages, including ERDAS Imagine and ArcGIS, will adjust image contrast automatically for display using a standard histogram stretch. In a typical histogram with a normal distribution, the tails of the histogram are “saturated” by limitations in display, where all bright values are white and all dark values are displayed as black. For example, in an area where the surface has high reflectance values (bright soils), it is difficult to discern small changes in pixel values. By stretching only a section of the histogram that includes these bright pixels, minute changes can be detected. Likewise, if a vegetated area has a dark appearance it is possible to expose more visual information if the histogram’s low tail is stretched out.

In areas of high contrast like sand, bright soil, vegetation etc. a histogram-stretch can help bring out information in the bright areas. In the example from Palo Alto shown in Figure 18, the grey histogram is the original distribution, and the pink histogram displays a stretch of high DN pixels, offering more information in the bright areas. (DN values are "digital numbers", the raw sensor response at each pixel to incoming reflected radiation.)

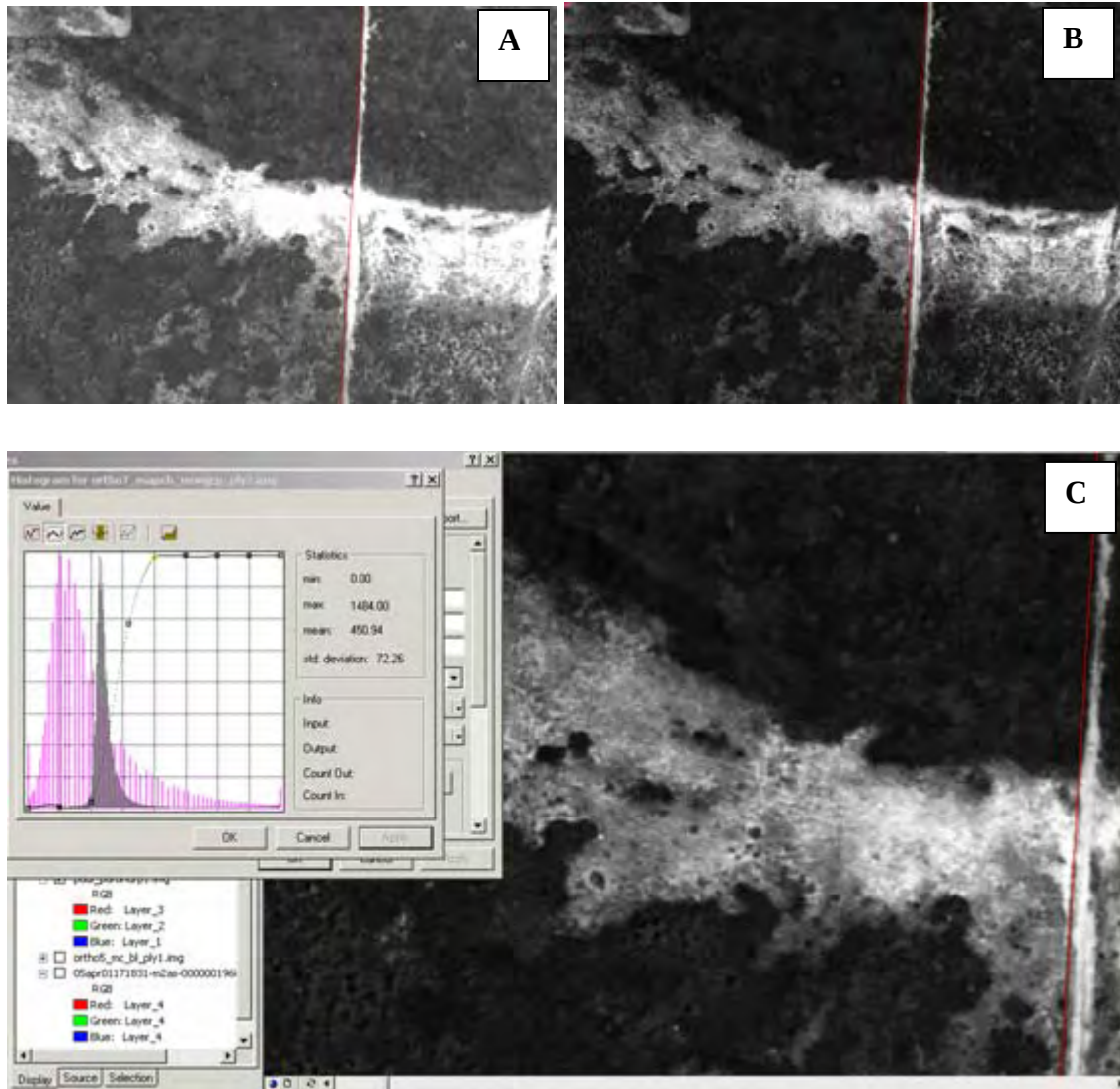


Figure 18. Depiction of histogram manipulation for areas with high contrast. A) High-contrast before histogram stretch; B) After stretch; C) ArcGIS screenshot showing the effects of a histogram stretch

Once trails and roads around Palo Alto were digitized in the GIS, they were compared to transect and field data collected by J. McGovern (Table 2). These field data consisted of notes on observed trails, roads, trash and fence breaks, all with associated GPS coordinates. Tabular field data files were imported into ArcGIS to create spatial point files with associated database attributes, and these were overlaid on the image with the digitized trail layers. If any field-collected points occurred within the vicinity of a digitized trail, the image was inspected to verify if the two were correlated. If a field point occurred in an area with no digitized trails, the area was inspected to insure that an error of omission was not committed by the GIS analyst. Note in Table 2 that only one field observation of a trail was recorded (PAAL15).

Table 2. Field notes recorded at Palo Alto Battlefield NHS.

Palo Alto Transect March, 2005			
X Coordinate	Y Coordinate	Point	Notes
2879244	652065	PAAL07	Fence break
2879718	652096	PAAL08	Cut in lower fence wire strand
2879967	652114	PAAL09	Fence break
2880163	652127	PAAL11	Fence Damage (wire pushed down)
2880464	652148	PAAL12	Fence Damage (wire pushed down)
2880631	652160	PAAL13	Fence break/some crushed vegetation present
2881345	652209	PAAL15	Fence Damage (evidence of climbing and trail to NE)
2880001	652178	PAAL16	Trash dump at edge of mesquite stand
2877807	653548	PAAL32	Furthest point I walked along NPS east boundary
2877038	653206	PAAL33	Fence Damage (pulled open)/some vegetation crushed on inside
2877151	653074	PAAL34	Fence break (missing section - 15-20m)
2877429	652781	PAAL35	Trash dump (vehicle bench seat) just inside wire, no other evidence
2877720	652465	PAAL36	Fence break

As previously noted, many trails were present on private land surrounding the park. The GIS operator noted only 6 single trails and 2 dual-track roads that appeared to cross the boundary into the park. When these incidents were compared to the field data, in consultation with J. McGovern, it was determined that none of these imagery-detected trails matched the one field-observed trail at PAAL15 or any of the other field-collected data points. The digitized tracks were assumed to be remnants from when the area was privately owned farm land. The field-recorded points described mostly piles of trash (which may or may not have been “border-related” trash) and fence damage, which could not be seen in the Quickbird imagery.

Thus a strict accuracy assessment of these results, using the ground information as reference data, would say they comprise 8 errors of commission, one error of omission, and no correct matches. But the results are not as discouraging as that. The 6 remnant trails and 2 roads visible in the imagery are real, just ignored in the field because they did not seem to be active border-related impacts, which is understandable. The one active trail seen in the field was too subtle to be seen in the imagery, so this is a true error of omission showing that, as expected, not all trails will be visible in the imagery, even if they have recent footprints on them. The impacts of fence damage and small trash accumulations also could not be seen in the imagery, and this does demonstrate some limitation in using remote sensing to detect and monitor impacts to cultural resources. From a nadir view, damage to fences, walls, poles and other vertically-oriented features with small "footprints" will not be visible. Also, subtle impacts such as individual pieces of trash will not be visible unless the image spectral and spatial resolution are adequate.

Transects and Trails at Ft. Bowie NHS

Northwest to Southeast

Twelve trail segments were located along this transect and digitized by the GIS operator. Several of the detected trails trended southeast to northwest in the same direction as the NWSE transect, and were out of visual range of the field observer. As noted in the field observations, many of the

trails observed in the field were cattle trails; the GIS operator pinpointed a livestock watering hole with converging livestock paths only a few hundred meters southwest of the transect. Some of the cattle trails observed in the field were not visible in the imagery. Likewise, observed foot prints recorded at field point NWSET03 were not detected by the observer, but a slight path heading toward the park boundary and Apache Pass Road could be detected in retrospect. (Note: field points 20-24 were situated outside of the image area) (Table 3).

Table 3. Field notes recorded at Ft. Bowie, NWSE transect.

Northwest to Southeast Transect April 7, 2005

X Coordinate	Y Coordinate	Point	Trail	Notes
643258	3558043	NWSET01	NA	Good scouting site-hilltop with large oak, no sign of use
643261	3557952	NWSET02	bare/litter	Possible stock trail. No footprints
643274	3557840	NWSET03	active/bare	Footprints on trail contouring on hillside. Trail continuous w/ previous pt. and NWSE2
643306	3557804	NWSET04	active/bare	Small trail w/ recent footprints or hoof prints
643435	3557284	NWSET05	bare	Faint deer trail (scat), unpromising as human trail
643440	3557253	NWSET06	old/bare+veg	Cow trail paralleling course to NWSE2, w/deer trail @ previous point. No human sign.
643539	3556936	NWSET07	NA	Old pickup mirror, no sign of a road.
643562	3556841	NWSET08	NA	Possible old stock trail along side of drainage perp to course
643685	3556301	NWSET09	NA	Good lookout spot, shady juniper on hillside. No human sign. Some cow trails
643372	3556150	NWSET10	NA	Photo site 1 showing view a) toward NWSE2 and b) toward NWSE1
643813	3555957	NWSET11	old/bare+veg	Cow trail, continues across drainage roughly parallel to course
643872	3555756	NWSET12	old/bare+veg	Large cow trail ~ 100° from course. No human sign
643916	3555623	NWSET13	old/bare+veg	Cow trail (medium size) crossing drainage
643916	3555594	NWSET14	old/veg	Cow trail ~ 100° from course
644057	3555533	NWSET15	old/veg	Cow trail. Forbs ~80% cover
644604	3555331	NWSET16	NA	Starting up hill slope towards saddle. See notes. No human sign.
645005	3554977	NWSET17	NA	Photo point: a) toward NWSE3 b) NWSE2 c) down slope
645098	3554724	NWSET18	old/veg	Small cow trail. No human
645138	3554664	NWSET19	old	Medium cow trail
644805	3554478	NWSET20	act bare/veg	Trail w footprints (1 set), see notes.
644568	3554594	NWSET21	active/veg	Cow trail, no footprints
644449	3554729	NWSET22	active/veg	Cow trail – re-crossing previous?
644406	3554761	NWSET23	active/veg	Re-crossing previous trail and beginning to follow it
644333	3554862	NWSET24	old/bare/veg	Old dual-track dirt road. No footprints. More notes
644224	3555100	NWSET25	NA	Road goes through gate in pasture. More notes
644028	3555276	NWSET26	old/veg	Med cow trail perp to course. More notes
643933	3555442	NWSET27	old/veg	Cow trail perp to course. 60-70% forb cover, no mesquite
643732	3555786	NWSET28	old/veg	Cow trail perp to course. Forbs, Burroweed, small mesquite and yucca
643415	3556228	NWSET29	NA	1 gal green oil can/water jug. No other human sign
643219	3557807	NWSET31	NA	Old baseball cap bill (or visor). Not new, prob. from trash site 5

Apache Pass Road

As mentioned previously, over the 4km transect the field observer noted only two signs of trails: one an active horse trail and the other an old unused east-west trail. There were no signs of broken fences, trash or other migrant artifacts along this transect (Table 4). The GIS observer noted an apparent trail (undetected in the field) crossing over the hill and joining Apache Pass Road.

Administrative Road

There were few obvious trails located on the Admin Road Transect. The GIS operator digitized one trail that coincided with field-observed footprints in a small drainage (Table 4). This trail segment was only 100 meters long and its source could not be ascertained, but it appears to terminate at the admin road. As stated previously in the field methods section, some trash was seen by the field observer, but it was covered by a canopy of trees and so could not be detected in the imagery.

Bear Springs Trail

As mentioned in the field methods section, it was unlikely that we would encounter any west-east trails along BST since the transect followed a N-S trail over the pass which migrants would likely travel. In fact, the image analyst located only 2 trails along the BST transect. One trail was large, and appeared to be an unused section or older portion of the BST. The other trail was located on the south side of the mountain in the pasture area. This trail ran north-south, and may have been a cattle trail or a fork of BST. Unfortunately both of these trails were out of view of the field observers and their use or condition were not noted. There was ample evidence of migrant traffic on BST, mostly scattered trash along and inside of the wash (Table 4 and Figure 19).

Table 4. Field notes recorded at Fort Bowie APT, ART and BST.

Apache Pass Transect April 7, 2005

X Coordinate	Y Coordinate	Point	Trail	Notes
644610	3558233	APT001	Old	Horse trail (E-W), no foot tracks.
646101	3558817	APT002	Old	Old trail (E-W). Non-migrant

Administrative Road Transect April 7, 2005

X Coordinate	Y Coordinate	Point	Trail	Notes
648160	3558024	ART001	Active	New footprints along drainage towards road.
648319	3558240	ART002	NA	Clothing and trash found in drainage. Recent. Covered by tree canopy.

Bear Springs Trail Transect June 3, 2005

X Coordinate	Y Coordinate	Point	Trail	Notes
648913	3558436	BST1	Old	No human sign. Likely animal trail.
648792	3557770	BST2	Active	No human sign. Likely animal trail.
648792	3557293	BST3	Old	No signs.
648828	3557008	BST4	Active	Garbage scattered; Water bottles, some in the wash
648783	3556309	BST5	Active	Water bottles in wash.
648817	3556273	BST6*	Active	Likely migrant; candy wrappers and backpack within 50 meters.
648926	3555580	BST7*	Active	Clothing, water bottles, cans, and backpack under pinon pines.
*Garbage found scattered intermittently between BST6 and BST7				

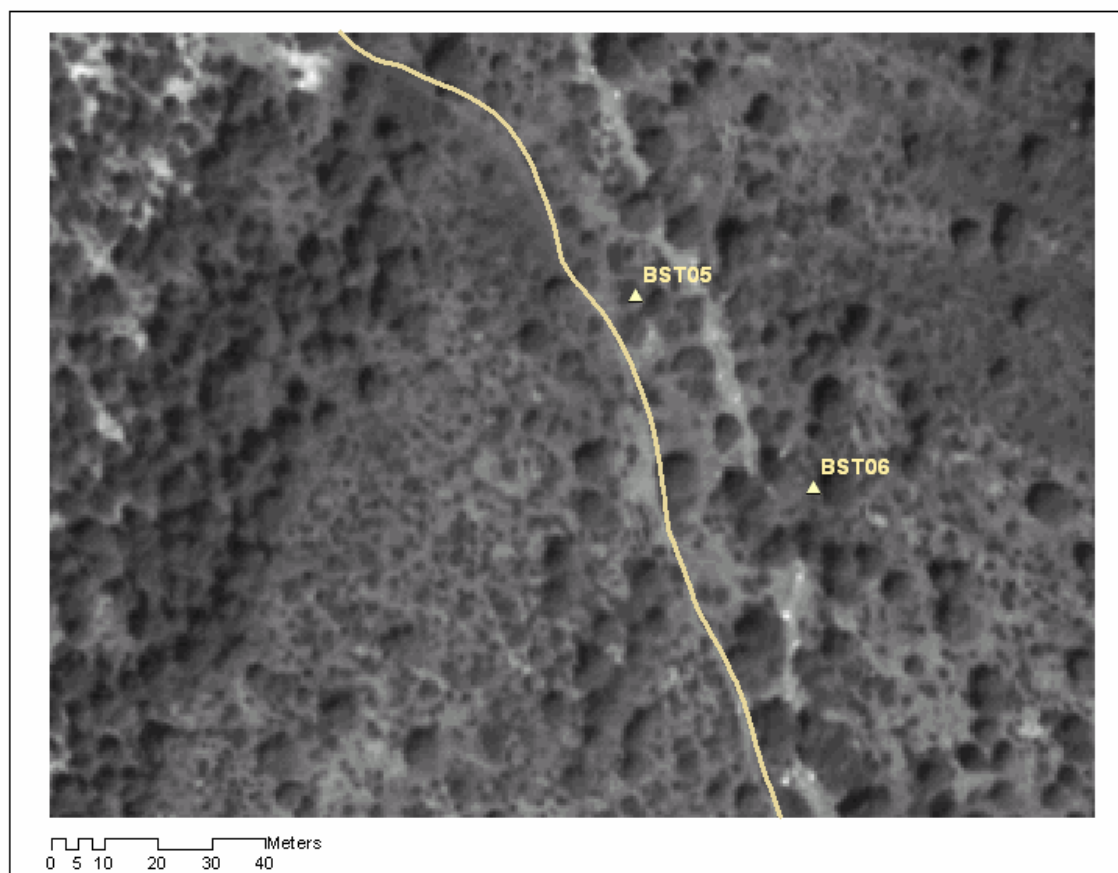


Figure 19. Location of trash observations alongside Bear Springs Trail.

Remote Sensing Experiments

To allow for quick image processing, experiments for the simulated trash area at Chiricahua were completed on a subset of the original Quickbird image. For trail extraction experiments using vegetation indices, we revisited the Organ Pipe Cactus Nat. Mon. Quickbird imagery and field data collected November, 2003 (Drake et al. 2004).

Experimental Trash Areas: Signature Mean Classification vs. Image Thresholding

On May 5, 2005 at 6:30 am the trash piles were collected from the site near the Chiricahua Nat. Mon. boundary. The piles were in good shape; only a few pieces of clothing and several water bottles had moved from their original locations. Much of the clothing had faded from sun exposure, and was covered with some dust and litter from nearby trees (Figure 20). The shadows present in the photographs are due to the low sun angle at 6:30 am; there were much less pronounced shadows at the time of the Quickbird image acquisition, about 10:30 am.





Figure 20. Experimental trash targets near Chiricahua Nat. Mon., with detail.

The trash piles staged outside of Chiricahua are visible in the pansharpened Quickbird image; the piles appear as bright white shapes contrasted against grass and bare ground (Figure 21). In the original default-stretched image, there also exist many spots in surrounding areas with bright reflectance; using this image it might be difficult to visually locate the piles without *a priori* knowledge of their ground coordinates. Changing the histogram distribution using a min-max stretch provides much better results, as the piles are clearly visible and discernible when compared to all surrounding image elements (Figure 21).

Subset images containing the experimental trash areas were first classified in ERDAS Imagine using both unsupervised and supervised methods to see if a specific spectral signature existed for disturbed areas, and if the signatures could be distinguished from other bright features in the area. The unsupervised classification procedure in ERDAS Imagine is based on the Iterative Self-Organizing Data Analysis Technique (ISODATA), which uses an iterative process to minimize spectral distance of cluster means. We experimented with increasing numbers of clusters (100-200) and iterations (10-30) to improve classification of the targets. For the supervised classification we selected five training areas in the image representing clothing pile, plastic container pile, bare ground, (senescent) grass, and tree. The unsupervised and supervised classifications failed to distinguish between the experimental trash piles and other bright areas in the scene, especially unpaved roads and bare ground (Figure 22).

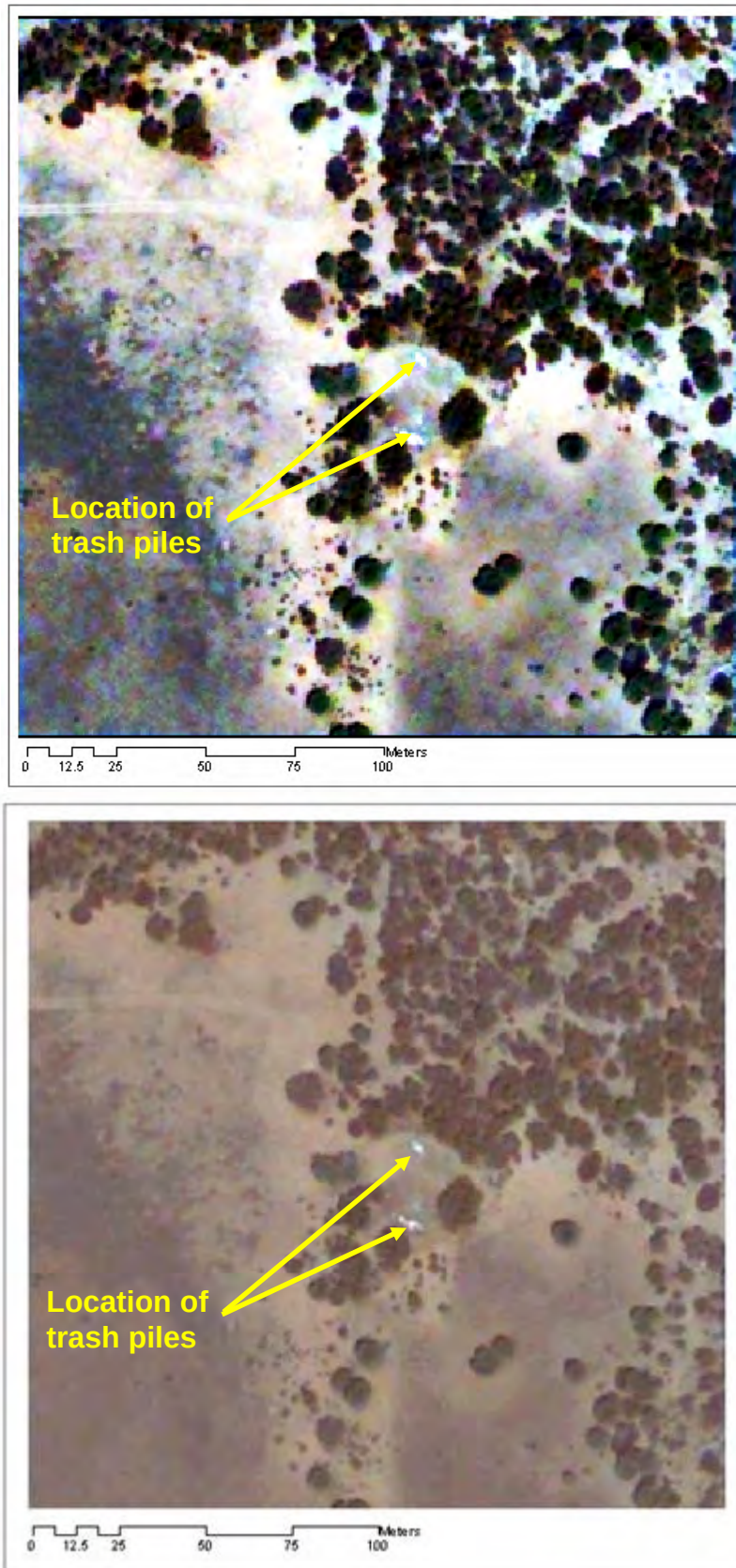


Figure 21. Location of trash sites in Chiricahua image (top); min-max stretch detail (bottom).

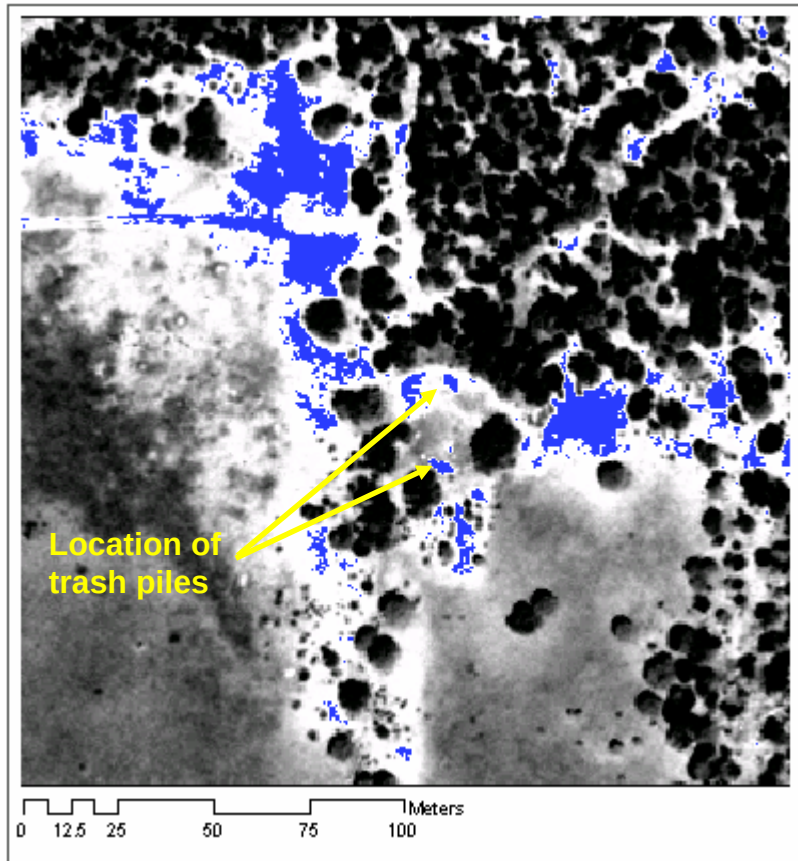


Figure 22. 200-class, unsupervised classification of the trash target area.

Knowing from the image histogram distribution that the trash piles had pixel values that exceeded those of the other image elements, and pixels representing the class of interest were outliers with high DN's on the histogram tail, we attempted to classify the image using a histogram threshold method. The test image (pansharpened) was processed using a principal components transform (PCT) with four principal components. Inspection of the individual components indicated that the first component contained most of the image information (explained 86.5% of image variance), while the 2nd-4th components contained little information of value.

The PC1 and panchromatic images proved useful for identifying the trash areas. Both images were manipulated using a histogram threshold classification ranging from 2-10 classes (Figure 23). Pixels of the two primary clothing piles are clearly distinguishable from nearby bare soil and rock. As it turns out, high DN values (like the trash piles) occur mostly in human-made material constructions like buildings, outbuildings and vehicles (Figures 24). Unlike the clothing, the pile of plastic bottles and clear 1-gallon water jugs was not distinguishable from surrounding

image elements. Apparently the nature of the material does not encourage bright reflectance in the panchromatic or multispectral bands.

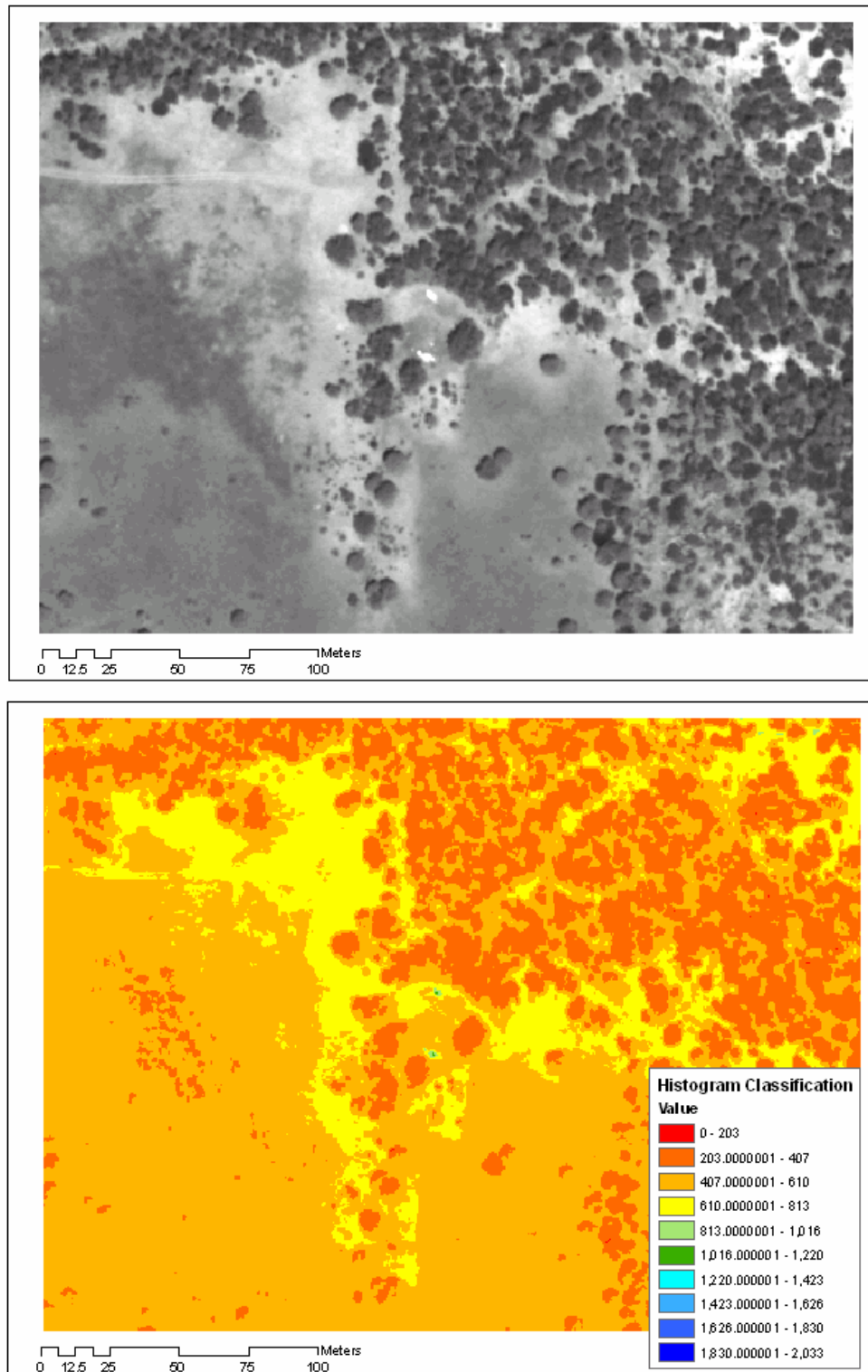


Figure 23. Histogram threshold classification of trash targets.

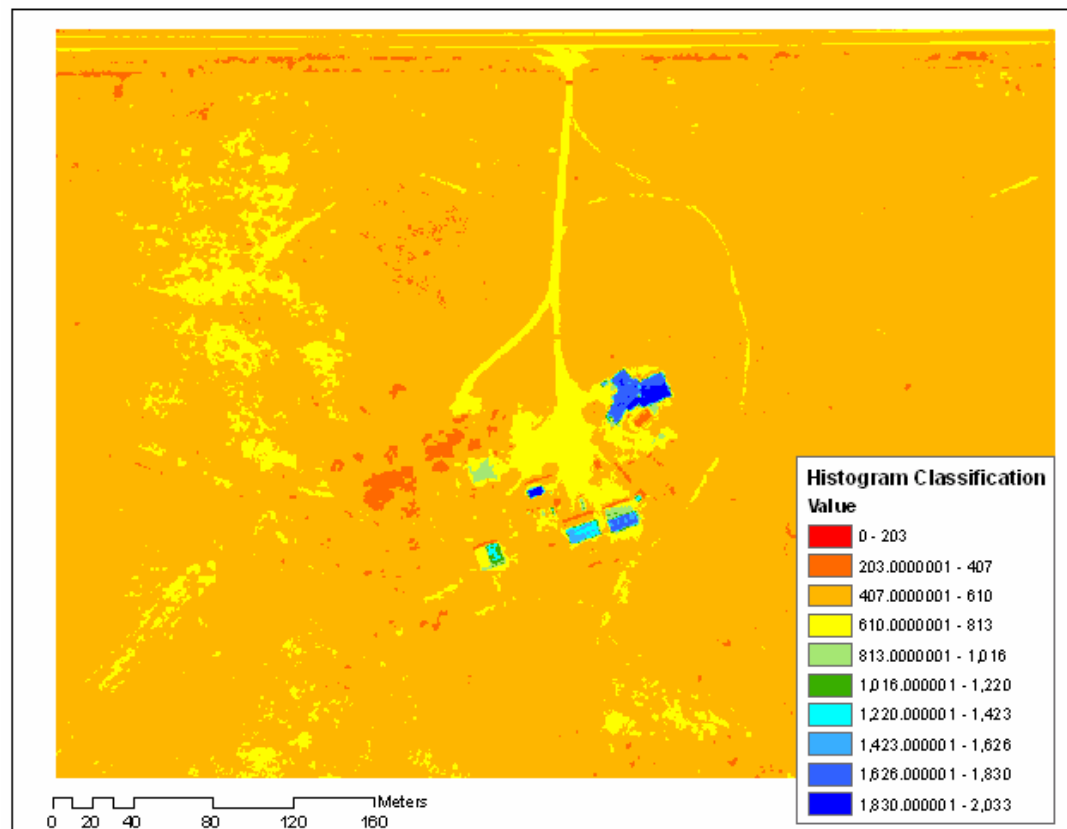


Figure 24. Histogram threshold classification of urban surfaces.

To test whether a histogram threshold classification would be useful for identifying small trash sites over a large image area, a classification experiment was conducted on half of the original panchromatic Quickbird image, the southern half that contains Chiricahua Nat. Mon. The image was classified in ArcGIS using an equal area classification with 10 classes. Most of the image pixels (99.89%) fell into the first four classes (Figure 25). The last four classes contained most of the bright DN pixels that made up the histogram tail (Table 5). The clearly distinguished clothing piles fell into classes 5 (.106%) and 6 (.004%), as did other human-made surfaces. It is evident from these figures, and from analyzing areas of the image, that a 10-class equal area classification adequately separates the human-made artifacts from natural features like rock outcrops, unpaved roads and sand-filled washes.

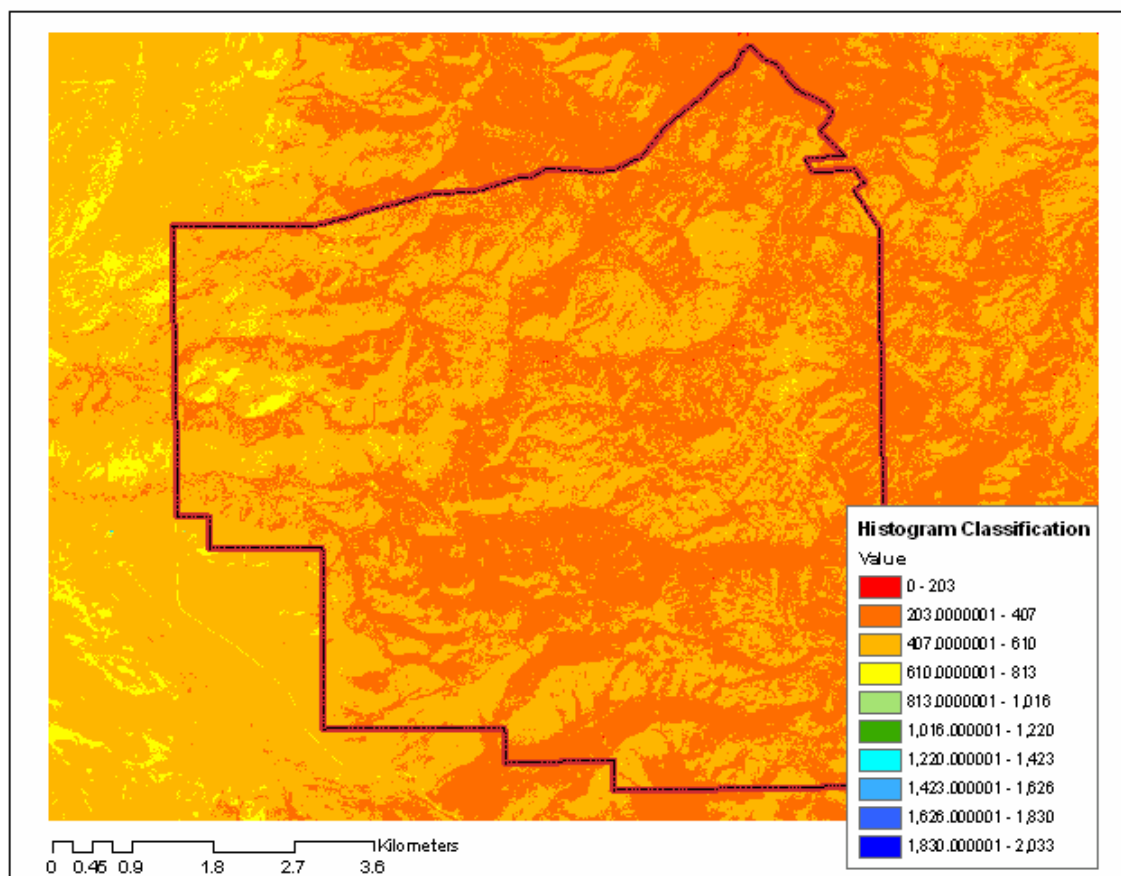


Figure 25. Histogram classification of area around Chiricahua Nat. Mon.

Table 5. Distribution of classified pixels around Chiricahua National Monument.

Class	Color	Class Value	Number of Image Pixels	Percent of Image
1		0-203	2782014	1.445
2		203-407	89743754	46.603
3		407-610	65668746	34.101
4		610-813	34157463	17.738
5		813-1,016	204132	0.106
6		1,016-1,220	8528	0.004
7		1,220-1,423	2483	0.001
8		1,423-1,626	1034	0.001
9		1,626-1,830	1044	0.001
10		1,830-2,033	605	0.000
Total			192,569,803	100

In theory, large trash piles, clothing piles and even abandoned automobiles can be detected from space using this equal area histogram threshold technique. If a panchromatic, high-resolution aerial image is imported into ArcGIS and classified into equal areas, the high classes can be queried using the GIS software and the location of the features can be noted. It should be stated that the clothing and trash piles we encountered in the field were located under tree canopies. Under these circumstances trash piles may not be detectable from space, since the bright pixels will mix with dark canopy, diluting the brightness of the objects of interest.

Vegetation Indices

Literature on lab spectrometry of disturbed soils suggests that there exist considerable spectral differences between disturbed and non-disturbed arid soils in the near infrared (NIR) region of the electromagnetic spectrum (see literature review, following section). We hoped to exploit this spectral difference for trail extraction through the use of vegetation indices (VIs). The use of vegetation indices to *directly* map border trails is not a likely outcome of this experiment, but in theory these spectral differences might help eliminate errors of commission where a wash or historic trail is mistaken for an active trail. To test this we processed Quickbird imagery using different vegetation indices (all based on red/near infrared band ratios), including the Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted VIs (SAVI, MSAVI).

The general theory behind these experiments is that disturbed soil will have a higher reflectance in the NIR band than undisturbed soil. When a multi-band image is converted to an NDVI image, disturbed soil should have a higher NDVI value than surrounding undisturbed soil. If we know that the NDVI value is not related to vegetation in that spot, we can assume that the high NDVI is related to reflectance of *recently* disturbed surfaces.

For these experiments, we revisited available Quickbird imagery and field data collected in Organ Pipe Cactus Nat. Mon. in November 2003 (Drake et al. 2004). We did this for two reasons: 1) we felt that the soils at Organ Pipe would be less influenced by vegetation (grasses) than at Chiricahua-Ft. Bowie and would influence the NDVI less, and 2) the trails recorded at Organ Pipe were numerous enough to allow statistical testing of our hypothesis.

A segment of the Organ Pipe image, starting at the southern Sonoyta Mountains and continuing ~1km past the Lukeville port of entry, which corresponded with the area of field-collected data, was subset from the orthorectified multispectral image (Figure 26). The original field data sheets were reviewed and pertinent trail information was compiled into a spreadsheet. Point files of the trail data were imported into ArcGIS, as were the manually delineated trails produced during the Organ Pipe/Coronado Nat. Mem. border impacts project (Drake et al. 2004).

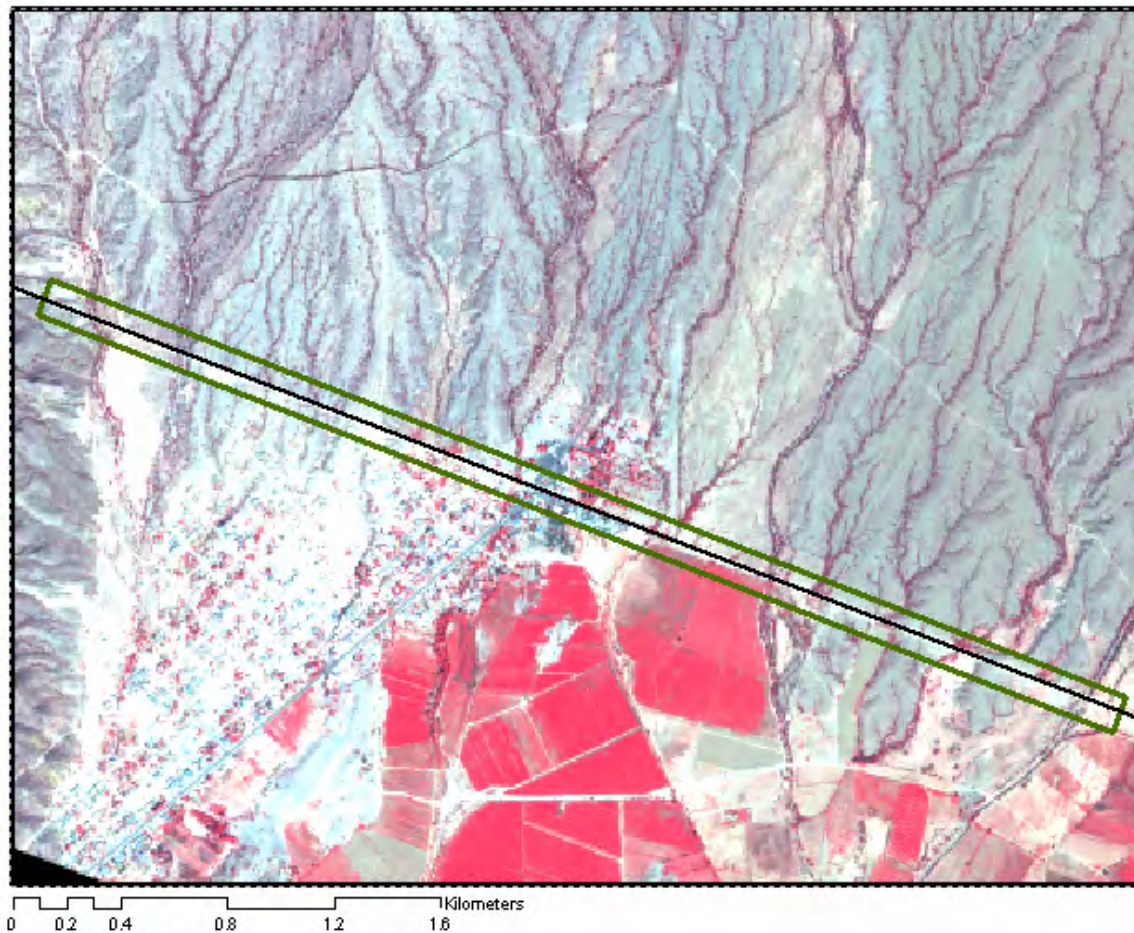


Figure 26. Location of Organ Pipe Cactus Nat. Mon. study area along the U.S./Mexico border at Lukeville.

The image was processed and pixel data (index values ranging from -1 to 1) were collected in areas that corresponded to known trails and disturbed areas and areas that contained old, undisturbed trails. The Quickbird image was processed in ERDAS Imagine using the following formula for NDVI:

$$\frac{nir - red}{nir + red}$$

and the Modified Soil Adjusted Vegetation Index (MSAVI) model (Qi et al.1994):

$$\frac{nir - red}{nir + red + L} (1 + L), L = 1 - 2yNDVI \times WDWI$$

where L is the soil-line constant (0.5), y is the slope of the soil line and the weighted difference vegetation index (WDVI) is calculated as:

$$nir - \gamma red$$

We were limited to one of the 2 images acquired for Organ Pipe in 2003, since it had rained between the time of field data collection and the time of image acquisition for one image. On this image there were a total of 18 trails documented. Of these 18, eight were active, meaning there were signs of footprints or tire tracks, and ten were old, meaning there were no such signs of recent use. Of these trails we included only those that were located in areas not dominated by vegetation or grasses (to reduce the influence of vegetation on VI values), resulting in seven active trails and six old trails (Table 6).

Based on GPS locations, 3x6 pixel boxes were situated over each of the documented trail locations and NDVI and MSAVI values were extracted from within each box (Tables 5 and 6). T-Tests were calculated separately for NDVI and MSAVI values to test the difference in VI values between active and old trails.

Mean NDVI and MSAVI values for active trails were higher than for old trails in both cases (Table 7), but these differences were not statistically significant. The null hypothesis that the means were similar for both samples was accepted for both MSAVI and NDVI (alpha = 0.05, p = 1). These results may have been influenced by the bare/vegetated surface status of three of the old trails (A52.1, A54.2 and A54.3). This is a shortcoming of an approach using VI to detect disturbed soils, since a disturbed area may have a VI value similar to an undisturbed area with local vegetation. A54.3 in particular has a high mean NDVI value, and may have skewed the results (Table 6). Unfortunately there was not a larger sample set to select from. Despite the small sample size, results suggest that vegetation indices are not an appropriate approach for identifying soil-related spectral changes in NIR bands. It is our opinion that the spectral difference between disturbed and undisturbed soils might be better exploited using hyperspectral imagery with multiple NIR bands. If the hyperspectral spatial resolution were fine enough, a ratio of 2 NIR bands might improve chances of successfully detecting disturbed soil.

Table 6. Field descriptions of trails in Organ Pipe Cactus Nat. Mon. used to test image processing methods.

Trail name	Status	Surface	Mean NDVI	Stdv NDVI	Mean MSAVI	Stdv MSAVI	Notes
A48.6	active	bare	0.118	0.025	0.197	0.031	recent cross country to north
A48.8	active	bare	0.085	0.011	0.156	0.019	new house opposite, lots of clearing
A49.3	active	bare	0.053	0.012	0.098	0.018	foot trail, large, recently used
A50.1	active	bare	0.079	0.005	0.146	0.008	large cross country road
A50.2	active	bare	0.105	0.021	0.198	0.027	road
A53.1	active	bare	0.047	0.007	0.089	0.012	wide clearing, few braided roads, fence down
A56.2	active	bare	0.069	0.020	0.129	0.035	large highway - vehicles, bikes, footprints in wash (trash)
A47.1	old	bare	0.082	0.015	0.151	0.027	old drive thru
A47.3	old	bare	0.071	0.024	0.132	0.041	drive thru up ridge
A49.1	old	bare	0.063	0.019	0.118	0.033	old road
A52.1	old	bare/rip	0.070	0.014	0.131	0.024	foot trail up wash
A54.2	old	bare/veg	0.050	0.006	0.096	0.011	old, previously major trail. Fence down
A54.3	old	bare/veg	0.103	0.025	0.186	0.040	old but major trail

Table 7. MSAVI and NDVI means used with t-tests.

Index	'Active' Mean (n=127)	'Old' Mean (n= 109)
MSAVI	0.1448	0.1355
NDVI	0.0793	0.0732

Review of Remote Sensing Techniques for Monitoring Border Impacts

The purpose of the following section is to:

- 1) review recent multispectral remote sensing experiments conducted by other researchers addressing trail detection;
- 2) explore the potential uses of hyperspectral imagery for border impacts monitoring;
- 3) list and describe the attributes of existing and future multispectral satellites that might further NPS border impact monitoring goals.

Review of Remote Sensing Techniques for Trail Detection

Kaiser et al. (2004) evaluated several image processing methods for detecting trans-border trails with multispectral imagery. The study, located in California along the US/Mexico border, used a similar approach to the current NPS border impacts and cultural impacts remote sensing projects. The researchers tasked an Airborne Data Acquisition and Registration (ADAR) sensor with a 0.6m multispectral (3 Visible and 1 NIR band) resolution in conjunction with GPS field surveys. They experimented with several image enhancement and feature extraction techniques. Image processing approaches used for mapping trails included: normalized difference vegetation index (NDVI), principal components analysis (PCA), and spectral mixture analysis (SMA). These image enhancements produced results of debatable quality. The SMA enhancement produced the best results for image interpretation, but the analyst correctly identified only 49% of the GPS field-mapped trails using this method. The semi-automated feature extraction technique provided slightly better results with 56% of trails mapped correctly.

Monitoring the effects of recreational activities on coastal sage scrub habitat, Witztum and Stow (2004) used 1m Airborne Data Acquisition and Registration (ADAR) red band reflectance values to estimate percentage of bare ground. When compared to ground cover plots ($n=30$), the red band explained more variability of bare ground ($r^2 = .55$) than NDVI ($r^2 = .26$) and SAVI ($r^2 = .15$). An inverted regression model was used to map percent bare ground from the ADAR red band. The accuracy of the percent bare ground map was not tested other than the statement of r^2 ($r^2 = .55$). The authors applied spectral transforms (PCA and Tasseled Cap) and spatial filters (high pass and edge enhancement) to the red band before visual image interpretation. PCA and edge enhancement filters resulted in the highest percentage of correctly delineated trails, but the detected percentage varied substantially among sites (28%-97%). Overall results for all four sites showed 74% of trails detected, with no errors of commission, which is surprising.

The generally high error of omission in these studies contrasts strongly with the predominant error of commission reported in the NPS border impacts study (Drake et al. 2004). These differences may be due to different ecosystem characteristics inherent in the California studies and the Arizona studies, or to differences in image processing methods and approaches taken to match ground data with field data.

It is our opinion that ADAR is not a good candidate for trail monitoring in border parks. Although the 0.6m resolution is nearly a quarter smaller than Quickbird multispectral (not panchromatic) pixels, individual ADAR images cover less than 1 km², so large datasets require

time consuming mosaicking efforts. Furthermore, anisotropic reflectance effects are known to occur in framed images and can theoretically influence DN brightness values at the outer edges of the frame. Finally, the accuracy reported in the previously discussed studies are not compelling enough to warrant the use of the more expensive multispectral imaging system.

Physical Basis for Spectral Enhancements of Digital Imagery

In arid regions dominated by nearly bare soil, soil conditions are known to influence, and can dominate, surface spectral reflectance characteristics in an image. Much research is based on the notion that in the NIR and longwave IR portions of the electromagnetic spectrum, disturbed soil exhibits different spectral reflectance characteristics than undisturbed soil. Successfully detecting areas of disturbed soil is dependent on the following: the difference in spectral contrast of soils is strongest immediately after the disturbance event; the intensity of disturbance effects decreases over time due to abiotic processes; and differences in spectral contrast are likely due to differences in particle size distribution on the soil surface.

Johnson et al. (1998) discovered upon returning to the lab after field excursions that the infrared spectral character of certain soils collected in the field had changed considerably. This finding encouraged further investigation into the differences in spectral values of pristine and disturbed soils. The researchers measured and collected soil samples from the Nevada Test Site, Nevada; Ft. Huachuca, Arizona and Camp Lejeune, North Carolina. The researchers found the greatest spectral contrast between disturbed and undisturbed soils in the infrared portion of the spectrum at 8-9.5 μm (Quickbird NIR wavelength = 7.6-9.0 μm) (Figure 27). The authors conclude that bare soils exposed to the elements for extended periods of time (1week-months) are cleansed of small particles that grip larger particles. When soil is disturbed, the smaller particles from the substrate will mix with and cover larger particles, increasing the observed spectral contrast (i.e. disturbed soils have higher emissivity and reflectance than undisturbed).

This observation made by Johnson et al. is the basis for using the NIR band for analysis of areas experiencing border impacts. In theory, the Quickbird satellite has the required spectral resolution to detect spectral contrast of disturbed soil. The problem in practice with using Quickbird imagery to detect narrow trails is its spatial resolution of 2.4m. In most cases pixels are mixtures of disturbed and undisturbed areas, so spectral contrast is diluted. Another potential drawback is temporal resolution. Ideally, to test for changes in spectral contrast in the NIR band it is necessary to use 'before' and 'after' data sets that have been calibrated to remove the effects of atmosphere, sun angle, etc. Furthermore, if the imagery is not acquired repeatedly (monthly intervals), some of the lesser-used, yet still impacted trails will not likely show up, given that the soil particles can become cleansed after rains or by wind within a period of weeks.

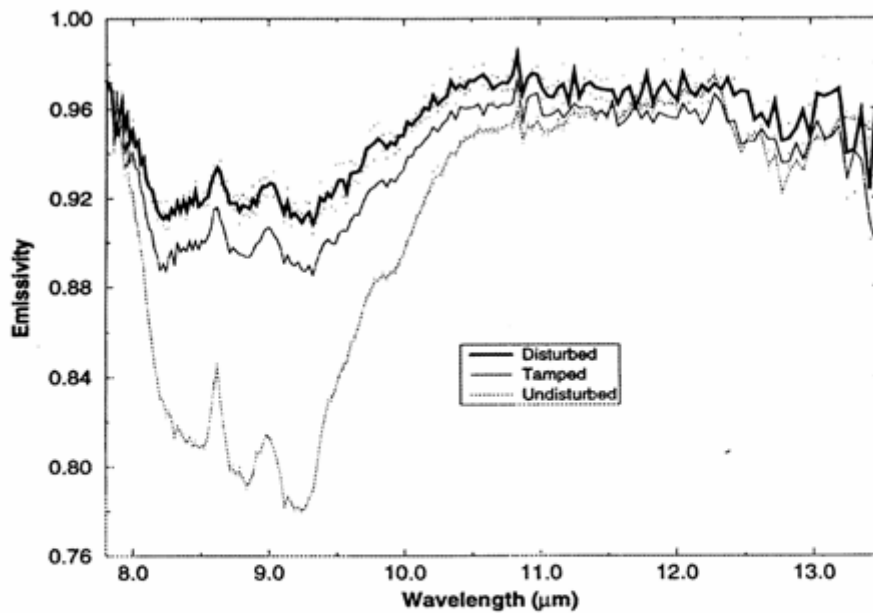


Figure 1. Example of downwelling radiance (DWR)-corrected emissivity spectra of undisturbed, disturbed and tamped (packed) soils from Ft. Huachuca, Arizona obtained with the μ FTIR spectrometer [cf. Horton et al. (1998), this issue, for details on DWR correction]. The spectral contrast difference between the undisturbed and disturbed soils is about 0.13 at 9.2 μ m. Note that the spectral contrast of the tamped soil is only slightly greater than that of the disturbed soil. Time constraints during acquisition resulted in three spectra averaged for the disturbed soil, two for the undisturbed soil, a single spectrum for the tamped soil. Dots represent standard deviation of averaged spectra.

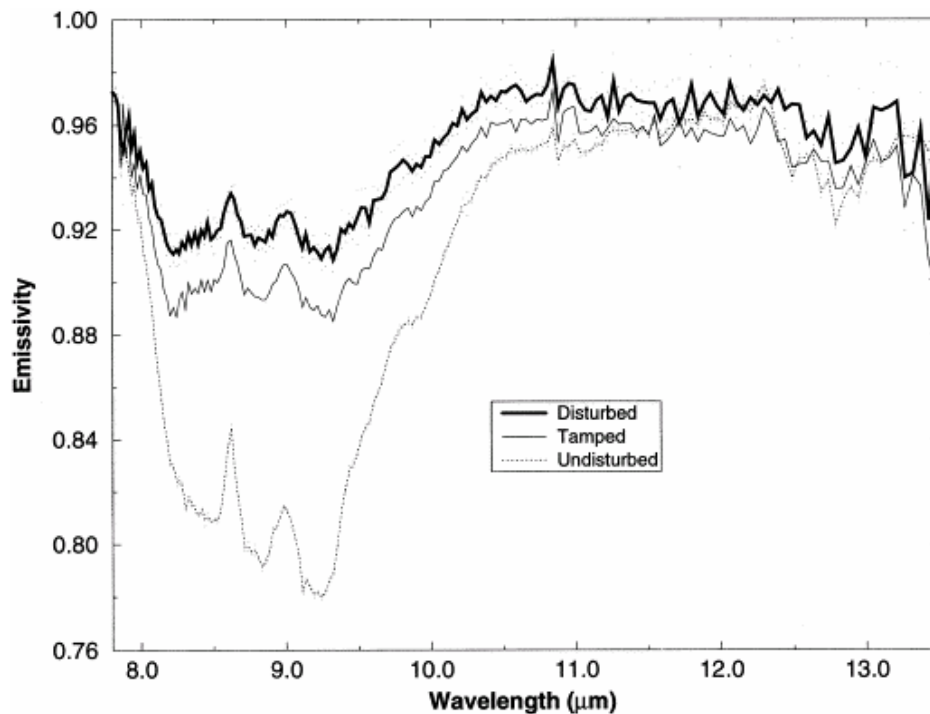


Figure 27. Spectral profiles of disturbed and undisturbed soils (taken from Johnson et al. 1998). Note the dip in emissivity values for undisturbed soils between 8–10 μ m.

Rationale for Hyperspectral Remote Sensing of Border Impacts

Hyperspectral imaging is a relatively recent development in the field of remote sensing, a mixture of traditional lab spectroscopy with aerially acquired and geographically registered pixel-based datasets. Imaging spectroscopy is commonly used for geologic applications where minerals with different chemical bonds emit and absorb energy in different regions of the electromagnetic spectrum (Clark 1999). Hyperspectral sensors typically capture more than twenty spectral bands with bandwidth as small as 10nm. For example, NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) has 224 continuous 10nm-wide channels spanning 0.4-2.5 μ m of the electromagnetic spectrum (Figure 28) (Green et al. 1998). There are literally hundreds of experimental and operational hyperspectral airborne sensors available in the United States. The following table illustrates typical bandwidth and number of bands using only a small sample of available sensors (Table 8).

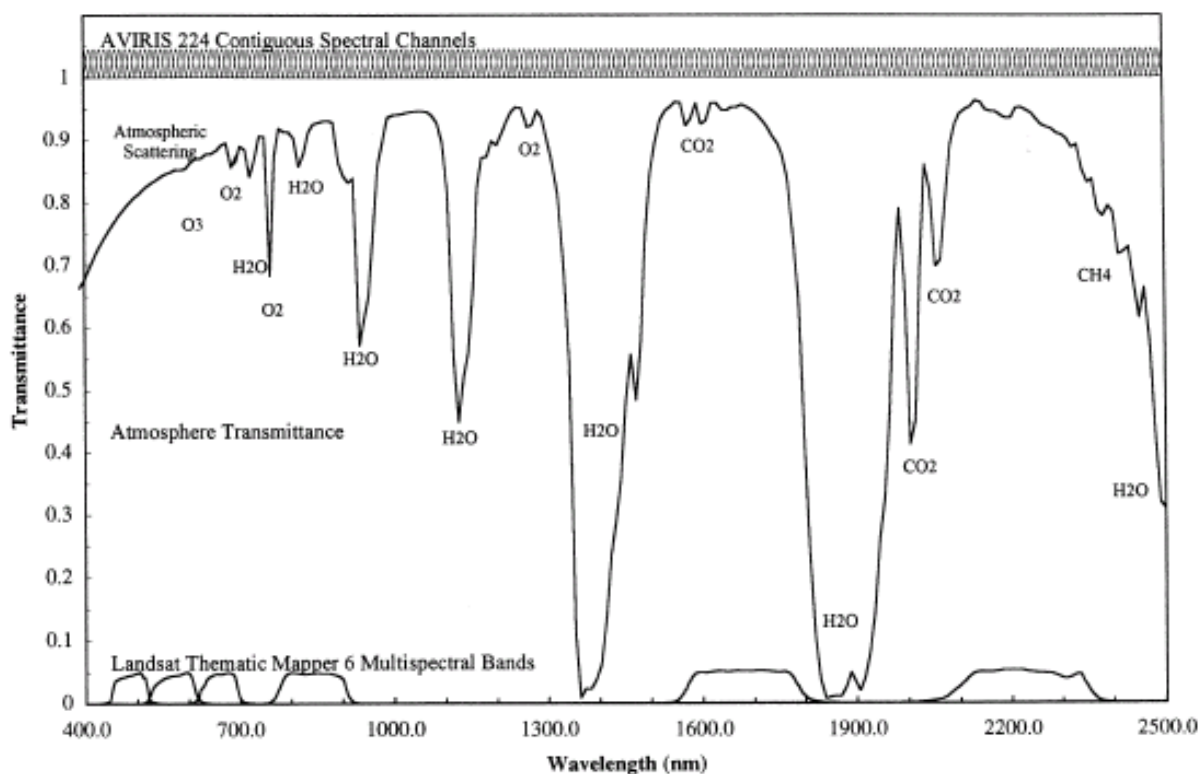


Figure 28. AVIRIS channels compared to Landsat TM multispectral bands (Green et al. 1998).

Table 8. Partial list of available hyperspectral sensors.

Satellite or Imaging Spectrometer	Launch Date	Number of bands and bandwidth
Airborne Visible Infra Red Imaging Spectrometer (AVIRIS)	airborne	224 bands (10nm)
Compact Airborne Spectrographic Imager (CASI)	airborne	288 bands (1.8nm VIS/NIR)
Earth Observer 1 (Hyperion)	2000	242 Bands (10nm) 30m GSD
High Altitude Reconnaissance Platform (HARP)	airborne	384 bands (128 in VNIR, 256 SWIR)
HyMap	airborne	126 bands (10-20nm)
Hyperspectral Digital Imagery Collection Experiment (HYDICE)	airborne	210 bands (10nm)
PROBE 1, 1.2	airborne	128 bands (64 VNIR, 64 SWIR)
TRWIS III	airborne	384 bands (5.25nm VIS, 6.25nm SWIR)

Hyperspectral Remote Sensing of Disturbed Soil

Hyperspectral image analysis is a potentially powerful tool for monitoring human impacts on border parks. Military applications of remote sensing for landmine detection have generated considerable research on uses of hyperspectral imagery for the detection of disturbed soil (DePersia et al. 1995, Maathuis and Van Genderen 2004). The implementation of hyperspectral remote sensing data for mine detection is based on the notion that initial mine placement will disturb the soil surface, creating contrasting spectral signatures when compared to surrounding undisturbed soil. According to DePersia et al. (1995), broadband or visible remote sensing systems can be used to detect changes in texture on the surface, but the local visual effects are ephemeral due to weathering processes. Infrared bands are also useful to some extent in detecting differences in surface and subsurface soil properties (particle size or soil moisture content; 1.1-2.0 μm is useful for moisture detection). These differences in soil properties are also influenced by abiotic conditions and have similarly short life spans.

The spectral region of 3-5 μm is the most useful for detecting soil disturbance for mine detection because of the spectral features of soil and mineral compounds (DePersia 1995). Disturbed soil is also known to have distinct spectral characteristics in the thermal region. When soil is disturbed, the density of the surface is changed, which may lead to lower thermal conductivity. Due to the requirements for successfully detecting thermal radiation, which is emitted rather than reflected, most satellite-based thermal sensors are designed with especially low spatial resolutions and are of limited use for border impacts monitoring. There exist some airborne sensors, like the Daedalus DS-1260 and DS-1268 Airborne Multispectral Scanners (AMS) and the NASA Thermal Infrared Multispectral Scanner (TIMS) that have spatial resolutions as low as 2.5m depending on the flight altitude (Jensen 2000).

DePersia et al. (1995) offer three generalized remote sensing models for determining disturbed areas: 1) dual band spectral processing; 2) a spectral matched filter approach; and 3) spectral anomaly detection. The first method, dual band spectral processing, requires one band be multiplied by a constant (one that might minimize unusable background noise in the output image), then subtracted from the other band. The resulting output image highlights disturbed areas of interest. The spectral matched filter technique is similar to the dual band, but includes many spectral bands and *a priori* knowledge of the target's spectral signature (i.e. subsurface soil signature, mixed or covered soil particles). Finally, spectral anomaly detection can be used with hyperspectral data to detect "color" differences in neighboring pixels.

Many of these experiments describing spectral characteristics of soil were conducted in the laboratory, and the applicability of the findings for remote detection are not evident. In their review of remote sensing techniques for minefield detection, Maathuis and Van Genderen (2004) acknowledge that the spatial resolution of most commercial satellite systems (covering most wavelengths) are far too coarse to pick up soil disturbance at the mine-scale. Spectral mixing may lead to unfavorable results. Soil spectral contrast also varies over different types of soils and surface textures (Kirkland et al. 2001), so it is likely that different processing techniques would be needed over different areas.

If hyperspectral signatures of the disturbed area are known, and the spatial resolution of the imagery approximates or is smaller than the disturbed area, a linear correlation coefficient (LCC) thresholding approach can be used to locate all pixels in the image containing similar signatures (Achal et al. 1999). Achal et al. (1999) successfully used this method with CASI imagery (sixteen-32nm VNIR bands with 10-20cm spatial resolution). Goovaerts et al. (2005) describe methods for detecting disturbed soil using a combination of geostatistical methods and Probe-1 hyperspectral imagery. The authors focused on two types of image anomalies around Yellowstone National Park: staged ground tarps (not unlike the target GCPs and simulated trash piles used at Chiricahua-Ft. Bowie) and mine tailings (considered disturbed soil). The authors used spatial statistics based on autocorrelation to remove “regional background” (all general scene elements) and enhance local contrast signals. The authors also suggest using a principal components transform for the multidimensional Probe-1 data sets to reduce the dimensionality of the data.

In grassland ecosystems, studies of grassland quality using hyperspectral imaging offer encouraging results for remote sensing-based trail detection. Multispectral imagery has long been used to monitor the effects of cattle grazing on grass dominated semi-arid ecosystems, where grazing impacts are monitored using multitemporal VI measurements (Pickup et al. 1994). At a study site in Grand Staircase-Escalante National Monument, Harris and Asner (2003) measured the effects of cattle grazing on park grasslands using a spectral unmixing approach with AVIRIS data. The approach was calculated to determine the percent bare ground, photosynthetic vegetation and non-photosynthetic vegetation in each pixel and establish a “grazing gradient” based on these three endmembers (Harris and Asner 2003). Spectral unmixing assumes that the relative abundance of surface materials produces a linear mixing of effects, which can be calculated per pixel. High accuracies have been reported with spectral unmixing techniques, but the method requires *a priori* knowledge of reference spectra in the area, and can provide inaccurate results if some spectral endmembers are inaccurately characterized or are neglected in analysis. In theory this approach to hyperspectral analysis could be used to measure border impacts at grass dominated border parks (e.g. Coronado Nat. Mem.) and could potentially be used to map trail networks.

While there are obvious advantages to using hyperspectral compared to multispectral imagery, there are also disadvantages. There are the logistical challenges of cost, data volume and processing software required. High spatial resolution hyperspectral sensors are typically mounted to small aircraft, and the use of both sensor and aircraft can be costly. With between 20 and 200+ bands per image, hyperspectral datasets are large and it may be difficult for park personnel with little remote sensing expertise or infrastructure to manage and analyze these data.

Current and Future Multispectral Satellite Programs

There are currently 20 satellites with optical sensors having 30m or better resolution in orbit (Table 9), and 15 more planned to launch by 2010 (Stoney 2006). Of these, 6 will have high-resolution panchromatic sensors with pixels 1 m or smaller (Table 10) (Stoney 2006). These numbers offer some promise for multispectral remote monitoring of border impacts. As more platforms are placed in orbit, the tendency will be for imagery prices to fall with competition.

With more affordable imagery, a monitoring program becomes more feasible and effective, as more frequent "looks" can be acquired and examined for change.

Table 9. Currently available multispectral land imaging satellites (Stoney 2006).

Satellite	Country	Launch Date	Panchromatic Resolution, m	Multispectral Resolution, m	Swath Width, km	Commercial Origin?
CBERS-2	China/Brazil	2003	20	20	113	no
DMC AIsat-1	Algeria	2002	x	32	600	no
DMC BiSat	Turkey	2003	12	26	52	no
DMC China	China	2005	4	32	600	no
DMC NigeriaSat-1 (SSTL)	Nigeria	2003	x	32	600	no
DMC ThaiPhat (SSTL)	Thailand	2004	x	36	600	no
DMC UK (SSTL)	UK	2003	x	32	600	no
EO-1 (ALI)	US	2000	10	30	37	no
EROS A1	Israel	2000	1.8	x	14	yes
IKONOS-2	US	1999	1	4	11	yes
IRS 1C	India	1995	6	23	70, 142	no
IRS 1D	India	1997	6	23	70, 142	no
IRS Cartosat 1	India	2005	2.5	x	30	no
IRS ResourceSat-1	India	2003	6	6, 23, 56	24, 140, 740	no
KOMPSAT-1	Korea	1999	6.6	x	17	no
Landsat 5	US	1984	x	30	185	no
Landsat 7	US	1999	15	30	185	no
MONITOR-E-1	Russia	2005	8	20	94,160	no
MTI	US	2000	x	5,20	12	no
OrbView 3	US	2003	1	4	8	yes
Proba	ESA	2001	8	18, 36	14	no
Quickbird-2	US	2001	0.6	2.4	14	yes
RocSat2	Taiwan	2004	2	8	24	no
Spot-2	France	1990	10	20	120	no
Spot-4	France	1998	10	20	120	no
Spot-5	France	2002	2.5	10	120	no
TERRA (ASTER)	Japan/US	1999	x	15,30,90	60	no
TopSat (SSTL)	UK	2005	2.5	5	10.15	no
Tsinghua-1	China	2000	x	39	600	no

Table 10. Planned multispectral sensors (Stoney 2006).

Satellite	Country	Launch Date	Panchromatic Resolution, m	Multispectral Resolution, m	Swath Width, km	Commercial Origin?
ALOS	Japan	2006	2.5	10	35,70	no
CBERS-2,3,4	China/Brazil	2006-10	2,5,20	20	60-120	no
IRS ResourceSat-2	India	2006	6.0	6, 23, 56	24, 140, 740	no
DMC VinSat-1	Vietnam	2006	4	32	600	no
KOMPSAT-2	Korea	2006	1	4	15	no
R26m	South Africa	2006	x	7.5	?	no
RazakSat	Malaysia	2006	2.5	5	x	no
Resurs DK-1	Russia	2006	1	3	28	no
OrbView 5	US	2007	0.41	1.64	15	yes
RapidEye-A-E	Germany	2007	x	6.5	78	yes
THOES	Thailand	2007	2	15	22,90	no
EROS-C	Israel	2008	0.7	2.5	7,16	yes
Pleiades-1,2	France	2008-09	0.7	2.8	20	no
WorldView-2	US	2008	0.5	1.8	16	yes
X-Sat	Singapore	2008	x	10	50	no
LDCM (NPOESS)	US	2010	10	30	177	no

Conclusions

The primary conclusion from this work is that remote sensing has some, though conditional, value for detecting and monitoring border-related and other impacts to cultural resources. There are many types of remote sensing instruments, on airborne and satellite platforms, and their applicability to this task varies. The key is having the right spectral bands available at a fine enough spatial resolution to capture small features like trails. The commercially (and conveniently) available 4-band multispectral imagery we employed, when sharpened to its potential 0.6 meter spatial resolution, can detect some foot trails and vehicle tracks on some (vegetated) substrates, and concentrations of trash such as clothing can be detected if they are not obscured by tree or shrub canopies (the same caveat applies to detection of trails or any other features of interest). To the extent that multiple images of the same area can be acquired and processed for change detection, remote sensing can be used for monitoring surface impacts to resources over time. Limitations of cost and image processing expertise will tend to shape a monitoring program. Hyperspectral remote sensors (airborne) have the potential to detect more subtle surface soil disturbances than 4-band sensors, but the issues of cost and required expertise are even more acute. A general strength of remote sensing is that it provides full areal coverage, and so offers more complete data than can practically be obtained from transects or sample plots.

That few quantifiable, border-related impacts to cultural resources at Chiricahua Nat. Mon., Ft. Bowie NHS and Palo Alto Battlefield NHS were documented in the field and imagery is a noteworthy outcome of this project. While this is positive for park management, and established baseline conditions for management against which any future impacts can be measured, it limited our findings and our ability to verify or refute our hypotheses related to quantitative comparison of satellite- and ground-based detection of impacts (1, 2 and 4, Introduction).

We are able to say qualitatively, and with some quantitative testing, that our hypothesis (3) related to vegetation indices was refuted. Vegetation indices based on 4-band radiance data are not a useful tool for detecting disturbance to sparsely vegetated soil surfaces. This is primarily due to the complex interactions of different vegetation and soil types in determining index values, and the possibility of confusing the effects of vegetation with those of soil disturbance. Trails and roads created on vegetated surfaces can be detected in high spatial resolution imagery by their visible impacts on the vegetation. These include, in principle, a reduction in the vegetation index values of damaged vegetation compared to adjacent healthy vegetation. In practice, trails are recognized by visual interpretation as lineaments with overall higher reflectance or brightness than the matrix they are in, usually due to the exposure of more bare soil.

The issue of ascribing a source or cause to any detected trails is not directly addressable by remote sensing, though sometimes inferences can be made through image interpretation. Recreational hiking trails can sometimes be differentiated from cross-border trails by their direction, origin and destination, for example.

Our last hypothesis was largely verified, with some confidence. While some types of trash such as clear plastic bottles are not spectrally distinct in 4-band imagery, other types such as clothing are very distinct and can be readily detected against a vegetated or bare soil background using

Quickbird panchromatic imagery if the clothing or trash are somewhat concentrated and cover a few square meters, and are not obscured by tree or shrub canopies.

Of the eight project objectives, all but one (3, Introduction) were completed successfully. Objective 3, determining a quantitative relationship between the trails and other impacts present on the ground and those visible in the imagery, was not achieved due to the unforeseen lack of significant impacts actually present near the three parks studied. The first two objectives involving acquisition, orthorectification and pansharpening of the imagery presented no difficulty. Experimental targets were placed in the field near enough to the time of image acquisition to avoid disturbance. The other objectives involved testing of image processing methods and review of literature possibly applicable to monitoring impacts to cultural resources, and produced some negative and some positive findings.

Objective 4, to test the ability of image processing methods to detect simulated trash piles, produced a positive result showing that trash consisting of discarded clothing is detectable in panchromatic imagery through histogram stretching and examining the brightest pixels. In contrast, however, accumulations of plastic bottles, another common type of border-related trash, are not detectable through spectral manipulation of panchromatic or 4-band visible-NIR imagery such as Quickbird.

Objective 5, to test the ability of image processing methods to distinguish active trails from surrounding bare soil, produced a negative result with Quickbird imagery. Active trails on dry, sandy soils were not spectrally distinguishable from their surroundings. Footprints and wheelprints are, of course, not visible in imagery with a spatial resolution of 0.6 m.

However, Quickbird resolution is sufficiently fine to detect trails on many vegetated surfaces, when the vegetation has been disturbed enough to expose some bare soil along the trail. Trails in tall grass can often be detected visually simply because the grass along the trail has been flattened somewhat. Thus our objective 6 produced a partly positive result, indicating that trail network density on most vegetated surfaces can be monitored using Quickbird imagery. Disturbance that is sufficient to produce even fairly subtle impacts to vegetation will generally be visible and can be monitored with repeated imagery acquisitions. More work is needed to establish quantitative relationships between the trails visible in imagery and those on the ground in different environments for one-time assessments of impacts to cultural resources, or to provide baseline information to start a monitoring program. But examining changes from an initial image to a later one of the same area, such as the creation of new trails or the re-growth of vegetation, should be a feasible and effective method for monitoring impacts.

Project objectives 7 and 8 were to review the most recent research on image processing techniques that might be applicable to impact detection and monitoring, and to look at other current and future sources of remote sensing imagery that could be practically employed. These reviews demonstrated a dearth of promising tools, unfortunately. The literature points toward hyperspectral sensors as having the best potential to detect soil surface disturbance and non-natural elements such as trash, but there are major obstacles to using this technology in an NPS monitoring program. The biggest of these is the need to have fine spatial resolution data to detect small areas of disturbance, resulting in impractical data volume and cost. Future

multispectral satellites with spatial resolution somewhat better than Quickbird's are expected to launch in the next few years – OrbView-5 with 1.64 m resolution in 2007, and WorldView-2 with 1.8 m resolution in 2008. With the right combination of NIR or mid-IR bands, these could provide data for examining surface disturbance at a resolution approaching that needed by NPS.

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