FINAL REPORT

Grant Number: MT-2210-05-NC-12

Project Title: Testing the Regional Reliability of Spectral Signatures of Archaeological Phenomena

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Date: September 30, 2006

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EXECUTIVE SUMMARY

The research reported herein focuses on developing and testing predictive models based on the satellite remote-sensing (SRS) of prehistoric and historic archaeological phenomena. With advances in the resolution of satellite-borne imagery, such as IKONOS, and the availability of software designed to process such imagery, such as ENVI, archaeological predictive modeling is positioned to progress beyond simplistic "indirect" correlational studies involving gross ecological categories or subjective landform designations. These developments are particularly important because previous applications of SRS have focused principally on comparatively uncommon large-scale and obtrusive archaeological remains, thereby constraining the range of SRS applications and disincentivizing the exploration of the technology's predictive modeling capabilities. To take advantage of these technologies, we investigate the potential of high-resolution SRS of small-scale and low-obtrusive archaeological phenomena from the Upper Basin of northern Arizona (Kaibab National Forest, Tusayan Ranger District) to develop a new approach to predictive modeling. We illustrate how the GPS-determined locations of the Upper Basin's masonry structures, brush structures, fire-cracked-rock piles, lithic scatters, and sherd-and-lithic scatters can be overlaid on the pixels of a geo-registered, clipped, and masked IKONOS image to yield distinctive spectral signatures. In this case, variation among these five types of archaeological phenomena was sufficiently robust, principally with respect to their reflectance properties, that they registered very differently with the IKONOS satellite sensors. The reliability of a predictive model based on these SRS-based spectral signatures was subsequently tested in newly surveyed terrain. The model correctly predicted the presence and the absence of the five types of archaeological phenomena at extremely high rates (100% and 99.4%, respectively). One major methodological finding of this study is that the resolution of pixels needs to be adjusted from the default imagery settings in order to avoid producing an over-abundance of false positives. In other words, failure to degrade the SRS image from 1m to 4m will result in heavy environmental mimicry of archaeological phenomena, which essentially over-predicts their regional frequencies (leading to inaccurate predictive estimates). Additional research is needed to understand how "tweaking" of pixel resolution affects the derivation of spectral signatures of different archaeological phenomena and the extent to which they then can be accurately estimated on a regional basis. As these "direct" predictive models are refined they will become increasingly more useful in historic preservation and heritage management, especially with respect to identifying archaeologically sensitive areas that require special management actions, such as dynamic monitoring, protection, or exclusion.

1. Introduction to the Research

With increasing recreational pressure on public lands and declining federal heritage-resource management budgets, cultural resources are at greater risk than ever (Uphus et al. 2006). Hence, there is a pressing national need to develop cost-effective and time-saving supplements, such as accurate predictive models, to traditional Phase I pedestrian based heritage-resource discovery and documentation strategies (Fowler 2002; Sullivan 1988). This research project investigates the potential of satellite remote sensing, or SRS, in developing models that directly predict the occurrences of small-scale and low-obtrusive archaeological phenomena based on their spectral signatures (Sever 2000:22). In essence, we are exploring the extent to which predictive models that are based on the remotely-sensed characteristics of known archaeological phenomena can be used to reliably forecast the occurrence of unknown archaeological phenomena. Importantly, our study differs from earlier applications of satellite-borne imaging (e.g., Custer et al. 1986; Schaber and Gumerman 1969), and hence has a greater chance of illustrating the advantages and limitations of this approach under various circumstances, because of the characteristics of archaeological data base that form the "known" side of the predictive model: (i) high density of small-scale phenomena (ca. 68.4 archaeological phenomena per square kilometer), (ii) accurate GPS-determined locations (i.e., 99% horizontal precision = 1.9m-3.2m), and (iii) consistent survey methodology (Sullivan et al. in press).

The basic idea behind this approach is a relatively simple one: because humans rearrange matter by selectively concentrating objects and materials from the natural environment, the byproducts of those activities will register differentially on the satellite sensors in comparison to unmodified portions of the same landscape (Ascher 1968; Sullivan in review). This anthropogenic perspective on remote sensing is fully compatible with the physical theory behind sensor design, i.e., variation (heterogeneity) in reflectance among pixels will record the consequences of human activity that arise as people move rocks and vegetation (thereby affecting their density per unit area), burn vegetation (Sullivan 1996), or obscure the Earth's surface by disposing of objects upon it (e.g., Buck et al. 2003).

2. SRS of Small-Scale and Low-Obtrusive Archaeological Phenomena

As Table 1 shows, application of SRS technology to the detection of archaeological phenomena has not only be uneven geographically, with clusters of studies having been conducted in the Old World and eastern North America (Johnson et al. 1988; Giardino and Haley 2006:50-52; Giardino and Thomas 2002), but biased toward the investigation of relatively large-scale and conspicuous remains, such as temples and platform mounds (e.g., Gidwitz 2002; Johnson and Haley 2006). In addition, the recent edited volume, Remote Sensing in Archaeology (Johnson 2006), devotes only a handful of pages to SRS -- the vast portion of the volume is focused on exhaustive treatments of terrestrial modes of remote sensing, and generally of fairly large-scale architectural phenomena (ca. 10m or larger; e.g., Challis et al. 2004). However, high-intensity, "full-

coverage," inventory surveys have shown that for many areas of the American Southwest (Anderson 1990), for instance, small-scale (< 10m) architectural remains are the most common type of obtrusive heritage property, particularly on public lands (Sullivan et al. 2002a). As well, low-obtrusive surface artifact-scatters are, in many parts of the country (if not worldwide), the most abundant type of archaeological site overall (Sullivan and Uphus 2002).

Table 1. Examples of the use of satellite remote-sensing (SRS) in the investigation of archaeological phenomena.

Study	**Area of Study**	**Size of Study Area**	**Phenomena**
Goossens et al.	Altai Mountains (Russian Republic)	Unspecified	Large-scale geographic areas
Giardino and Thomas	Cumae (Italy), Koobi Fora (Kenya), Troy (Asia Minor), Aksum (Ethiopia), Gainesville (Mississippi)	N/A	Large-scale geographic areas
Fowler	Iron Age hillfort Figsbury Ring, Wiltshire, UK	9km x 15km	Medium-scale site features (roads, ancient fields, etc.)
Harrower et al.	southern Yemen	370km x 185km	Large-scale landscape types
Challis et al.	al-Raqqa (northern Syria)	Unspecified, but photos entail several kilometers	Large-scale "small" ancient city; medium-scale site features (e.g., clay pits, roads, etc.)
Johnson et al.	northern Mississippi	78,430 acres	Large-scale landscape types
Montufo	Part of the island of Mallorca, Spain	1,250 sq km	Large- to medium-scale agricultural boundaries and fields
Johnson	northern Mississippi	1,760 hectares	Large-scale landscape types
Johnson and Haley	Hollywood Mound in northern Mississippi	20m x 20m test unit	Medium-scale site features (large houses)
Gidwitz	Bajo la Justa (Yaxha Site, Peten district, Guatemala)	23 sq miles	Large-scale geographic features (bajos); medium-scale site features (temples)

One of the main aspects of our research, then, is to ascertain whether it is possible to develop discovery and interpretive protocols based on SRS that will facilitate research and, ultimately, management of the most common and less obtrusive forms of heritage resources (cf. Goossens et al. 2006; Sullivan et al. 2002b). In contrast to previous SRS studies, therefore, our research explores the remotely-sensed properties (spectral signatures) of known archaeological phenomena to build, test, and assess the accuracy of direct predictive models regarding the location and identification of unknown (i.e., previously undiscovered) small-scale and low-obtrusive archaeological phenomena (e.g., Frohn 2003).

3. The Upper Basin Study Area in Northern Arizona

The Upper Basin is a graben of the northeastern portion of the Coconino Plateau that originates from the eastern South Rim of the Grand Canyon in northern Arizona (Figure 1; Babenroth and Strahler 1945; Huntoon 1990). For the past 4,000 years, at least, a dense pinyon-juniper forest has covered the majority of the Upper Basin countryside (Cole 1990). Despite variation in the extent of different vegetation communities (Rand 1965), the density of trees and shrubs does not hinder observation of the ground's surface, which means that visibility and accessibility are high (Sullivan 2000).

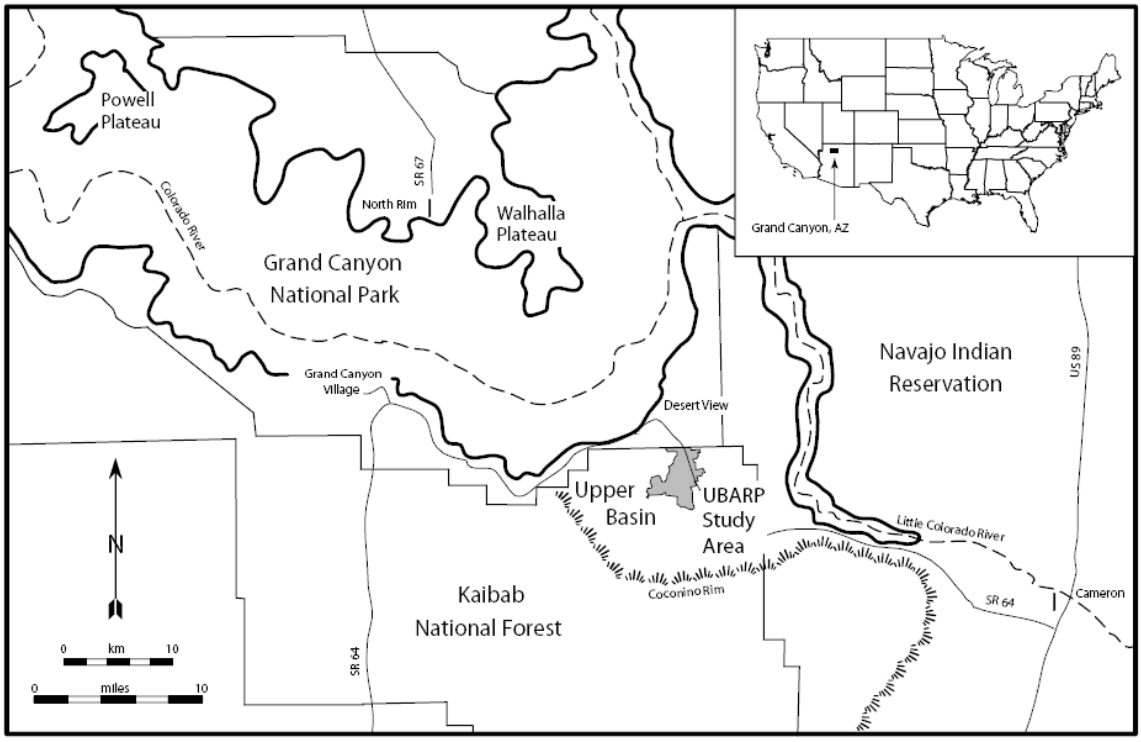

Figure 1. Location of the Upper Basin in northern Arizona (UBARP = Upper Basin Archaeological Research Project).

Furthermore, geoarchaeological investigations of an alluviated valley within the Upper Basin, known as Simkins Flat, as well as systematic inspection of major drainages within the area, have disclosed no buried archaeological phenomena (Sullivan and Ruter 2006). Therefore, archaeological phenomena in the study area stand an excellent chance of being detected by SRS and by intensive surface survey (for ground-truthing purposes).

Since 1989, the Upper Basin Archaeological Research Project (UBARP) has been conducting archaeological investigations in the Upper Basin employing both intensive survey (i.e., inter-surveyor distance is 10m) as well as strategic excavation of a variety of sites (Sullivan 1986; Sullivan et al. 2003; see also Whittlesey 1992). For the purposes of this study, we focus on five of the most common types of archaeological phenomena that have been recorded on survey and that have been the focus of detailed recording and excavation (Uphus 2003): masonry structures, brush structures, fire-cracked-rock piles, lithic scatters, and sherd-and-lithic scatters (Table 2; details for each survey area are provided below). These prehistoric and historic archaeological remains, such as architectural ruins (masonry structures and brush structures) that average 6.9m in maximum length (median = 6.2m, n = 348), fire-cracked-rock piles that do not exceed 8m in maximum length (mean is 4.1m, median is 4.0m, n = 133), and artifact scatters (non-architectural remains and non-feature remains) that average 36.1m in diameter (median = 29m, n = 490), are small-scale phenomena by any measure (e.g., Hargrave 2006).

Table 2. Counts and percents of archaeological phenomena broken down by type and survey area. Survey Area “0” represents the “training” data for the predictive model that

		TYPE					
SURVEY AREA		Masonry Structure	Brush Structure	Fire-cracked-rock Pile	Lithic Scatter	Sherd-and-lithic Scatter	Total
0	Count	219	105	142	496	182	1,144
	Percent within Survey Area 0	19.1%	9.2%	12.4%	43.4%	15.9%	100.0%
1	Count	14	10	0	36	10	70
	Percent within Survey Area 1	20.0%	14.3%	.0%	51.4%	14.3%	100.0%
2	Count	4	1	3	40	6	54
	Percent within Survey Area 2	7.4%	1.9%	5.6%	74.1%	11.1%	100.0%
3	Count	4	0	2	12	5	23
	Percent within Survey Area 3	17.4%	.0%	8.7%	52.2%	21.7%	100.0%
Total		241	116	147	584	203	1,291

was tested subsequently with data from Survey Areas 1, 2, and 3.

The positions of these phenomena have been determined by differentially-corrected GPS software (Trimble Pathfinder 2.9) and consequently are horizontally accurate to within 1.9m-3.2m of their "true" locations on the Earth's surface (which is the highest resolution possible given the capabilities of our Trimble GeoExplorer 3 data logger units; cf. Harrower et al. 2002:39). For consistency, the actual GPS "point" was taken in the field at the center of the interiors of architectural remains (masonry structures and brush structures) and features (fire-cracked-rock piles), and at the densest concentration of artifacts for the lithic scatters and sherd-and-lithic scatters (Uphus 2003). These procedures were intended to provide as much "sensor-registerable" contrast as possible between environmental and cultural phenomena.

Survey Area 0 ("Training Data")

The archaeological phenomena of Survey Area 0, which is 16.20 square kilometers in area and has been surveyed repeatedly at high intensity between 1989 and 2003, serve as the "training" data for the predictive modeling study (Figure 2). The density per square kilometer of masonry structures (n = 219), brush structures (n = 105), fire-cracked-rock piles (n = 142), lithic scatters (n = 496), and sherd-and-lithic scatters (n = 182) is 13.5, 6.5, 8.8, 30.6, and 11.2, respectively.

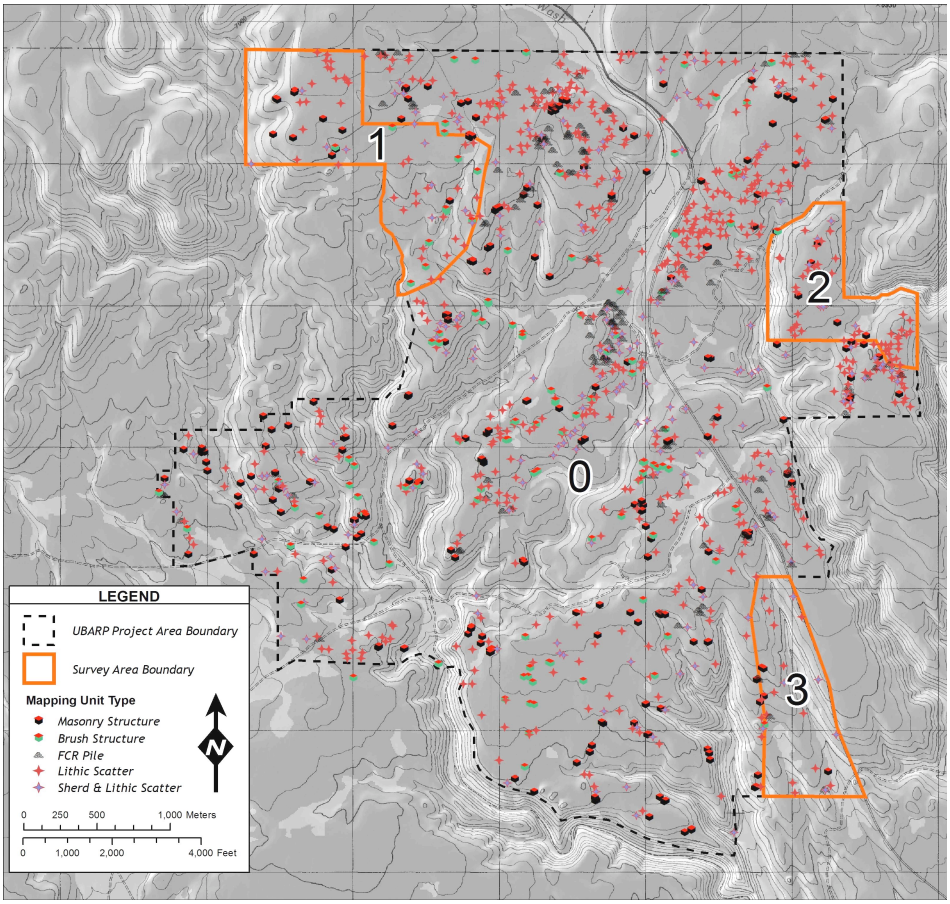

Figure 2. UBARP Study Area showing the locations of 1,144 archaeological phenomena in Survey Area 0 broken down by type (Survey Areas 1-3 are shown for context).

Survey Area 1

Survey Area 1 (surveyed in 2006) is 1.32 square kilometers in area, and 70 archaeological phenomena were found within it (Figure 3). Overall, the density per square mile of archaeological phenomena (53.0) is considerably lower than that of Survey Area 0 (70.6), which is attributable to the more rugged terrain of Survey Area 1. The densities of specific types of archaeological phenomena are, with the exception of brush structures, lower, as well: for masonry structures (n = 14), brush structures (n = 10), fire-cracked-rock piles (n = 0), lithic scatters (n = 36), and sherd-and-lithic scatters (n = 10) the density values are 10.6, 7.6, 0.0, 27.3, and 7.6, respectively.

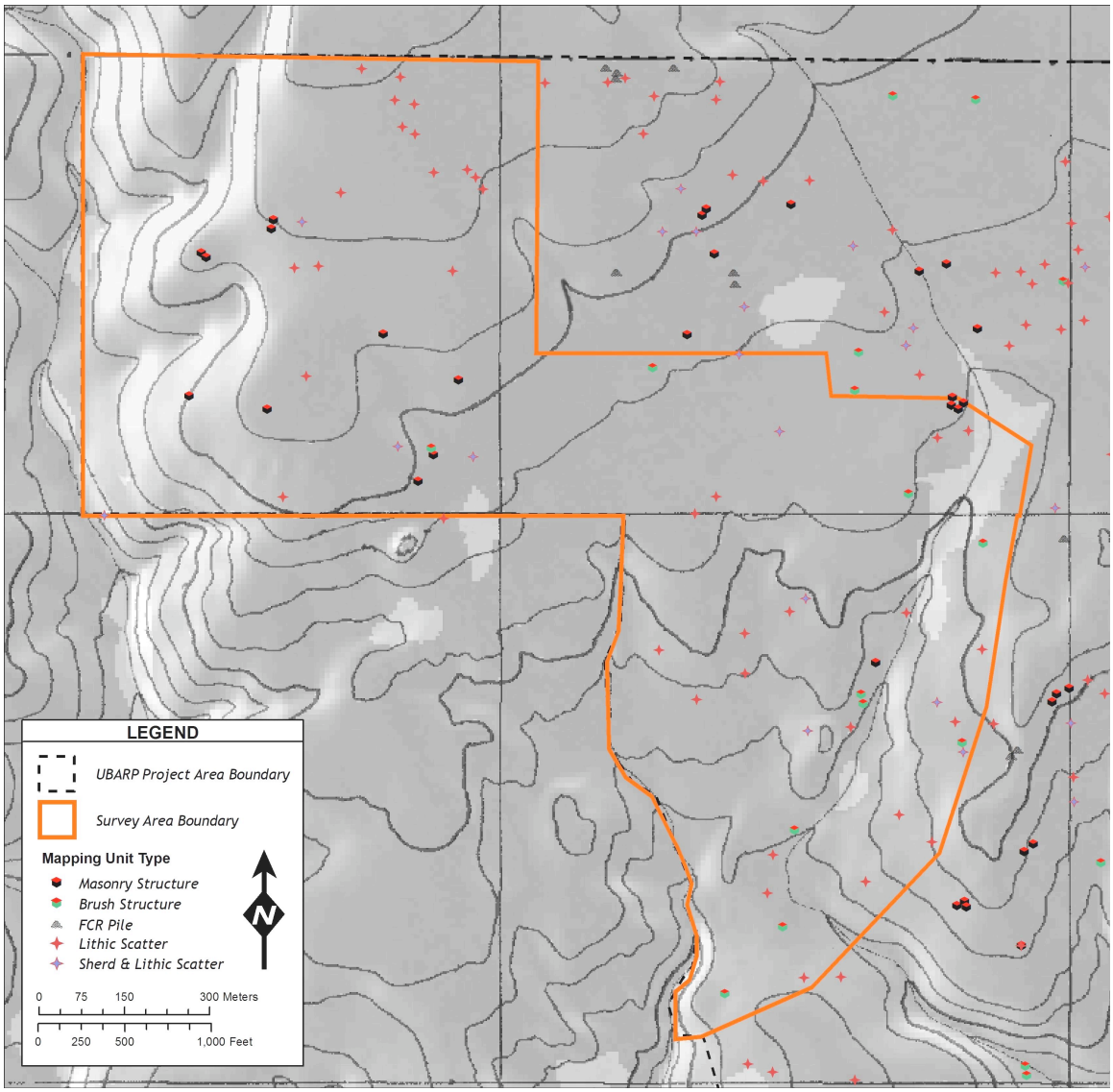

Figure 3. Spatial distribution of 70 archaeological phenomena, broken down by type, in Survey Area 1.

Survey Area 2

Survey Area 2 (surveyed in 2006) is .71 square kilometers in area, and 54 archaeological phenomena were found within it (Figure 4). Overall, the density per square mile of archaeological phenomena (76.1) is comparable to Survey Area 0 (70.6) and considerably higher than that of Survey Area 1 (53.0). Interestingly, with the exception of lithic scatters, the densities of specific types of archaeological phenomena are dramatically lower than Survey Area 0: for masonry structures (n = 4), brush structures (n = 1), fire-cracked-rock piles (n = 3), lithic scatters (n = 40), and sherd-and-lithic scatters (n = 6) the density values are 5.6, 1.4, 4.2, 56.3, and 8.5, respectively.

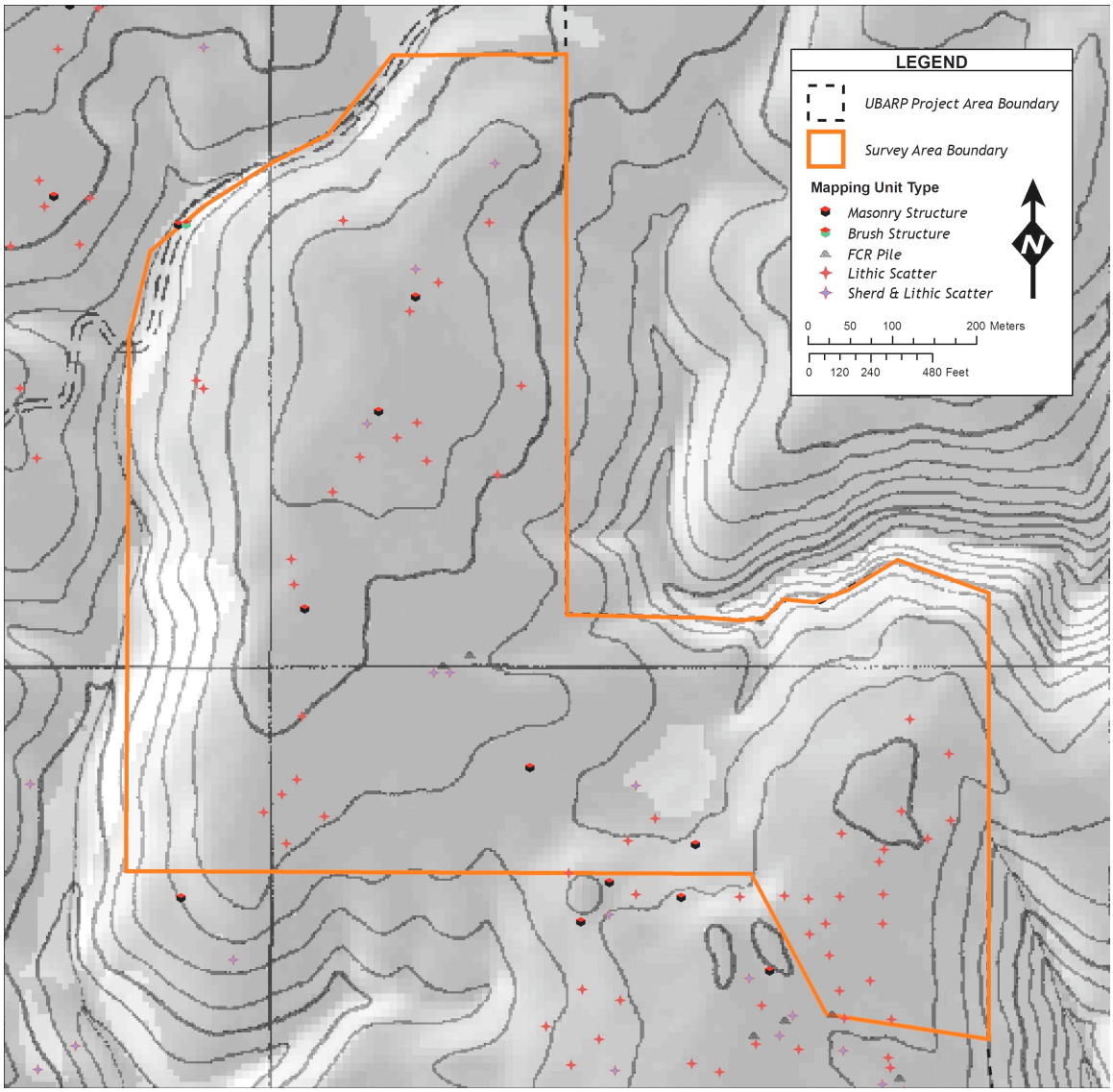

Figure 4. Spatial distribution of 54 archaeological phenomena, broken down by type, in Survey Area 2.

Survey Area 3

Survey Area 3 (surveyed in 2006) is .65 square kilometers in area, and 23 archaeological phenomena were found within it (Figure 5). The density per square mile of archaeological phenomena (43.8) is the lowest of any survey area, which may be attributable to the fact that Survey Area 3 lies at the southern edge of the dense zone of the pinyon-juniper woodlands in the Upper Basin where the countryside is far more open and juniper begins to outnumber pinyon (Brewer et al. 1991; the yellow-green areas in Figure 10 below illustrate this pattern). However, with the exception of lithic scatters, the densities of specific types of archaeological phenomena are comparable to those for Survey Area 2: for masonry structures (n = 4), brush structures (n = 0), fire-cracked-rock

piles (n = 2), lithic scatters (n = 12), and sherd-and-lithic scatters (n = 5) the density values are 6.2, 0.0, 3.1, 18.5, and 7.7, respectively.

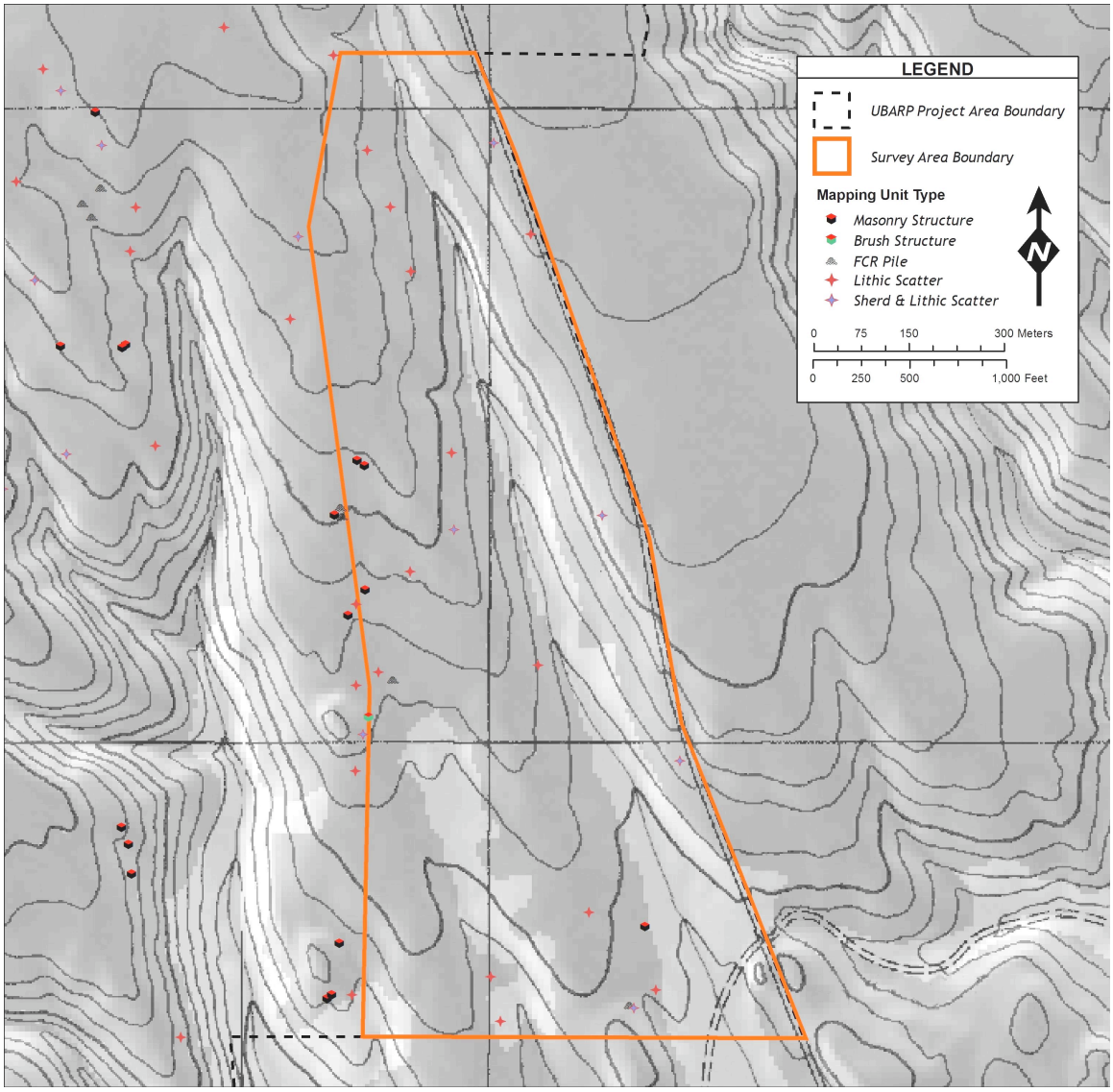

Figure 5. Spatial distribution of 23 archaeological phenomena, broken down by type, in Survey Area 3.

Discussion

Of the four survey areas, Survey Area 2 is notable because of its comparatively low frequency and density (per square kilometer) of masonry structures and its very high frequency and density of lithic scatters (Figures 6 and 7). In terms of "footprint"

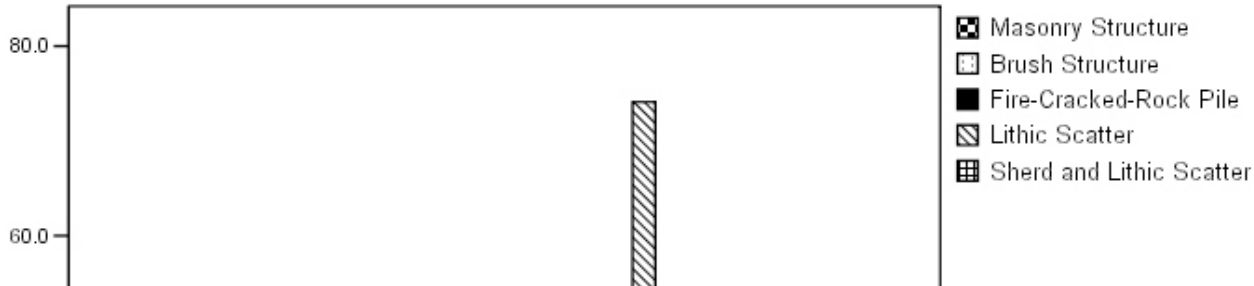

Figure 6. Bar chart diagram showing the percentages of the five types of archaeological phenomena located in the four survey areas.

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measures, a series of Kruskal-Wallis nonparametric tests revealed no statistically significant differences among the four survey areas with respect to masonry or brush structure size (Chi-square = .996, p = .802 for masonry structures; Chi-square = 2.336, p = .311 for brush structures), fire-cracked-rock pile size (Chi-square = .419, p = .811), and sherd-and-lithic scatter size (Chi-square = 4.612, p = .203). However, lithic scatters from Survey Area 1 are significantly larger than those from Survey Areas 0, 2, and 3 (Chi-square = 20.696, p <.001). These results suggest that the spectral characteristics of the "knowns" from training set data for structures (both masonry and brush), fire-cracked-rock piles, and sherd-and-lithic scatters from Survey Area 0 are likely to produce accurate predictors for the same types of archaeological phenomena in Survey Areas 1-3. Our prediction for lithic scatters in Survey Area 1 is that they will be "over-resolved," i.e., the model will forecast a large number of false positives (cf. Alpin 2006:2124).

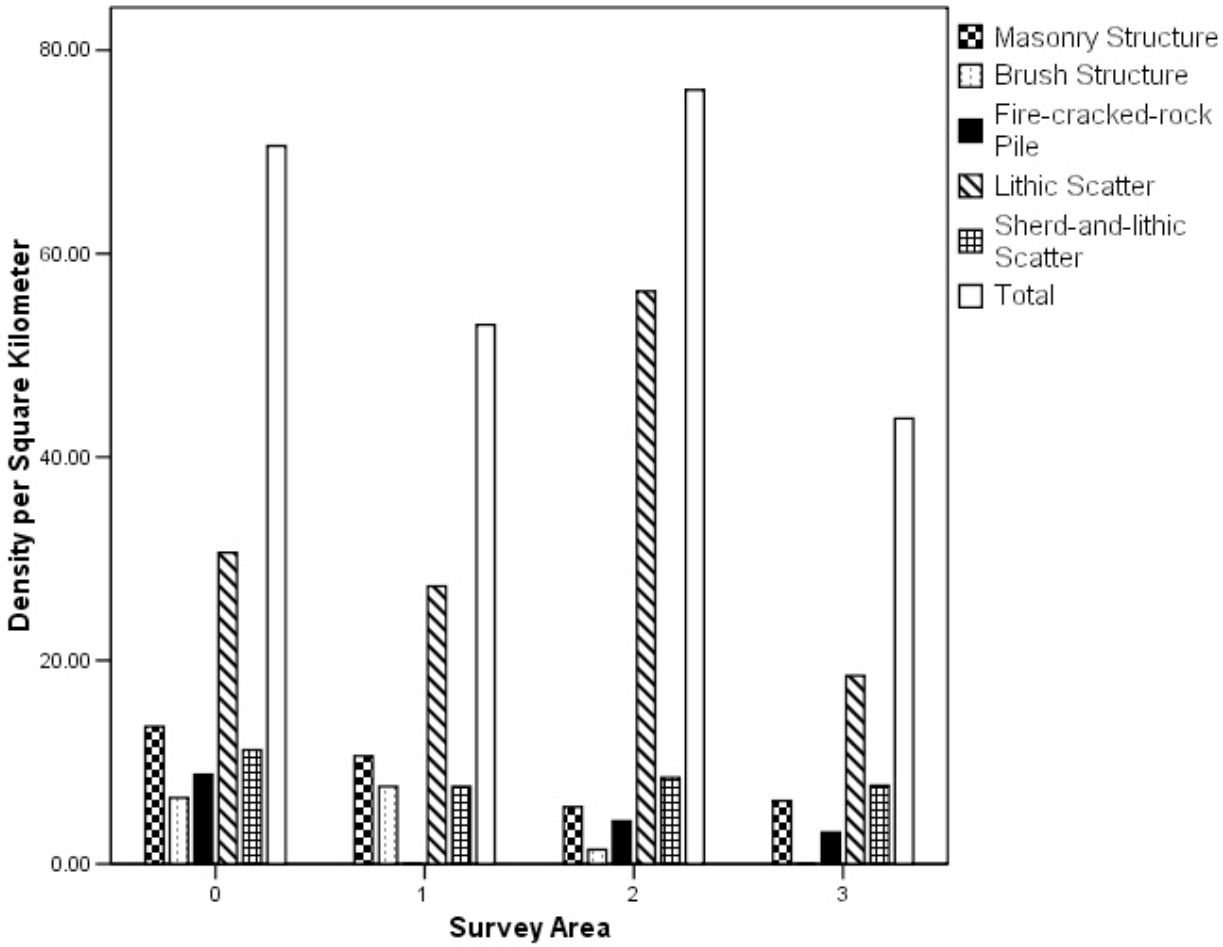

Figure 7. Bar chart diagram showing the density of five types of archaeological phenomena located in the four survey areas.

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4. The IKONOS Image

IKONOS is derived from the Greek word for "image." The IKONOS satellite is the world's first commercial satellite to collect black-and-white images with 1-meter resolution and multispectral imagery with 4-meter resolution. The IKONOS satellite weighs about 1,600 pounds and orbits the Earth every 98 minutes at an altitude of approximately 680 kilometers (423 miles). In 1999, IKONOS was launched into a sun-synchronous orbit and can produce imagery of the same geography every three days. Standard products include 1-meter black-and-white, 4-meter multispectral (all bands), 1-meter color (true color, false color, or 4-band), and a 1-meter and 4-meter data bundle (see for example, http://www.vterrain.org/Imagery/processing.html).

The IKONOS image for this study consists of a 7.144km x 7.110km rectangular swath with an upper left UTM coordinate of 423999.574E and 3984831.839N. It is a pan-merged image (Figure 8) with a spatial resolution of 1m per pixel, three discrete bands in the visible spectrum (blue, green, and red), and one band in the near infrared (Table 3). All imaging processing and preprocessing was performed with RSI's ENVI 3.5 and ENVI 4.2 software.

Figure 8. Pan-merged IKONOS image that has been clipped, registered, and masked (see section on Pre-processing below).

Table 3. Wavelengths of the four bands of the IKONOS image.

Band	Wavelength
Blue	0.45 - 0.52 mm
Green	0.51 - 0.60 mm
Red	0.63 - 0.70mm
Near IR	0.76 - 0.85 mm

Pre-processing

A satellite image does not conform to any map projection and, therefore, must be registered in order for data in the image to accurately reflect the actual geophysical ground (Jensen 1998). Establishing a ground-control point (GCP) requires the taking of a GPS point at a landmark that is distinct and conspicuous on the satellite image. For this study, five GCPs, spatially dispersed throughout the area, consisted of isolated trees or bushes that could be pinpointed to a specific pixel on the IKONOS image (Figure 9).

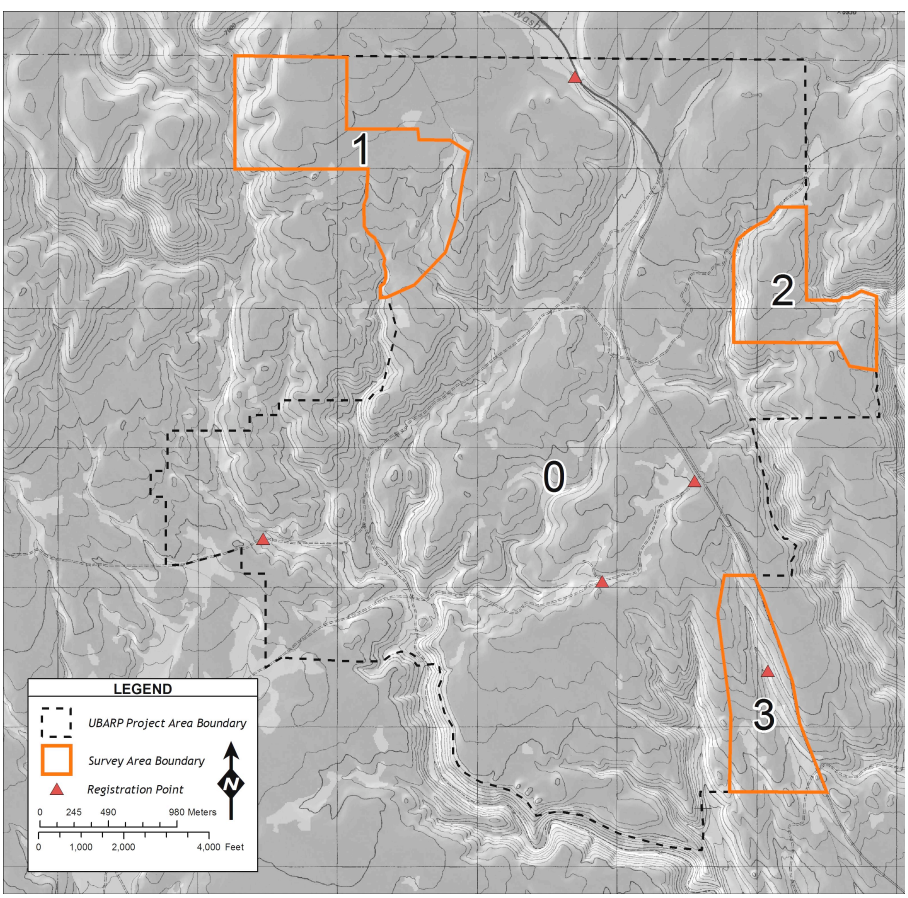

Figure 9. Locations of the five ground-control points (GCPs) that were used to register the IKONOS image in the UBARP study area (the four survey areas provide context). The GCPs were then used to "warp" the satellite image so that it corresponds to the desired map projection (NAD 1927, which is the datum used for GPS differential correction). The image was resampled using the nearest neighbor function in order to completely preserve the data inherent to each pixel.

Once the image was registered, it was combined and correlated with Geographical Information System (GIS) boundary data (shape files). All unnecessary portions of the image were then clipped and removed from any subsequent processing and calculations. A masking procedure was performed to eliminate possible areas of sensor "confusion." Disturbed places, such as vehicle pull-offs and parking areas, impromptu (and illegal) camp sites, construction dumps, quarries, cow tanks, and roads were selected for removal from the image. Sage flats, which are homogeneous expanses of sagebrush (*Artemisia tridentata*), were likewise removed because they are devoid of archaeological phenomena as well. The total area of "masked" terrain is 1.157 square kilometers.

The image was then degraded, altering its resolution from 1m per pixel to 4m per pixel, in order to better represent the properties of small-scale phenomena. The new resolution more satisfactorily corresponds to the size of the project's archaeological phenomena, particularly fire-cracked-rock piles, masonry structures, and brush structures (Alpin 2006). For instance, the most common masonry structure (n = 140) in the study area is a single-room ruin with a median length of 4.0m (mean = 4.2m); the same pattern holds for fire-cracked-rock piles (median = 4.0m, mean = 4.1m, n = 134).

Atmospheric interference was removed from the image by means of an Internal Average Relative Reflectance (IARR) calibration utility. Image data were converted from radiance to observed apparent reflectance, normalized to an average spectrum, and the average spectrum was then removed from each pixel to yield the apparent reflectance.

Processing

Noise was removed from the image by a Minimum Noise Fraction (MNF) transformation. In SRS studies, "noise" is random information that does not have any correlation with the pixel it is intended to represent; hence, it is an unfortunate side-effect of sensor technology. Some noise, such as atmospheric interference that was removed with IARR, is routine and predictable. Other types of noise originate from random sources, including sensor "blips" at the time of image acquisition (e.g., power surges, data corruption, etc.), as well as from interference produced by radio waves, microwaves, and

solar flares. The MNF procedure runs two cascaded Principal Component transforms – the first using an estimated noise covariance matrix to decorrelate and rescale the noise, and the second to remove the noise-enhanced data. The net result of the MNF transformation is an image whose non-coherent bands have been reduced, thus separating noise from the image (Figure 10).

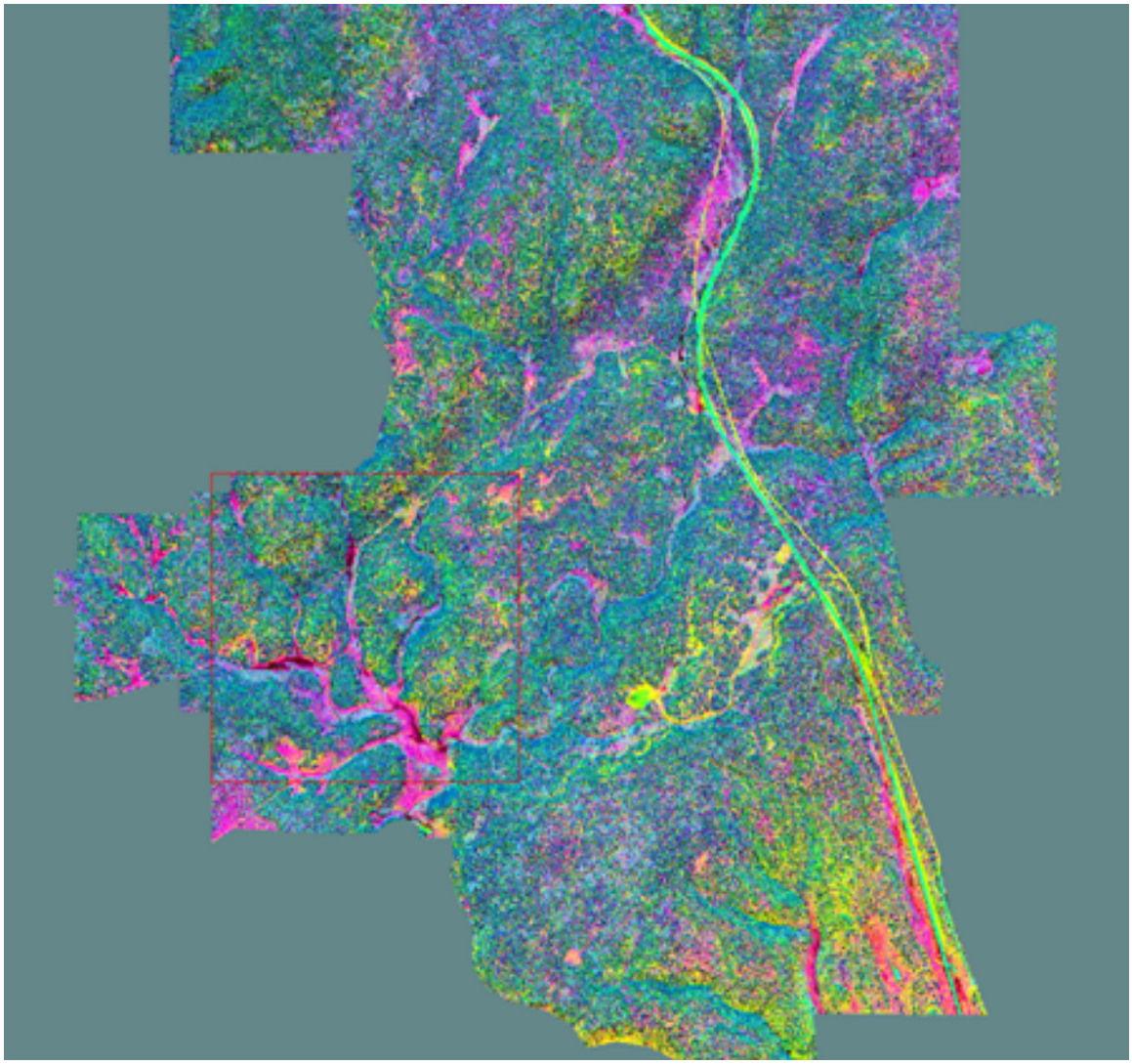

Figure 10. IKONOS image of the UBARP Study Area after the application of a Minimum Noise Transformation.

In order to identify any existing correlation between neighboring pixels, a Mean Co-occurrence Texture (MCoT) filter operation was performed. The MCoT uses a gray-tone spatial dependence matrix to calculate texture values, and then determines the number of mean-relationships occurring between a pixel and its neighbors. By combining

both the spectral data (from the MNF) and textural data (from the MCoT) on the pixel level, a coherent spectral dataset was created (cf. Haralick et al. 1973).

5. Predictive Modeling of Small-Scale and Low-Obtrusive Archaeological Phenomena

The MNF-transformed spectral dataset was overlaid with GPS-determined locations of the five types of archaeological phenomena from Survey Area 0. By using differentially corrected GPS points, as well as the registered image, these data were able to be aligned in such way that each individual archaeological phenomenon corresponds closely to its respective pixel. Once the GPS data were overlaid on the spectral dataset, five regions of interest (ROIs) were created, each one corresponding to a type of archaeological phenomena – lithic scatter, sherd-and-lithic scatter, masonry structure, fire-cracked-rock pile, and brush structure. A Pixel Purity Index (PPI) procedure was run on each ROI to extract mixed pixels. Mixed pixels are those that represent multiple phenomena on the ground (e.g., a 4m x 4m pixel can represent a juniper bush, a limestone boulder, and a portion of a masonry structure). In contrast, "pure" pixels are solely representative of single phenomenon (e.g., a 4m x 4m pixel that represents only a fire-cracked-rock pile). The n-Dimensional Visualizer (n-DV) was then run upon the resulting set of pure pixels to isolate and identify pixel endmembers. Endmembers are the most extreme spectral representations of the pure pixels, that is, the pure pixel that most definitively distinguishes a ROI (in this case, each of the five types of archaeological phenomena).

Figure 11 shows the spectral signatures that have been derived for the five types of archaeological phenomena (ROI endmember) from Survey Area 0. As can be seen, brush structures are clearly distinguishable from masonry structures, and both contrast with fire-cracked-rock piles. Such small-scale obtrusive phenomena are themselves dissimilar from the larger, low-obtrusive lithic scatters and sherd-and-lithic scatters.

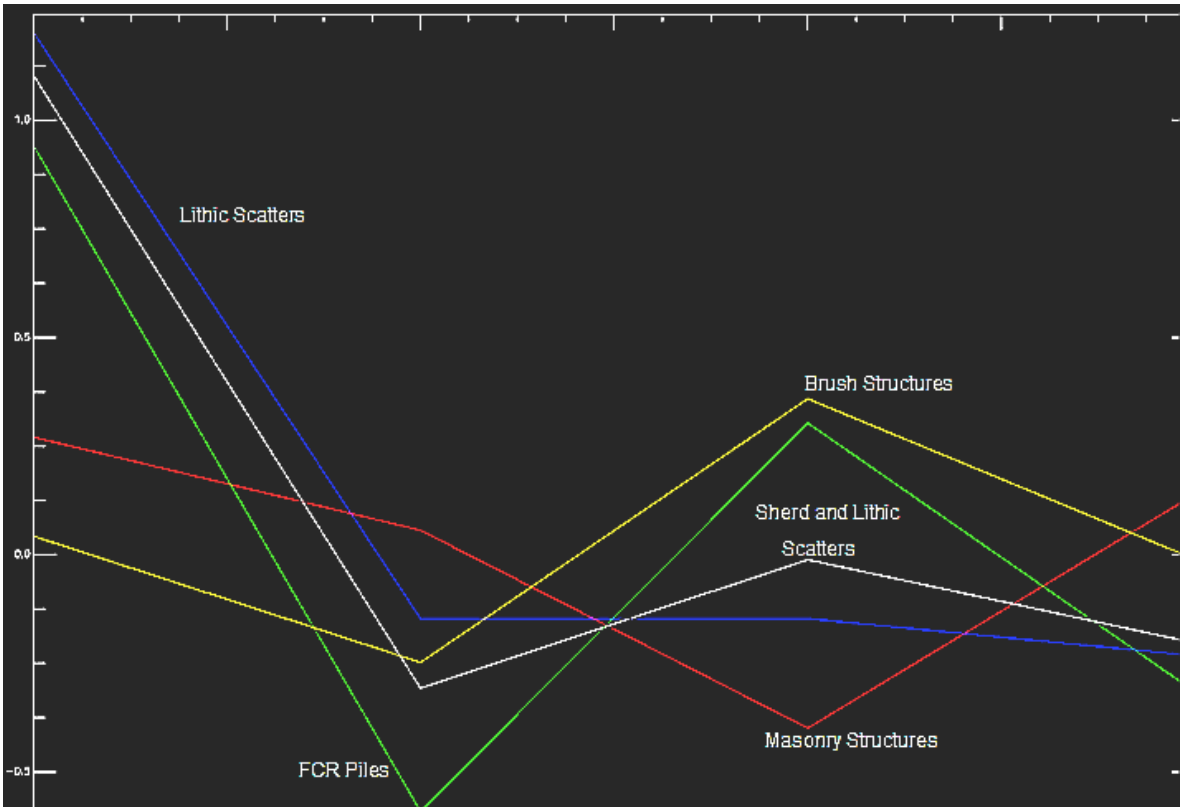

Figure 11. Spectral signatures for five types of archaeological phenomena at 4m resolution (X-axis refers to Band Number; Y-axis refers to Pixel Data Value).

6. Results

A Matched Filtering (MF) mapping technique was used to amplify the responses of the five identified endmembers, while diminishing the responses of the "undesired" pixels, allowing for a "match" of a pixel to its respective endmember. By customizing the options and thresholds of the MF technique, the resulting probability map (Figure 12 [symbols have been magnified 4x]) predicts which 4m pixels in Survey Areas 1-3 are likely to disclose the five ROIs (types of archaeological phenomena).

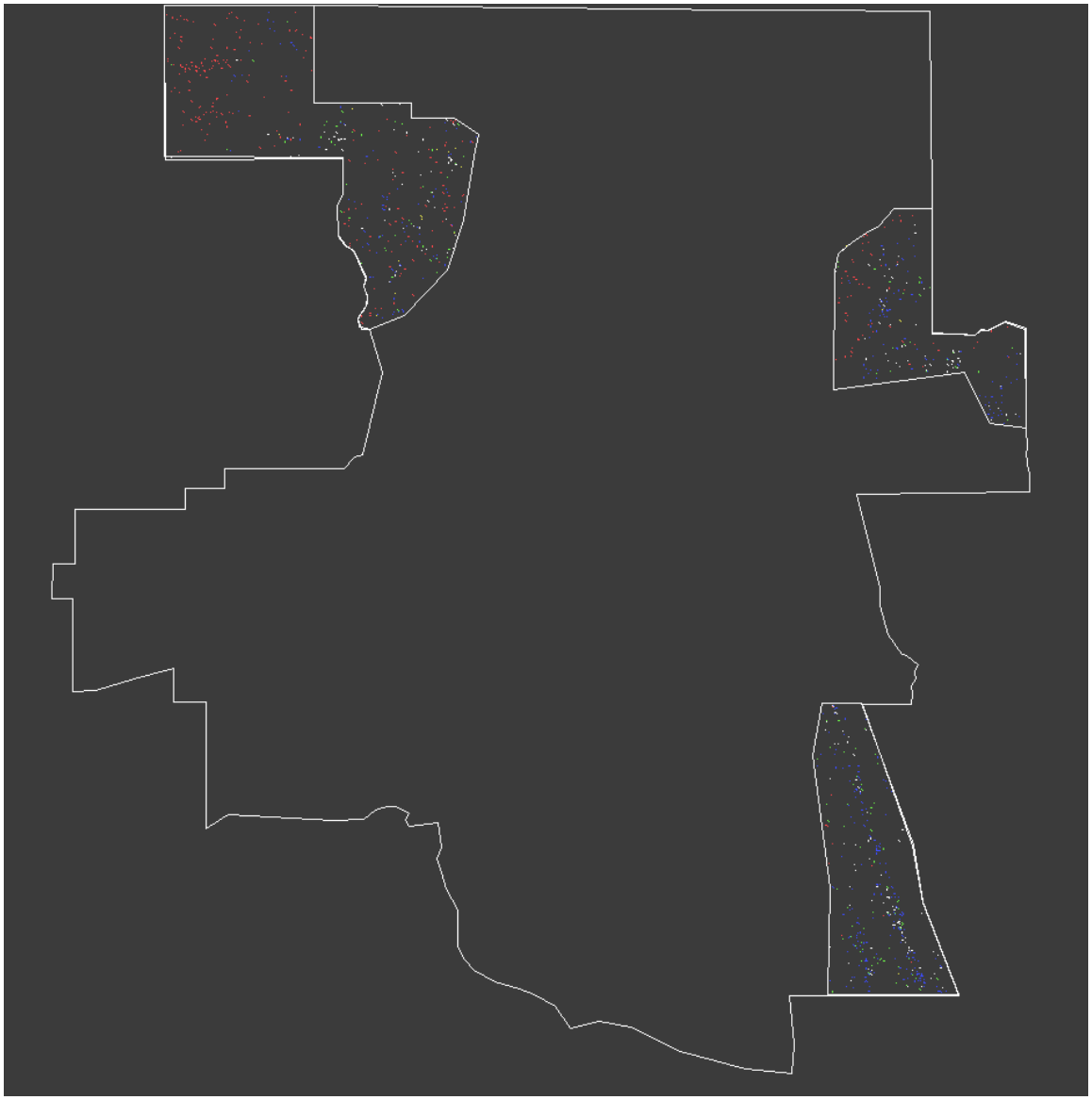

Figure 12. Probability map showing the locations of 4m pixels that are predicted to disclose the remains of masonry structures (red), brush structures (yellow), fire-cracked-rock piles (green), lithic scatters (blue), and sherd-and-lithic scatters (white).

The regional reliability of the model was assessed by comparing its predictions with the results of the intensive survey of Survey Areas 1-3 combined (Table 4). First, we are assuming that, based on the intensity of the survey and the thoroughness of coverage, there are no false negatives, i.e., cases where the model incorrectly predicted the absence of archaeological phenomena (Sullivan et al. in press). Second, the model correctly predicted the presence of all archaeological phenomena (i.e., 100% true positives).

Table 4. Reliability assessment of the spectral-signature predictive model.

Type	Survey Results	Model Predictions	True Positives	False Positives
Masonry Structure	22	299	22	277
Brush Structure	11	17	11	6
Fire-Cracked-Rock Pile	5	137	5	132
Lithic Scatter	88	367	88	279
Sherd-and-Lithic Scatter	21	193	21	172

Third, the prevalence of true negatives, i.e., those instances where the model correctly predicted the absence of archaeological phenomena, is extremely high (99.4%; the calculation of this value proceeded as follows: from the total of 167,500 4m pixels in Survey Areas 1-3 combined was subtracted 147 true-positive pixels and 866 false-positive pixels to yield 166,487 true-negative pixels, which when divided by 167,500 yields 99.4%). Fourth, the incidence of false positives, i.e., those instances where the model incorrectly predicted the presence of archaeological phenomena, is very low (0.5%).

Discussion. By these simple measures, a probability model based on the MNF-transformed spectral characteristics of five known ROIs (n = 1,144) successfully predicted the presence of five types of unknown archaeological phenomena (n = 147). Equally noteworthy, the model nearly perfectly predicted the absence of archaeological phenomena, which from a stewardship perspective is vitally important because scarce

heritage-management resources can be targeted strategically in an informed decision environment.

Regarding the prevalence of false positives, examination of Figure 12 reveals that the majority of over-predictions of masonry structures and lithic scatters occurred in Survey Areas 1 and 3, respectfully. We hypothesize that those false positives are attributable to environmental mimicry of anthropogenic phenomena. As noted above, Survey Area 1, which has a comparatively high density of red dots (symbolizing masonry structures), is topographically heterogeneous, particularly in its northwestern reaches. Consequently, natural accumulations of rubble there may have been misconstrued as concentrations of rocks that originated by human action. Analogously, Survey Area 3, which has a comparatively high density of blue dots (symbolizing lithic scatters), is cut by several active, deeply incised, and entrenched linear drainages whose freshly-exposed bedrock cobbles may have been misinterpreted as lithic scatters. Still, from a regional perspective, the incidence of false positives seems very low.

7. Conclusions

Regional Reliability of Spectral Signatures. This study has demonstrated that a "direct" predictive model using SRS-based spectral signals of different types of small-scale and low-obtrusive archaeological phenomena correctly forecasts their regional presence and their absence at extremely high rates (100% and 99.4%, respectively). Although the frequency of false positives for all types of archaeological phenomena appears troubling, from a heritage-property management perspective there is little cause for concern because its estimates err on the side of caution, i.e., it is best to incorrectly forecast the presence of heritage properties (false positives) than to incorrectly predict their absence (false negatives).

Future Research Directions. The research described here has only provided a glimpse of the potential of SRS-based predictive modeling of archaeological phenomena. As noted above, one clear problem that needs to be resolved by future research is the environmental mimicry of archaeological remains, which interestingly appears to affect brush structures less than other types of archaeological phenomena (Table 4). The number of false positives could be reduced by experimenting with different images, pixel resolutions, and different masking protocols. For masonry structures and fire-cracked-rock piles, for instance, more distinctive spectral signatures might emerge if a snow-covered image of the same terrain were analyzed with the same pixel resolution and analytical protocols described above. Then, by using a step-wise masking procedure to remove those pixels that pertain to null terrain (archaeologically empty pixels), masonry structures, fire-cracked-rock piles, and brush structures, the remainder of the image could be analyzed, perhaps using a larger pixel resolution, to refine the spectral signatures for the artifact scatters. Additionally, to reduce the over-prediction of artifact scatters may require the creation of a spectral library of weathered chert versus flaked chert (cf. Buck

et al. 2003), sherd-covered ground, and the creation of a new probability map that incorporates those reflectance properties.

Although this study was inspired by an aspiration to develop advanced technological supplements to traditional Phase I pedestrian surveys, high-intensity survey, somewhat ironically, is as crucial as ever, particularly in the short run, for several reasons. First, it is essential to ascertain first-hand what is causing environmental phenomena to be misconstrued as archaeological phenomena, which means visiting a large sample of the false positive pixels in Survey Areas 1-3 to test the hypotheses advanced above (see Discussion). Such re-surveying would provide an opportunity to test our assumption that no false negatives exist in Survey Areas 1-3, thereby evaluating the possibility that what we are interpreting as false-positive pixels may actually be false-negatives. Second, once the causes of over-prediction are more fully understood, survey will be needed to determine whether the results of this particular SRS-based predictive model can be extended to new, unsurveyed terrain.

Importance of SRS in Historic Preservation. As federal bureaucracies shrink, both in terms of human and financial resources, those agencies chartered with managing and protecting public lands find the task increasingly difficult. The potential of advanced technology, particularly SRS, represents one cost-effective strategy, relatively inexpensive in view of the availability of archived images, to ensure that heritage resources do not become at risk from inattention, vandalism, or indifference. In addition, for those remote or isolated management areas, where nearly inaccessible terrain makes pedestrian survey difficult, and thus expensive, land managers can now gain a least a provisional appreciation of the scale of territory that contains and, equally importantly, does not contain archaeological resources, thereby stretching scarce heritage dollars even further.

8. Acknowledgments. We are grateful to Dr. David W. Morgan, Chief, Archaeology and Collections, NCPTT, for his prompt and knowledgeable advice regarding inter-institutional administrative details and protocols. Thanks are extended to Ms. Elizabeth Otero, Resource Specialist, Kaibab National Forest (KNF), Mr. Tom Mutz, Lands and Minerals Specialist, Williams Ranger District (KNF), and Mr. Joe McCurry, Recreation Specialist, Tusayan Ranger District (KNF) who ensured that all housing and special-use permits were processed expeditiously. We are particularly thankful to Dr. John A. Hanson, Forest Archaeologist, Kaibab National Forest, for his long-term intellectual and administrative support of the Upper Basin Archaeological Research Project. Dr. Richard Harknett, Faculty Chair, and Ms. Joy Dunn, Administrative Assistant, of the C. P. Taft Research Center (University of Cincinnati) provided invaluable assistance by artfully interdigitating funds from the Graduate Enrichment, Departmental Research, and Faculty Release Fellowship programs.

9. References Cited

Anderson, Bruce A. (compiler). 1990. The Wupatki Archeological Inventory Survey Project: Final Report. Southwest Cultural Resources Center Professional Paper No. 35. National Park Service, Santa Fe.

Aplin, P. 2006. "On Scales and Dynamics in Observing the Environment." International Journal of Remote Sensing 27:2123-2140.

Ascher, Robert. 1968. "Time's Arrow and the Archaeology of a Contemporary Community." In Settlement Archaeology, edited by K. C. Chang, pp. 43-52. National Press Books, Palo Alto.

Babenroth, D. L., and A. N. Strahler. 1945. "Geomorphology and Structure of the East Kaibab Monocline, Arizona and Utah." Bulletin of the Geological Society of America 56:107-150.

Brewer, D. G., R. K. Jorgensen, L. P. Munk, W. A. Robbie, and J. L. Travis. 1991. Terrestrial Ecosystem Survey of the Kaibab National Forest. USDA Forest Service, Albuquerque.

Buck, P. E., D. E. Sabol, and A. R. Gillespie. 2003. "Sub-Pixel Artifact Detection Using Remote Sensing." Journal of Archaeological Science 30:973-989.

Challis, K., G. Priestnall, A. Gardner, J. Henderson, and S. O'Hara. 2004. "CORONA Remotely-Sensed Imagery in Dryland Archaeology: The Islamic City of al-Raqqa, Syria." Journal of Field Archaeology 29:139-153.

Cole, K. L. 1990. "Late Quaternary Vegetation Gradients through the Grand Canyon." In Packrat Middens, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 240-58. University of Arizona Press, Tucson.

Custer, J. F., T. Eveleigh, V. Klemas, and I. Wells. 1986. "Application of LANDSAT Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain." American Antiquity 51:572-578.

Fowler, M. J. F. 2002. "Satellite Remote Sensing and Archaeology: a Comparative Study of Satellite Imagery of the Environs of Figsbury Ring, Wiltshire." Archaeological Prospection 9:55-69.

Frohn, R. C. 2003. “Remote Sensing Investigation of Study Area 8.” In Archaeological Survey Methodology and Results, edited by A. P. Sullivan, pp. 61-70. National Technical Information Service Report No. FHWA/OH-2003/020. Springfield, VA.

Giardino, M. J., and B. S. Haley. 2006. “Airborne Remote Sensing and Geospatial Analysis.” In Remote Sensing in Archaeology, edited by J. K. Johnson, pp. 47-77. University of Alabama Press, Tuscaloosa.

Giardino, M. J., and M. R. Thomas. 2002. “NASA Remote Sensing Research as Applied to Archaeology.” The SAA Archaeological Record 2:15-19.

Gidwitz, T. “Pioneers of the Bajo.” Archaeology 55:28-35

Goossens, R., A DeWulf, J. Bourgeois, W. Ghelye, and T. Willems. 2006. “Satellite Imagery and Archaeology: the Example of CORONA in the Altai Mountains.” Journal of Archaeological Science 33:745-755.

Haralick, R. M., Shanmugan, K., and Dinstein, I. 1973. "Textural Features for Image Classification." IEEE Transactions on Systems, Man, and Cybernetics 3:610-621.
Hargrave, M. L. “Ground Truthing the Results of Geophysical Surveys.” In Remote Sensing in Archaeology, edited by J. K. Johnson, pp. 269-304. University of Alabama Press, Tuscaloosa.

Harrower, M., J. McCorriston, and E. A. Oches. 2002. “Mapping the Roots of Agriculture in Southern Arabia: the Application of Satellite Remote Sensing, Global Positioning System and Geographic Information System Technologies.” Archaeological Prospection 9:35-42.

Huntoon, P. W. 1990. “Phanerozoic Structural Geology of the Grand Canyon.” In Grand Canyon Geology, edited by S. S. Beus and M. Morales, pp. 261-309. Oxford University Press, Oxford.

Jensen, J. R.
1998 Introductory Digital Image Processing: a Remote Sensing Approach (2nd ed.). Prentice Hall, New Jersey.

Johnson, J. K., and B. S. Haley. 2006. “Case Study 5: Using Geophysical Results in a Multivariate Exploration of Airborne Imagery at the Hollywood Mounds, Mississippi.” In Remote Sensing in Archaeology, edited by J. K. Johnson, pp. 259-265. University of Alabama Press, Tuscaloosa.

Johnson, J. K., T. L. Sever, S. L. H. Mabry, and H. T. Hoff. 1988. "Remote Sensing and GIS Analysis in Large Scale Survey Design in North Mississippi." Southeastern Archaeology 7:124-131.

Montufo, A. M. 1997. "The Use of Satellite Imagery and Digital Image Processing in Landscape Archaeology: A Case Study from the Island of Mallorca, Spain." Geoarchaeology: An International Journal 12:71-85.

Rand, P. J. 1965. Factors Related to the Distribution of Ponderosa and Pinyon Pines at Grand Canyon, Arizona. Ph.D. dissertation, Department of Botany, Duke University, Chapel Hill, NC.

Schaber, G. G., and G. J. Gumerman. 1969. "Infrared Scanning Images: An Archaeological Application." Science 164:712-713.

Sever, T. L. 2000. "Remote Sensing Methods." In Science and Technology in Historic Preservation, edited by R. A. Williamson and P. R. Nickens, pp. 21-51. Kluwer Academic/Plenum Publishers, New York.

Sullivan, A. P., III. 1986. Prehistory of the Upper Basin, Coconino County, Arizona. Arizona State Museum Archaeological Series No. 167. University of Arizona, Tucson.

Sullivan, A. P., III. 1988. "Current Issues in Regional Archaeology." In Tools to Manage the Past: Research Priorities for Cultural Resources Management in the Southwest, edited by J. A. Tainter and R. H. Hamre, pp. 81-89. General Technical Report RM-164. USDA Forest Service Rocky Mountain Range and Experiment Station, Fort Collins.

Sullivan, A. P., III. 1996. "Risk, Anthropogenic Environments, and Western Anasazi Subsistence." In Evolving Complexity and Environmental Risk in the Prehistoric Southwest, edited by J. A. Tainter and B. B. Tainter, pp. 145-67. Addison-Wesley Publishing Co., Reading, MA.

Sullivan, A. P., III. 2000. "Theory of Archaeological Survey Design." In Archaeological Method and Theory: An Encyclopedia, edited by L. Ellis, pp. 600-605. Routledge, New York.

Sullivan, A. P., III. In review. "An Archaeological View of the Archaeological Record." In Archaeological Concepts for the Study of the Cultural Past, edited by A. P. Sullivan. University of Utah Press, Salt Lake City.

Sullivan, A. P., III, and A. H. Ruter. 2006. "The Effects of Environmental Fluctuations on Ancient Livelihood: Implications of Paleoeconomic Data from the Upper Basin." In

Environmental Change and Human Adaptation in the Ancient Southwest, edited by D. E. Doyel and J. S. Dean. University of Utah Press, Salt Lake City.

Sullivan, A. P., III, and P. M. Uphus. 2002. "An Analysis of Phase I Surveys." In Best Management Practices of Archaeological Study Methods, edited by A. Ioannides and A. P. Sullivan, pp. 92-134. National Technical Information Service Report No. FHWA/ OH-2002/036. Springfield, VA.

Sullivan, A. P., III, P. B. Mink, and P. M. Uphus. 2002a. "From John W. Powell to Robert C. Euler: Testing Models of Grand Canyon's Prehistoric Puebloan Settlement History." In Culture and Environment in the American Southwest: Essays in Honor of Robert C. Euler, edited by D. A. Phillips, Jr. and J. A. Ware, pp. 49-68. Anthropological Research Paper No. 8. SWCA, Phoenix.

Sullivan, A. P., III, P. M. Uphus, C. I. Roos, and P. B. Mink. 2002b. "Inadvertent Vandalism: The Hidden Challenge for Heritage Resource Management." Cultural Resources Management 25:42-46.

Sullivan, A. P. III, R. A. Cook, M. P. Purtill, and P. M. Uphus. 2003. "Economic and Land-Use Implications of Prehistoric Fire-Cracked-Rock Piles, Northern Arizona." Journal of Field Archaeology 28:367-382.

Sullivan, A. P., III, P. B. Mink, and P. M. Uphus. In press. "Archaeological Survey Design, Units of Observation, and the Characterization of Regional Variability." American Antiquity.

Uphus, Patrick M. 2003. The Influences of Ecosystem Variability on Prehistoric Settlement: Testing Terrain-Based Locational Models for the Upper Basin, Northern Arizona. M.A. thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

Uphus, P. M., A. P. Sullivan, III, and P. B. Mink. 2006. "Identifying At-Risk Heritage Resources with GIS: Modeling the Impact of Recreational Activities on the Archaeological Record." International Journal of Risk Assessment and Management 6: 330-343.

Whittlesey, S. M. (ed.). 1992. Investigations at Lee Canyon: Kayenta Anasazi Farmsteads in the Upper Basin, Coconino County, Arizona. Technical Series No. 38. Statistical Research, Inc., Tucson.

Appendix A
Interim Report (Attachment A)

1. Institution/Organization:
University of Cincinnati
Department of Anthropology

2. Project Title:
Testing the Regional Reliability of Spectral Signatures of Archaeological Phenomena

3. *Grant Agreement Number*:
MT-2210-05-NC-12

4. Summarize requested amendments (if any) to the original Grant Agreement or Work Cost/Budget and provide the approval date(s).

a. A no-cost extension was requested and approved. The grant's new end-date is now September 30, 2006.

b. A request to internally reallocate grant funds among budget lines at the Principal Investigator's discretion and in the best interests of the project was approved.

5. Briefly describe progress to date for completing the project objectives as outlined in the Grant Agreement. Address each objective and associated task(s).

Objective A: The following list enumerates the activities that have been accomplished with respect to this project objective (Objective A).

- An archived IKONOS image was selected and acquired.

- The image was "clipped" electronically, using the study area boundaries, to remove extraneous portions from subsequent calculations and processing.

- Boundaries of the three study areas ("unknowns") to be surveyed during Task B, as well as the area of the "training set" data (previously surveyed terrain) were acquired, combined and correlated with the project's Geographical Information System (GIS) and satellite image data using ENVI software.

- Atmospheric interference was removed from the image by means of Internal Average Relative Reflectance (IARR), which accomplishes the following:
  a. Converts the image data from radiance to observed apparent reflectance.
  b. Normalizes the image to an average spectrum, which is used as a reference spectrum for further processing.

c. Each pixel of the image is divided by this averaged reference spectrum to yield the apparent reflectance.

- Data Transformations:

To remove extraneous or misleading information ("noise") from the analytical image, reduce the inherent dimensionality of the data (i.e., non-coherent image bands), and reduce computation requirements for subsequent processing, two Principal Components (PC) analyses were run:

a) PC 1 uses an estimated noise covariance matrix to decorrelate and rescale the noise.

b) PC 2 runs a standard Principal Component to remove "noise- whitened" data.

To reveal relationships between the remote-sensed properties of a pixel and its neighbor, a gray-tone spatial dependence matrix was created to calculate texture values (the measures calculated include mean, variance, homogeneity, contrast, dissimilarity, entropy, second angular moment, and correlation).

- Spectral and textural data transformations were combined with image data to create the modeling dataset (hereinafter dataset).

- Training data (from previously surveyed terrain) were overlaid with the dataset. In this procedure, GIS data of archaeological, geological, and geographic phenomena are combined using ENVI software and aligned so that each phenomenon corresponds to its respective (world-referenced) geophysical pixel.

- Five Regions of Interest (ROI) were created for each training category. ENVI isolated five ROI as a training set for creation of the predictive models. Each ROI is equivalent to one of the five site types that are the focus of this study: masonry structures, sherd-and-lithic scatters, lithic scatters, fire-cracked-rock piles, and brush structures. Basically, an ROI is user-defined and tells the computer how to interpret and label pixels so it can look for pixels in non-training set areas ("unknowns") that are similar, which are then classified as one of our five site types.

- Endmembers were created from the five Regions of Interest. For this analysis, endmembers were created using a cascaded pair of transforms: a Pixel Purity Index (PPI) to extract unmixed pixels that correspond only to archaeological phenomena, and an n-Dimensional Visualizer to interactively identify pixel endmembers. Spectral endmembers are most easily defined as "spectrally pure" ground features (a pixel that is characteristically only a fire-cracked-rock pile, or a lithic scatter, or a masonry structure). They are chosen from the purest pixels of

the image that correspond to one of our ROIs. Thus, all endmembers are pure pixels, but not all pure pixels are endmembers.

- Matched filtering was run for each of the five categories (ROIs). The intent of this procedure was to maximize the response of identified endmembers and to suppress the response of the composite unknown background, thus "matching" the known signature. The output is a gray-scale image with values ranging from 0 – 1.0, which can be used as a means of estimating the relative degree of a pixel's match to the reference endmember.

- Probability maps were created from the matched filtering procedure. For this activity, the gray-scale image was interactively analyzed for floating-point units that most likely match the investigated phenomena (with 1.0 being a perfect match).

- Color-coded maps were produced according to the degree of match for each category (ROI). Variation in color represents the relative probability that a pixel contains anthropogenic phenomena.

- A total of 15 color-coded maps, one for each of the five ROIs (site types) for the three study areas, was produced to guide the ground-truthing of the predictive models (Objective B).

Objective B: Ground-truthing of the predictive models will occur in April and May.

6. What difficulties have you encountered to date in completing grant work?

There was initial difficulty in securing housing for fieldwork associated with testing the predictive models, which necessitated a revised schedule for when Objective B could begin. Fieldwork is now scheduled for April 4-May 12, 2006.

7. What changes in objectives or budget or products are anticipated? Nothing at this time.

8. Will you be able to complete work under this grant as scheduled? If not, why?

As noted above, we have requested and received a no-cost extension for this project in order to compensate for the delay in field testing (ground-truthing) the predictive models.

9. What products (if any) have been produced to date?

a. A project outline was sent to Kimberly S. Eppler, NCPTT Archeology and Collections Program Intern, for possible incorporation on the NCPTT website.

b. Five color-coded maps were produced for each of the three study areas ("unknown" terrain) that are to be surveyed. Each map showed the probability that pixels within the map contained archaeological phenomena that correspond to one of the five site types (ROIs).

10. What products (if any) are currently underway? Nothing else at this time.

Signature of Principal Investigator:
Alan P. Sullivan
Date: March 28, 2006

Appendix B
Quarterly Progress Reports

I. For the second reporting quarter (4/1/06-6/30/06), and with regard to Task 4, "Ground-Truthing the Predictive Models," high intensity survey of the "targeted" terrain (hatched areas in Figure 2 of the grant proposal [p. 4]) was conducted between April 3 and May 12, 2006. The following results, which are illustrative rather than exhaustive (complete details will be forthcoming in the Final Narrative Report), were achieved.

a. The locations of five image-registration points, which involved the identification of specific 1m x 1m IKONOS-image pixels in the field, were determined with GPS technology (the data were subsequently processed, using differential-correction methods, to achieve a spatial resolution of between 1.5m – 2.1m).

b. High-intensity survey (inter-surveyor spacing was 10m) of Survey Areas 1, 2, and 3 was conducted with two teams of surveyors. The locations of all archaeological phenomena (called Mapping Units, or MUs) encountered during survey were GPS determined and differentially-corrected. In addition, measurements of MU non-assemblage attributes (e.g. size, evidence of vandalism, erosion, etc) and assemblage characteristics (e.g., artifact-type frequencies) were recorded.

c. Between May 15, and June 30, 2006, post-field processing of survey data was completed. This part of Task 4 involved downloading and transferring data files from the GPS units, creating EXCEL data files, checking the files against field records, correcting the data files for any errors, and updating the GIS.

II. For the third and final reporting quarter (7/1/06 – 9/30/06), project personnel have been engaged in the following activities.

a. Task 4: It became clear that, once the IKONOS image was registered accurately, the original predictive models had grossly over-estimated the presence of archaeological phenomena. In order to correct for this problem, it was decided to mask out the following sources of sensor "confusion" from the pan-merged IKONOS image: sage flats (which contain no archaeological phenomena), disturbed areas, such as quarries and cow tanks, as well as roads. The models are now being re-run with the registered and "masked" image. In addition, spectral signatures of archaeological phenomena are being determined using a pixel-resolution of 4m, which is more appropriate for the scale of the study area's archaeological remains (particularly masonry structures, brush structures, and fire-cracked-rock piles) than the image's default pixel-size of 1m (which creates an unacceptably large number of false positives).

b. Task 5: (Evaluating the Models' Reliability): In the Final Narrative Report, under preparation, will be an evaluation of the extent to which the archaeological

phenomena discovered in Survey Areas 1, 2, and 3 were accurately predicted by the spectral characteristics of archaeological phenomena of previously surveyed terrain ("training data").

Appendix C
Administrative Summary (Attachment B)
NCPTT 2005 Grants

1. Institution/Organization:
University of Cincinnati
Department of Anthropology

2. Project Title:
Testing the Regional Reliability of Spectral Signatures of Archaeological Phenomena

3. *Grant Agreement Number*:
MT-2210-05-NC-12

4. Amendments to the original Grant Agreement or Work Cost/Budget and approval date.

a. A no-cost extension was approved on 3/7/06. The grant's new end-date is September 30, 2006.

b. A request to internally reallocate grant funds among budget lines at the Principal Investigator's discretion and in the best interests of the project was approved on 3/7/06.

5. Final grant products.

a. The Narrative Final Report includes a discussion of the problem and its historical background, description of the technical basis of satellite remote sensing (SRS) of small-scale and low-obtrusive archaeological phenomena, description of the study area in northern Arizona, description of the acquisition and processing of the IKONOS image, description of the methods used to acquire and integrate archaeological survey data and SRS data, description of predictive-model building methods and accuracy assessment, discussion of the results, and conclusions regarding future research directions and the importance of SRS in historic preservation.

b. The Narrative Final Report minimally includes maps of the study area in northern Arizona as well as the four survey areas in the study area (training-data survey area and the three test-survey areas) that show the distribution of the five types of modeled archaeological phenomena (masonry structures, brush structures, fire-cracked-rock piles, lithic scatters, and sherd-and-lithic scatters).

c. The Narrative Final Report includes a pan-merged IKONOS image that has been registered, clipped, and masked, and a MNF-transformed IKONOS image.

d. The Narrative Final Report includes seven high-resolution images that illustrate the research activities entailed by the investigation of the research problem.

e. The Narrative Final Report includes a 400-word summary description of the objectives, investigative tasks, and principal findings of the sponsored research that is suitable for a general audience.

f. The Narrative Final Report includes copies of the Interim Report (Attachment A), Administrative Summary Report (Attachment B), and two quarterly Progress Reports.

6. Differences between the planned and actual work costs.

As the following table shows, substantial differences (+ $11,532.16) materialized in the travel costs – vehicles, lodging, food -- associated with the ground-truthing of the SRS-based predictive models (Task 4). Less dramatic differences in salaries and benefits (+ $863) for project personnel and for supplies (+ $169.75) are apparent.

	Planned (budgeted)	Actual
Salaries and Benefits	23270	24133
Travel	3900	15432.16
Supplies	377	546.75

7. Final Work-Cost budget breakdown.

The following table shows the cost distribution of major expense categories broken down by Federal (NCPTT) and University of Cincinnati (UC) funding sources.

	Federal	UC Match (budgeted)	UC Match (unbudgeted)
Salaries	20298	30673	
Fringe Benefits	3835	9202	
Travel	3030	2100	10302.16
Supplies	412		134.75
Consultant	2500		
Indirect Costs	9925	13852	3444.18
Project sub-total	40000	55827	10781.09

PROJECT TOTAL: $106,608.09

8. Explanation for the difference between planned (budgeted) and actual work-costs.

The principal reason for the difference between the total project budgeted costs and the actual total projects costs, which including direct costs ($10,436.91) and indirect

costs ($3,444.18) totals $10,781.09, is attributable to unanticipated and dramatic increases in (i) gas prices (ca. $3.50 per gallon), (ii) vehicle rental costs, and (ii) housing expenses.

9. Significance of sponsored research for historic preservation.

With increasing recreational pressure on public lands and declining federal heritage-resource management budgets, cultural resources are at greater risk than ever. Hence, there is a pressing national need to develop cost-effective supplements to traditional Phase I pedestrian based heritage-resource discovery and documentation strategies. As this project has shown, applying knowledge of the likelihood of where heritage resources are located and where they are not located, informed by SRS-based predictive models, will enable historic and cultural properties specialists to strategically allocate funds for inventory and documentation purposes, and thereby develop management plans to extend scarce preservation and management dollars.

10. Availability of publications to NCPTT.

Reprints of publications that incorporate data and methods that arose in the course of this NCPTT sponsored research will be forwarded to NCPTT as soon as they become available to the Principal Investigator.

11. Availability of other grant-related data or information.

Data files, image files, and GIS shape-files are available upon request to the Principal Investigator.

Signed:
Alan P. Sullivan
Professor of Anthropology
University of Cincinnati
September 30, 2006

Appendix D
General Summary of NCPTT–Sponsored Research: Testing the Regional Reliability of Spectral Signatures of Archaeological Phenomena

Satellite remote sensing (SRS) has been employed for several decades in various applications ranging from military espionage to large-scale landscape management. The technology relies upon the simple concept that when light strikes an object, its spectral signature changes depending upon what reflected it. This geophysical fact has been exploited for the past twenty years, for example, to help identify deposits of minerals, petroleum, and even certain species of flora with SRS (for examples, see the USGS spectral library at http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib.desc+plots.html).

By expanding this technology to archaeological phenomena, researchers and heritage mangers will have a new tool to study and preserve the legacies of human culture. The logic behind this new application is basic – the remnant effects of anthropogenic environmental alterations can be detected through the discerning sensors of satellites. Conventional archaeological applications of SRS primarily explored uncommon large-scale remains with relatively prominent footprints, such as temples and platform mounds. In contrast, this study focused on common small-scale archaeological remains whose low-obtrusive nature makes them inherently difficult to differentiate from surrounding natural phenomena. Using a high-resolution (1m) IKONOS satellite image of the Upper Basin of northern Arizona (Kaibab National Forest, Tusayan Ranger District), spectral signatures were created for five types of archaeological phenomena (masonry ruins, brush structures, fire-cracked-rock piles, lithic scatters, and sherd-and-lithic scatters) whose locations had been determined with GPS technology. These signatures then were applied to unsurveyed terrain to create a "probability map" that directly predicted whether or not individual pixels (4m by 4m) would contain archaeological phenomena. By ground-truthing the model's predictions with intensive survey, it was determined that they correctly forecast all pixels that contained archaeological phenomena (100% accuracy) as well as nearly all those pixels that were void of them (99.4% accuracy). Additional research will focus on reducing the number of false positives, i.e., those pixels that the model incorrectly predicted contained archaeological remains.

With increasing recreational pressure on public lands and declining federal heritage-resource management budgets, cultural resources are at greater risk than ever. However, SRS offers a cost-effective approach for heritage-resource discovery and documentation strategies that, when coupled with digital change-detection procedures, for instance, holds out the possibility for enhanced protection and management of cultural properties. Exploring the capabilities of SRS for a variety of problems in archaeology will help us gain a better understanding of the role of advanced technology in "seeing" and preserving the remains of ancient cultural worlds.

Appendix E
Color Images of Grant-Related Research Activities

Preparing to find a specific 1m pixel on the IKONOS image whose position in the Upper Basin of northern Arizona is to be determined with a Trimble GeoExplorer 3 GPS data logger and differential correction software (Trimble Pathfinder 2.90).

Finding a specific pixel on an IKONOS image to geo-register the image in the UBARP study area of northern Arizona with GPS technology.

Fixing the location of a brush structure in the Upper Basin of northern Arizona with a Trimble GeoExplorer 3 GPS data logger.

Fixing the location of a masonry structure in the Upper Basin of northern Arizona with a Trimble GeoExplorer 3 GPS data logger.

Two members of a four-person survey team, spaced 10 meters apart, prepare to examine a portion of the Upper Basin in northern Arizona for traces of archaeological phenomena.

Differentiating two types of archaeological phenomena – a fire-cracked-rock- pile (left, foreground) and a one-room masonry structure (center, background).

Processing the IKONOS image of the UBARP study area with ENVI software.