A PATTERN RECOGNITION MODEL FOR THE MOUNT GRAHAM RED SQUIRREL

James R. Hatten, Senior GIS Analyst

Nongame Branch, Wildlife Management Division
Arizona Game and Fish Department

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Program Chief: Terry B. Johnson
Arizona Game and Fish Department
2221 West Greenway Road
Phoenix, Arizona 85023-4399

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EXECUTIVE SUMMARY

The Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) was classified as a unique subspecies endemic to the Pinaleno Mountains in 1894, and was considered common in the early 20th century (Spicer and others 1985). However, a subsequent decline in the Mount Graham red squirrel (MGRS) population led some to believe that it had been extirpated by the 1960s (Minckley 1968). The cause of the decline in the MGRS population is unknown, but might be attributable to one or more of the following factors: 1) habitat destruction, 2) disease, 3) cone crop failure, or 4) introduction of the tassel-eared squirrel (*Scuirus aberti*). Fortunately, the MGRS was not extirpated and its population appears to be rebounding since the 1960s. It was still considered rare enough in the 1980s for the United States Fish and Wildlife Service (USFWS) to list it as endangered on June 3, 1987.

To estimate the MGRS population more accurately, a survey methodology was devised and implemented in 1991 which stratified the upper Pinalenos into three vegetation series (spruce-fir, ecotone, and mixed conifer). Biologists determine the total number of squirrel middens within each series, and thereafter visit randomly selected middens to determine occupancy. Once done, the population of MGRS is calculated by multiplication of occupancy rate against total midden count. This method results in very tight confidence intervals (high precision), but the accuracy of the population estimate is dependent upon knowing where all the middens are located.

The number of MGRS middens increased from approximately 200 in the late 1980s, to greater than 1,000 in 1999. It is not clear if this rise is the result of an increasing population, or increased survey efforts and a better survey methodology. Regardless of cause, the increase in midden numbers requires more field work since a percentage of randomly selected middens must be examined each year. Thus as the population goes up, so does the survey effort. One benefit from greater survey efforts is an increase in our knowledge of the mountain. We now hypothesize that there might be areas outside the survey boundary that contain middens or suitable habitat. However, more effort is needed to survey for new middens outside of the survey boundary.

Due to the uncertainty of the current MGRS population estimate and the increasing resources necessary to conduct surveys, we are exploring alternative sampling methodologies. An analysis was conducted to ascertain whether satellite imagery and a Geographic Information System (GIS) could identify potentially suitable habitat for the MGRS. We hypothesized that the spectral and structural characteristics of the forest canopy, in conjunction with topographic information, could identify potentially suitable habitat of MGRS (a technique called pattern recognition). This habitat information could then be used to refine our current midden-based survey, or aid in the development of a plot-based survey methodology.

In order to construct a pattern recognition model, 30 m resolution satellite imagery was processed with a series of clustering algorithms to identify spectrally unique forest types. This information was overlaid on the AGFD midden locality data (1,018 sites) to identify spectrally suitable habitat. Only half of the midden data were used in model development, while the other half were used in model validation (accuracy assessment). The topographic data (slope, aspect and elevation) were also used to help understand the distribution patterns of the MGRS middens. The primary result of the GIS analysis was the division of the Pinaleno Mountains into two

spectral classes: suitable and unsuitable. An accuracy assessment revealed that 93 percent of the randomly selected middens were correctly classified, i.e. they were located within the suitable habitat class. Positional error within the imagery, and coarse resolution, appeared to result in most of the misclassification.

The GIS analysis also identified spectrally suitable habitat outside the survey boundary, within all aspect classes. Field visits to 19 random sites outside the survey boundary found no new middens, but did detect MGRS at two northward-facing sites, and good habitat at two eastward-facing sites. In contrast, sites with a westward or southerly aspect, and outside the survey boundary, tended to be poor habitat. From these field investigations we conclude that the current survey boundary appears too high on the north and east ramparts of the Pinaleno Mountain range. However, the slopes in these areas are steep and treacherous, which greatly diminishes the feasibility of future search efforts. While it may never be feasible (or wise) to search many of the steeper slopes, some of the more accessible slopes should be periodically visited to assess squirrel activity and to fine-tune our population estimates.

Another benefit from the GIS analysis was quantification of the destruction caused by the 1996 Clark Peak fire. By comparing imagery between 1993 and 1997 with a change detection algorithm, it became evident that 2.6 percent of the spectrally suitable habitat was destroyed in the fire. Remote sensing, coupled with change detection, appears promising as a tool for monitoring MGRS habitat throughout the Pinaleno Mountains.

The products of this investigation are MGRS habitat suitability maps derived from the spectral and structural components of the forest canopy. These maps correctly classified 92.6 percent of the known MGRS middens, and can be used in planning, monitoring, and restoration efforts. The maps can form a foundation for a new survey protocol or in refining the current survey methods, and for remotely monitoring MGRS habitat from a temporal and spatial perspective.

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James R. Hatten

INTRODUCTION

The Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) was classified as a unique subspecies endemic to the Pinaleno Mountains in 1894, and was considered common in the early 20th century (Spicer and others 1985). However, a subsequent decline in the Mount Graham red squirrel (MGRS) population led some to believe that it had been extirpated by the 1960s (Minckley 1968). The cause of the decline in the MGRS population is unknown, but might be attributable to one or more of the following factors: 1) habitat destruction, 2) disease, 3) cone crop failure, or 4) introduction of the tassel-eared squirrel (*Scuirus aberti*). Fortunately, the MGRS was not extirpated and its population appears to be rebounding since the 1960s. It was still considered rare enough in the 1980s for the United States Fish and Wildlife Service (USFWS) to list it as endangered on June 3, 1987.

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The number of MGRS middens increased from approximately 200 in the late 1980s, to greater than 1,000 in 1999 (Fig. 1). It is unclear if this rise is the result of an increasing population, or increased survey efforts and a better survey methodology. Regardless of cause, the increase in midden numbers requires more field work since a percentage of randomly selected middens must be examined each year. Thus as the population goes up, so does the survey effort. One benefit from greater survey efforts is an increase in our knowledge of the mountain. We now believe there might be areas outside the survey boundary that contain middens or suitable habitat. However, more effort is needed to survey for new middens outside of the survey boundary.

Estimating the MGRS population requires a mountain-wide survey effort of all suitable habitats, which can be difficult because the topography is very rugged and prohibits complete surveys each year. Therefore, it would be advantageous to develop a habitat suitability model that can help us identify where to concentrate our mountain-wide survey efforts. Specifically, the objectives of this investigation were: 1) identify potentially suitable MGRS habitat, and 2) identify the most appropriate survey boundary for population estimation.

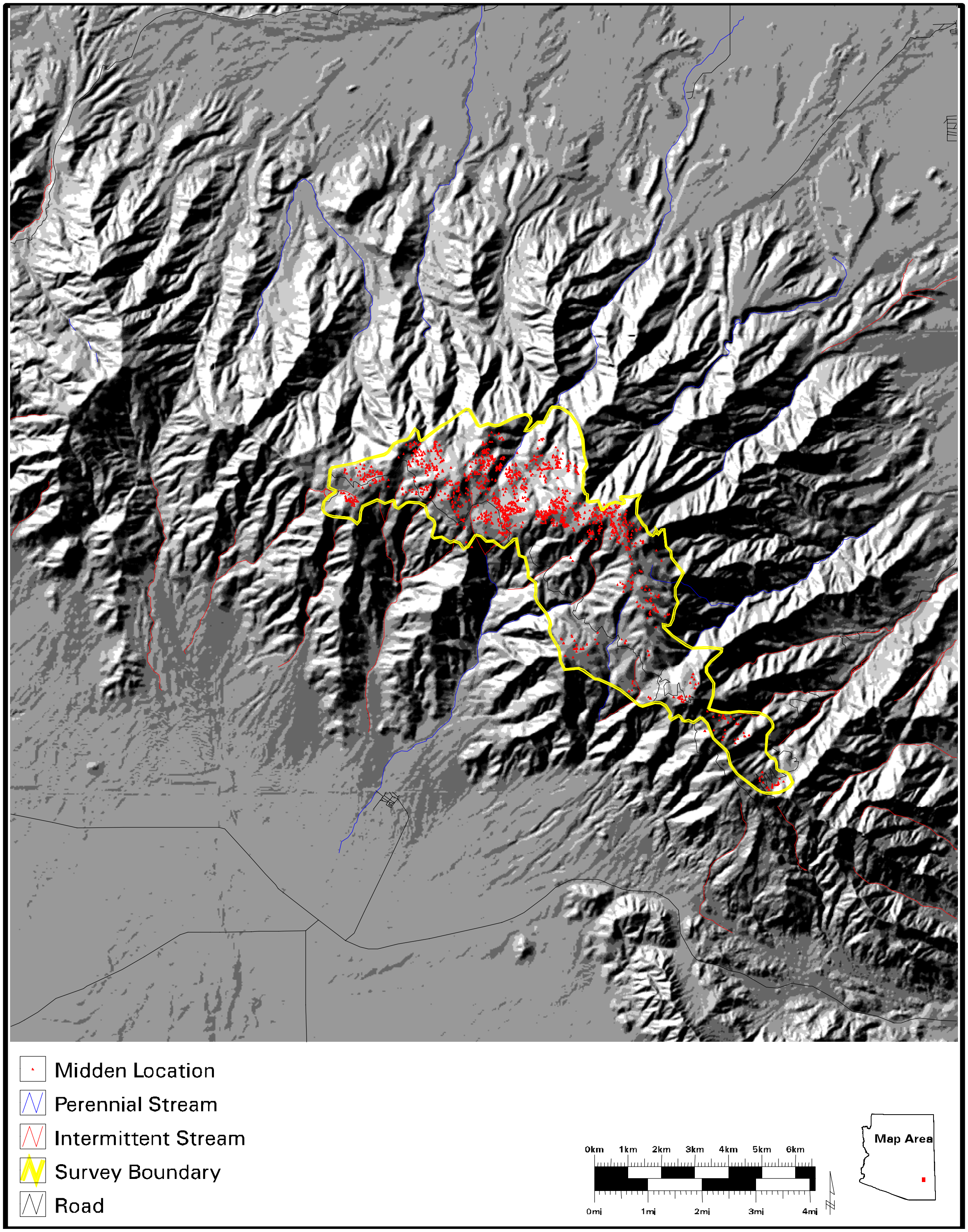

Figure 1. A shaded relief image of the Pinaleno Mountains, with the survey boundary, middens, major roads, and streams overlaid.

BACKGROUND

Development of a habitat suitability model requires that spatial, spectral, and habitat information be combined and incorporated into a modeling environment that results in a habitat suitability map. Key to creating a habitat suitability model is having the requisite data to build the model. Spatial data must identify where squirrels have been observed, habitat data describes important aspects of the squirrels' habitat, and spectral data provides information on the structural properties of the forest canopy. The trick is to incorporate (or correlate) important habitat characteristics found within the squirrel's home range, which varied between 1.6 and 6.3 ha in the Pinaleno Mountains (Froehlich and Smith 1990), with variables that are suitable for modeling at the landscape scale (such as satellite imagery). This is where remote sensing and a Geographic Information System (GIS) become important.

Remote Sensing and Classification

Avery and Berlin (1992) defined remote sensing as "the technique of obtaining information about objects through the analysis of data collected by special instruments that are not in physical contact with the objects of investigation". Remotely sensed imagery has been used worldwide to classify features like vegetation, minerals, and landuse practices. There are two basic approaches to spectral classification (Schrader and Pouncey 1997), supervised and unsupervised. In a supervised classification, the analyst uses reference (field) data to train the computer to recognize spectral signatures of interest (like a forest canopy). In contrast, in an unsupervised classification, the computer finds clusters of pixels with an iterative, self-organizing algorithm, grouping pixels into their most likely classes based upon their values. Both methods require the analyst to interpret the resultant classification, ideally with reference (field) data. Classification works best when it is iterative, regardless of the method chosen, whereby field data are used to refine and improve classification accuracy.

A supervised classification has the advantage of using data collected a priori, thus the analyst has up-front knowledge about the resultant classification. The disadvantages to the supervised classification approach are that a lot of field work is required to collect the spectral signatures, and the feature the analyst wishes to distinguish may not have enough spectral uniqueness to separate it from it's surroundings. In contrast, an unsupervised classification works well if the features of interest have enough spectral uniqueness for the computer algorithm to distinguish them, thus saving some up-front work. This technique can be advantageous if there is a lack of personnel or time to collect the requisite spectral signatures. Regardless of the classification techniques used, the benefits of remotely sensed imagery are large when working in very remote, rugged terrain such as in the Pinaleno Mountains.

Geographic Information Systems

A GIS is ideal for the examination of spatial data because it is "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" (ESRI 1994). A GIS can display information in both vector (points, lines, polygons) and raster (cell) format, depending on the goals of the analyst. For spatial analysis, where a continuous surface is important (like the Pinaleno Mountains), a raster format is

preferable because the grid (cell) environment is faster and more efficient than the vector format (ESRI 1992). For MGRS analysis, a GIS was a necessary tool in the development of a habitat suitability model because it tied together the spatial, habitat, and spectral information.

The analysis presented here was not the first attempt to model MGRS habitat. Pereira and Itami (1991) developed a GIS-based habitat model for much of the mountain using multiple logistic regression. Their study assessed the potential impacts of telescope development on MGRS habitat. Pereira and Itami used both topographic, vegetation, and proximity (nearness to openings) variables in their models. The topographic variables were slope, aspect, and elevation, which were extracted from digital elevation models. The vegetation variables were food productivity, canopy closure, and tree diameter at breast height, which they obtained by digitizing a USFS forest stand map.

Pereira and Itami (1991) found that elevation, slope, aspect (E-W, not N-S), and canopy closure were statistically significant variables in their models. Their best model correctly identified 90 percent of the squirrel activity, while only 27 percent of the inactive areas were misclassified. There is an unexplained aspect of their study which casts some doubt on their results, namely, the study area boundary itself, which came from the MGRS study (USFS 1988). Within their study boundary, 212 active squirrel sites were identified, while the rest of the area was classified as unoccupied. This implies that the entire area was searched, but this is unlikely since the combined efforts of the MGRS cooperators have yet to survey the entire area 10 years later. This presents a fundamental problem for Pereira and Itami's analysis and conclusions, since their methods required that the study area be fully searched. Until this discrepancy is addressed, it is difficult to accept their major conclusions.

METHODS

DIGITAL DATABASE PREPARATION

The Dictionary of Natural Resource Management (Dunster 1996) had several definitions for "model," but the definition that best fits the approach presented here is: "An idealized representation of reality developed to describe, analyze, or understand the behavior of some aspect of it." There is no statistical relation implied whenever the word model is used in this paper unless specifically stated. Whenever the term "modeling" is used, it refers to the act of GIS cell-based modeling, or image processing techniques, to create the MGRS habitat suitability map.

The database chosen for model development was the AGFD MGRS midden database, which contained 1,128 midden locations collected over a 15 year period. In order to increase spatial accuracy, only site locations obtained with a global positioning system (Hurn 1989) were selected, which reduced the number of midden locations to 1,022. The AGFD midden database was ideal for model creation because a suite of variables had been collected at many of the midden sites (tree diameter, over-story, under-story, habitat type and seral stage). While there was a lot of good information in the database, only the middens' location and habitat type (i.e.

mixed-conifer, spruce-fir) were used. All other variables used in the analysis were extracted from satellite imagery or digital elevation models. This does not imply that the unused variables were unimportant, but rather their utility has yet to be determined. Another database examined was the USFS forest stand map, which was created by field surveyors, and provided information about the forests of Mt. Graham. The USFS forest stand database was not used in the modeling because it did not cover the entire mountain, and many of the stand variables were qualitative and less useful for modeling purposes (Pereira and Itami 1991).

ARC/INFO, a GIS developed by Environmental Systems Research Institute (ESRI), was used for all GIS operations, including digital surface modeling and overlay operations. ARC/INFO has both raster (cells) and vector (point, line, area) capabilities. ARC GRID was used for all surface (raster) modeling, and ARC/INFO used for all vector and overlay operations. A continuous elevation surface was created by converting Digital Elevation Models (DEMs) into grids, then mosaicing them together with GRID's MOSAIC function. The resultant grid had a 98.5 feet (30 m) resolution (each cell was 9,695 feet^2 or 900 m^2) and covered the entire Pinaleno Mountains. Two more grids were created by extracting slope and aspect from the elevation grid with GRID's SLOPE and ASPECT functions. GRID's RECLASS function was then used to aggregate the data into classes that were used in overlay analyses. Elevation data were aggregated into a range of elevation classes and examined (Fig. 2). Slope data were aggregated into 10 degree increments (Fig. 3**),** while aspect data were aggregated into 4 classes (Fig. 4): north (315 – 45 degrees), east (46 – 135 degrees), south (136 – 225 degrees), and west (225 – 314 degrees).

IMAGE PREPARATION

ERDAS IMAGINE, an image processing software package developed by ERDAS INC., was used for all image processing tasks. A 7-band Thematic Mapper (TM) image (Fig. 5) was used for model development; the image was acquired on June 19th, 1993, and had a resolution (pixel to ground ratio) of 93.5 feet (28.5 m). While the TM image had 7 bands, only bands 1 – 5 were selected, which corresponds to blue, green, red, near infrared (IR) and mid IR portions of the electromagnetic spectrum. The 6th band used in the classification (Fig. 6) was the Normalized Difference Vegetation Index (NDVI), which was created with ERDAS' NDVI function (band 4 – band 3 / band 4 + band 3). NDVI was included in the classification because of its utility in discriminating differences in vegetation density and biomass (Jensen 1981), and for minimizing the effects of shadows.

Before image classification occurred it was necessary to update the 1993 TM image due to changes in the forest canopy, and to correct for positional error (RMS) within the image. The big change in the forest canopy since 1993 resulted from the Clark Peak fire (1996). A change detection was conducted with 1993 and 1997 TM images (Fig. 7), accomplished by calculating NDVI for both images and identifying where NDVI had decreased by at least two classes. Field reconnaissance, in conjunction with overlay analysis in the office, showed the change detection was successful. The 1993 image was used instead of the 1997 image for model development because it was higher quality, due to professional post-processing by the manufacturer (Earth Satellite Corporation).

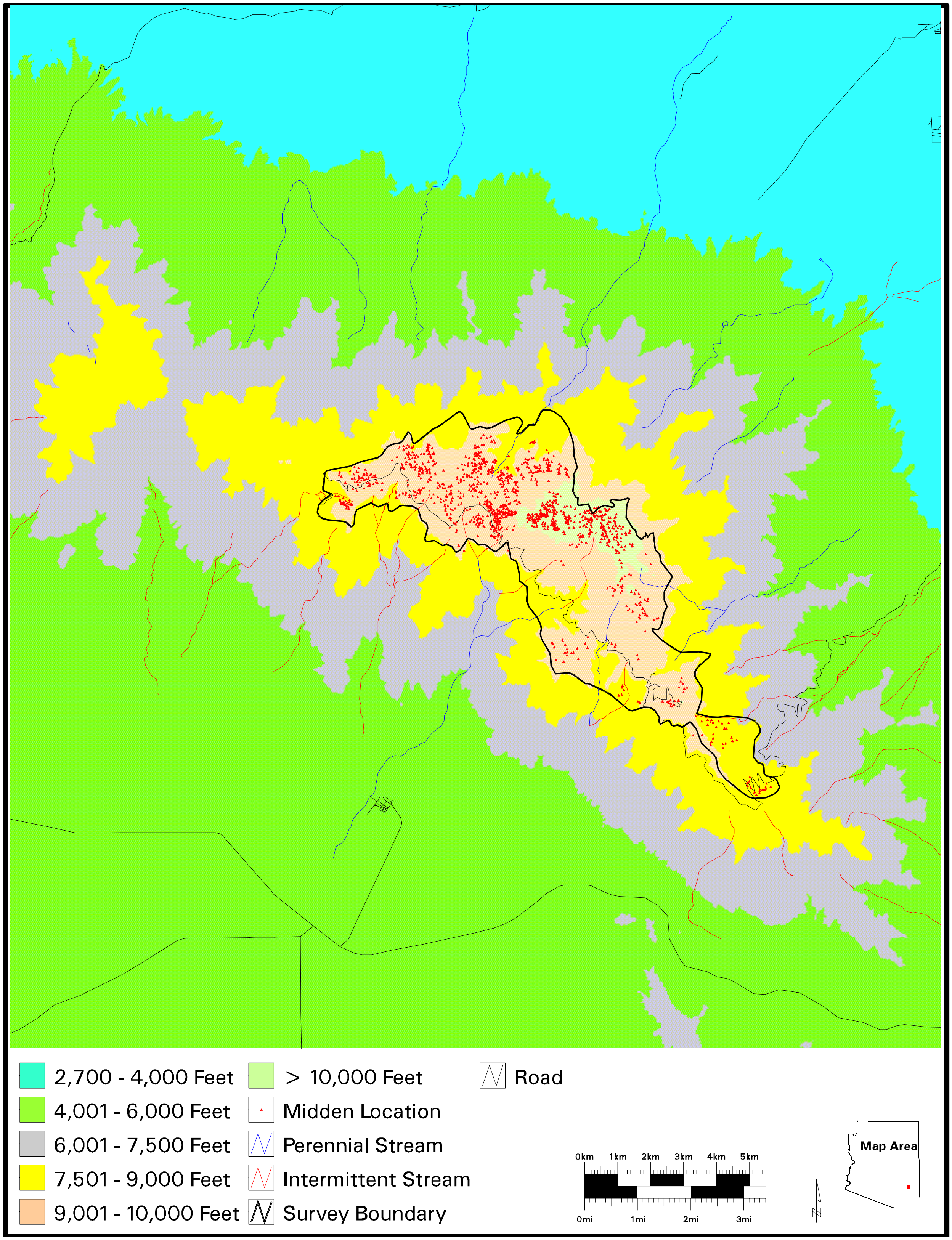

Figure 2. Elevation zones of the Pinaleno Mountains, with the survey boundary, middens, major roads, and streams overlaid.

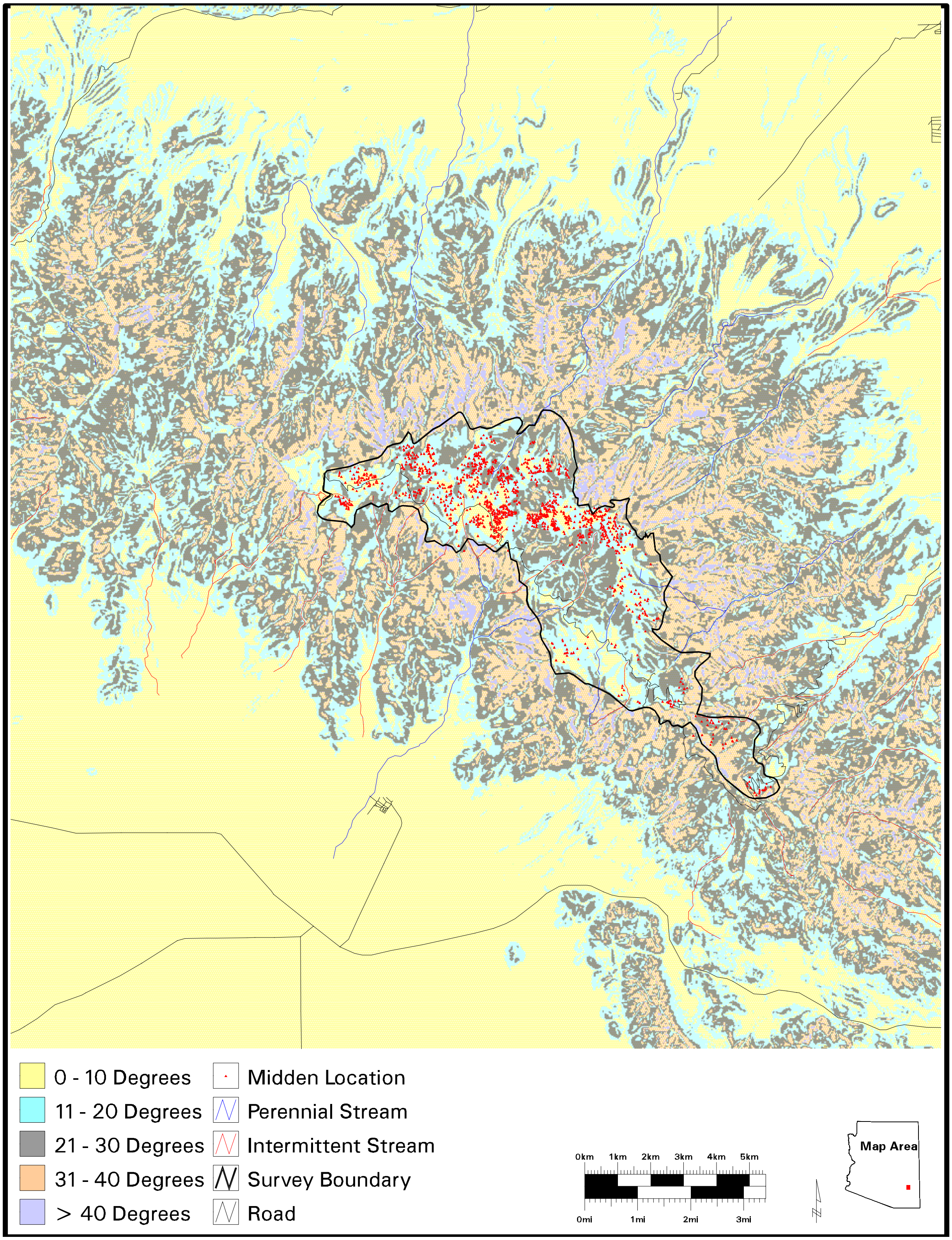

Figure 3. Slope classes of the Pinaleno Mountains, with the survey boundary, middens, major roads, and streams overlaid.

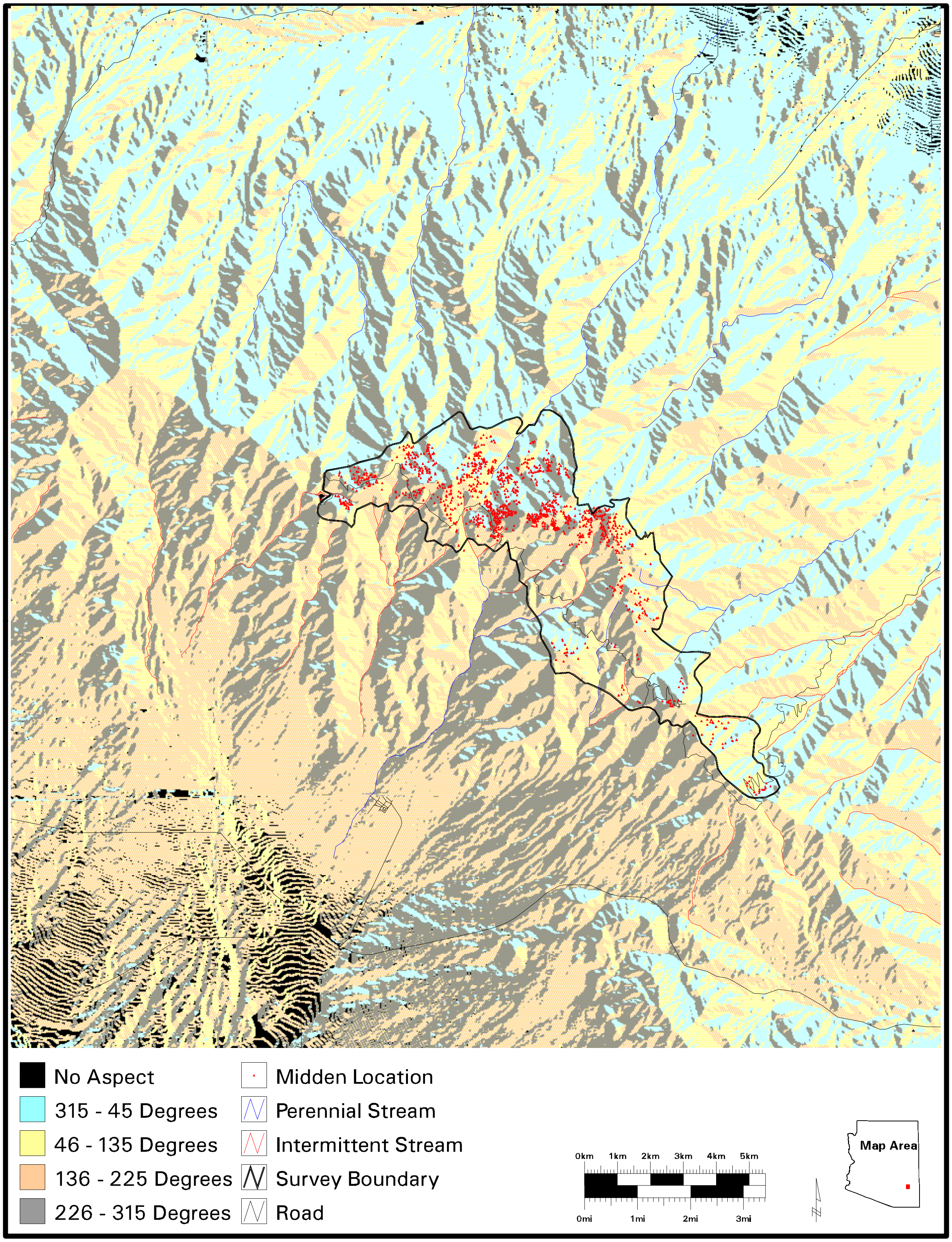

Figure 4. Aspect classes of the Pinaleno Mountains, with the survey boundary, middens, major roads, and streams overlaid.

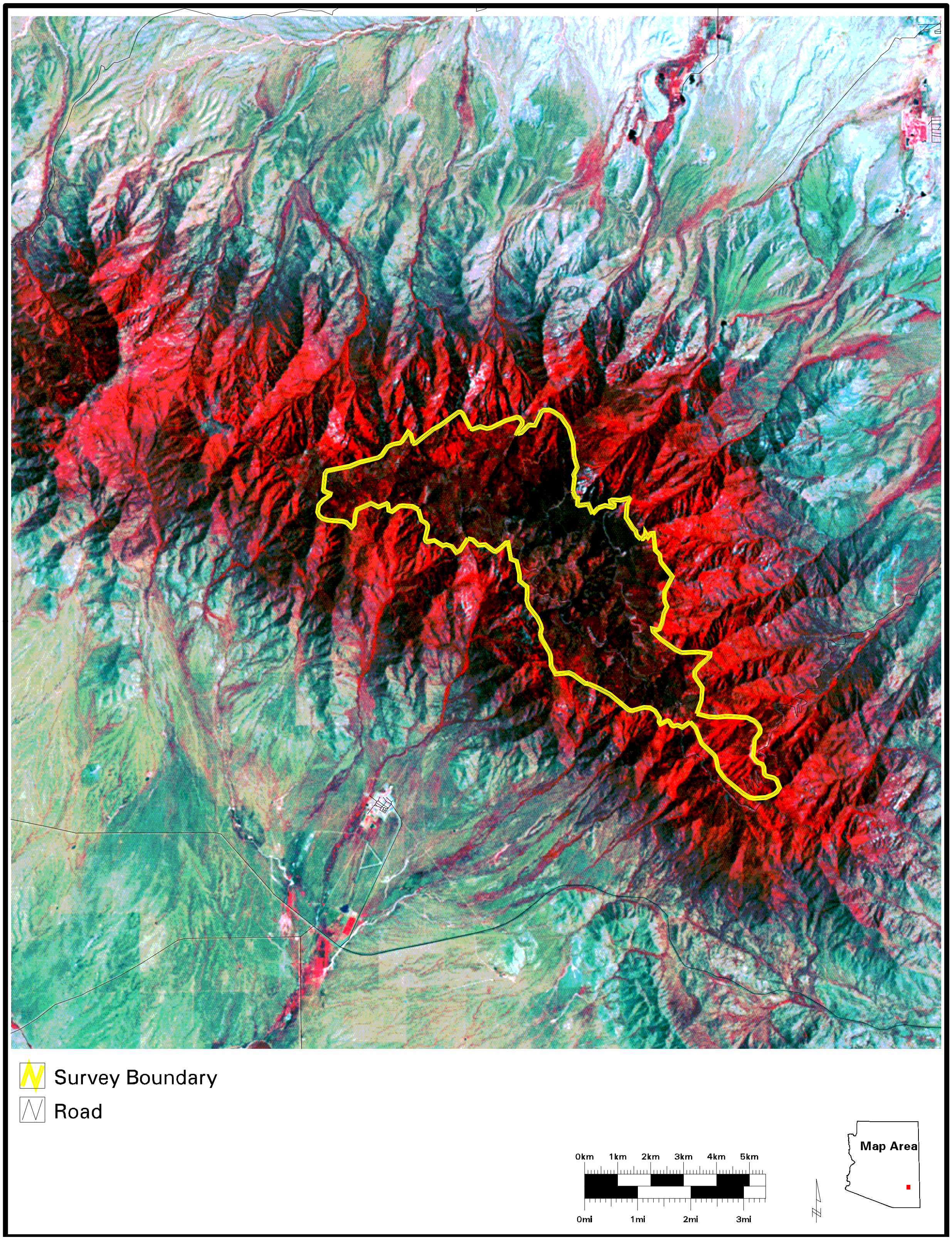

Figure 5. A TM image (false-color infrared) of the Pinaleno Mountains, with the survey boundary and roads overlaid.

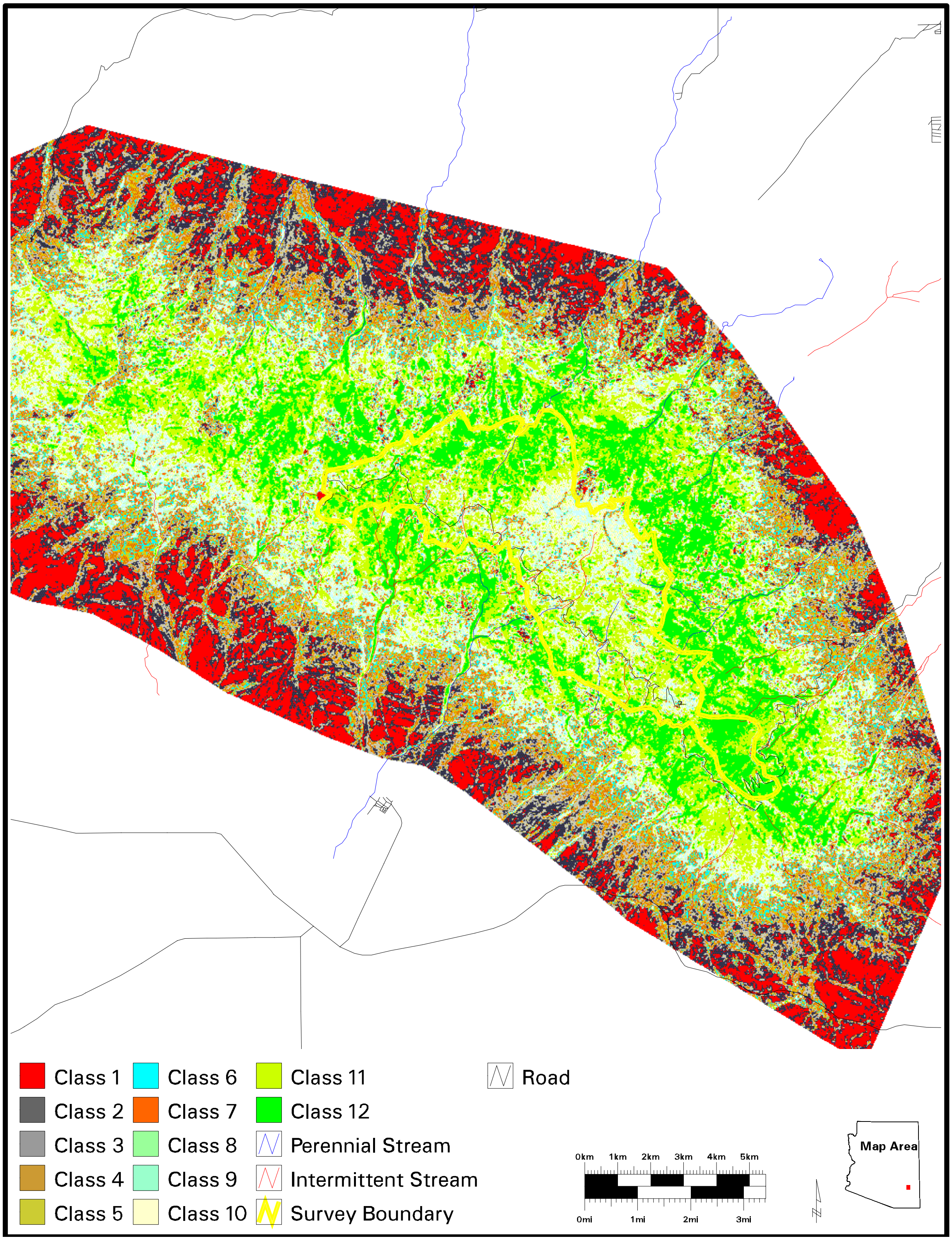

Figure 6. The normalized difference vegetation index for the Pinaleno Mountains; relative density and biomass of vegetation increases with NDVI class.

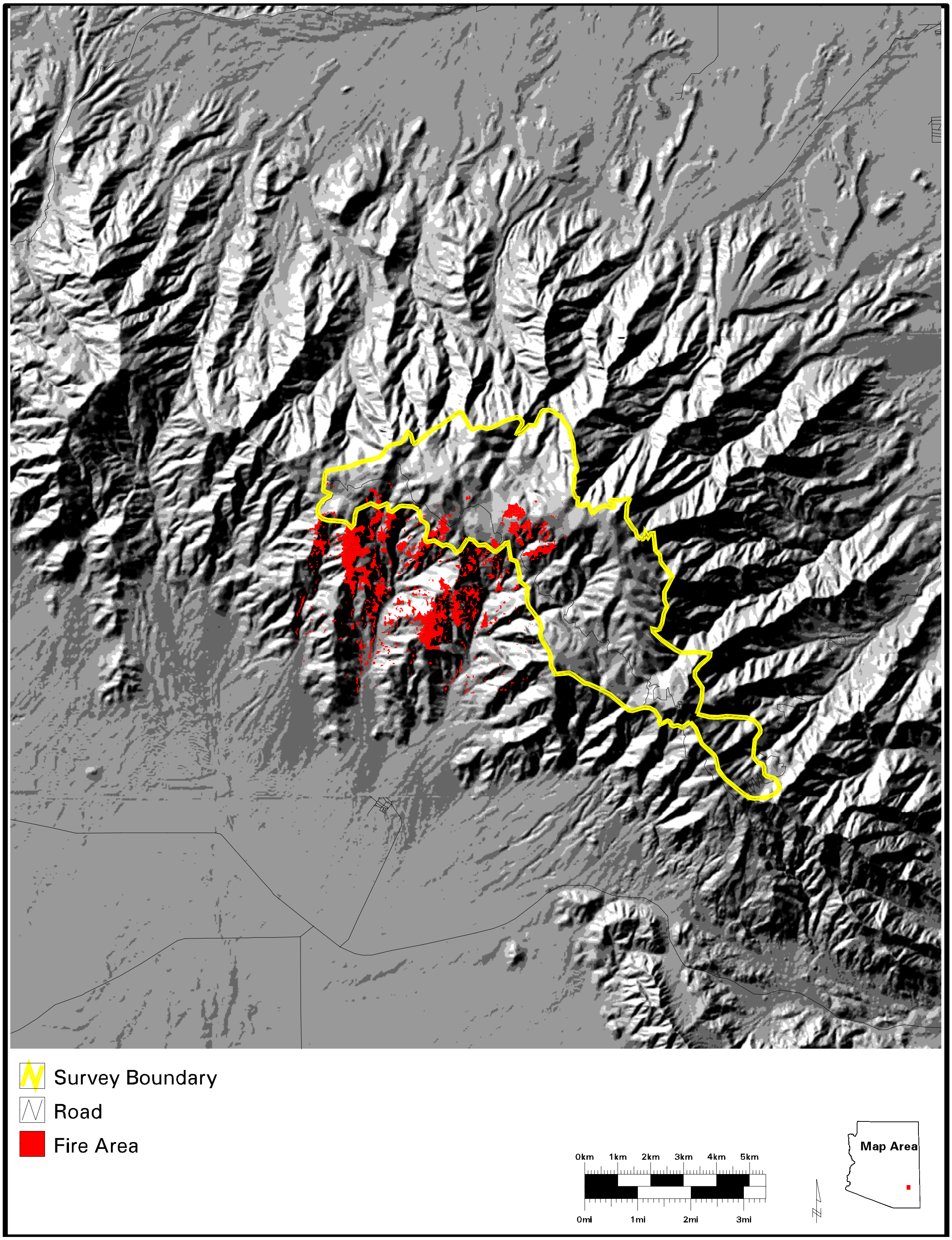

Figure 7. The results of a change detection analysis which revealed the Clark Peak fire burn area.

In order to insure the best classification results, it was necessary to re-register the TM imagery to reduce positional error resulting from the manufacturer. The original 1993 TM image had +/- 2 pixels error (57 m; 187 feet), determined by overlaying it onto a digital USGS topographic map (which was what the original image had been registered to). Positional error was reduced by 1 pixel by clipping the image to the study area, re-registering it to a digital topographic map, then ortho-rectifying it to a digital elevation model. The resultant image had a slightly lower resolution (pixel to ground ratio of 30 m), but almost twice as low positional error. This insured that when reference data obtained with highly accurate GPS units were overlaid onto the classified image, the best results were obtained.

MODEL DEVELOPMENT

The primary objective of this analysis was to identify (model) potentially suitable MGRS habitat. A hypothesis was developed, and tested, that the spectral and structural characteristics of the forest canopy, in conjunction with topographic information, could identify potentially suitable habitat of the MGRS (a technique called pattern recognition). The habitat information could then be used to refine our current midden-based survey, or aid in the development of a plot-based survey methodology. The image processing technique used for hypothesis testing was pattern recognition, which is “the science and art of finding meaningful patterns in data, which can be extracted through classification” (Schrader and Pouncey 1997). The AGFD midden database contained the midden locality and habitat information, while the TM image provided the spectral properties of the forest canopy. Ideally, combining the two would produce a suitability model. A pattern recognition model may not key in on some of the micro-habitat features that a MGRS utilizes, but it can be an effective surrogate if the spectral and structural properties of the forest canopy correlate to important micro-habitat features. Hereafter, the terms “pattern recognition model” and “habitat suitability model” were used interchangeably.

While the habitat suitability model was based upon the spectral properties of the forest canopy, ancillary topographic information (slope, aspect and elevation) were used to help interpret and apply the model. The midden data were overlaid on the topographic variables and the frequency histograms examined. Ideally, midden frequency should have been corrected (standardized) by the area surveyed, which would have given a relative midden density for each habitat type. Unfortunately, standardizing the data by area was not possible since detailed records had not been kept of all the areas searched. In addition, some hazardous areas were never searched. Since the data were not standardized by area searched, definitive statements could not be derived, but they were useful in illuminating patterns.

In order to develop the model, approximately 50 percent of the midden database (511 locations; Fig. 8) were randomly selected and used in spectral analysis. The remaining 507 middens were used to assess the accuracy of the model. Creation of the model was iterative: 1) middens were overlaid on the spectral classes produced from the unsupervised classification, 2) frequency histograms were examined to identify which spectral classes contained the most middens, 3) modifications were made to the thematic (classified) image in order to simplify and improve the model, 4) Steps 1 – 3 were repeated, and 5) an accuracy assessment was conducted on the final product.

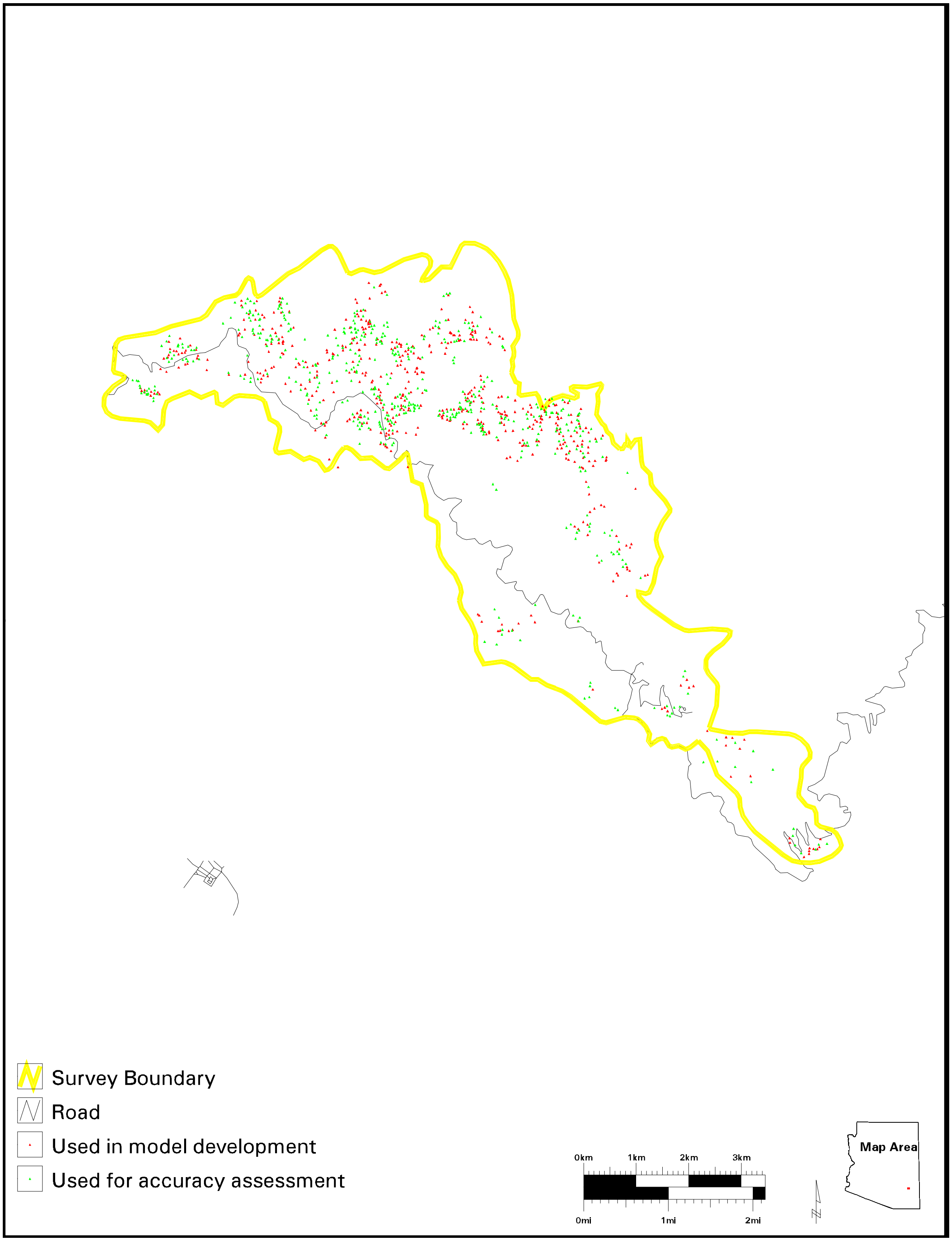

Figure 8. The survey boundary with the randomly selected middens used in model development and accuracy assessment overlaid.

In classification it is beneficial to identify and mask areas that are spectrally unsuitable, then restrict the classification to the unmasked areas - effectively zeroing in on important areas. In order to identify and mask unsuitable areas, the midden data were overlaid on the 12 NDVI classes. The NDVI classes that did not contain middens became a mask for subsequent analyses (Fig. 9). Next, a 12-class thematic image was created from the unmasked portion of the TM image with the ISODATA algorithm; ISODATA stands for iterative, self-organizing data (Schrader and Pouncey 1997). The ISODATA unsupervised technique is a clustering algorithm ideally suited for this analysis because it was designed to identify clumps (classes) in the data, based upon spectral properties it analyzes. The ISODATA parameters were set to 12 spectral classes, using 2 standard deviations, and a convergence threshold of 95 %, meaning that less than 5 percent of the pixels could change class during an iteration before the program terminated. The ISODATA algorithm resulted in 12 classes derived from the spectral properties of the forest canopy of the Pinaleno Mountains (Fig. 10**)**. Next, the midden data were overlaid on the 12 spectral classes and the resultant frequencies examined. Spectral classes that contained relatively few middens were collapsed into a single unsuitable class, while the others were considered spectrally suitable. There were no criteria to guide this process of spectral class clumping, just careful examination of the midden data overlaid on the imagery. Next, information collected at the midden locations was used to characterize vegetation composition within each spectral class. Spectral classes which contained two or more habitat types were collapsed (merged) with other mixed classes in order to create the most effective, simple model.

Accuracy Assessment

Accuracy assessment was the final step in model development. There was really a need for two accuracy assessments because there were two study areas: 1) potentially suitable habitat within the survey boundary, and 2) potentially suitable habitat outside the survey boundary. While there was a lot of data within the survey boundary (the midden database) to use as a reference, virtually no data existed outside the survey boundary. So in a very real sense, areas outside the survey boundary were terra incognito for red squirrel analyses. In contrast, accuracy assessment within the survey boundary was straightforward, since the midden locations were used to identify suitable habitat. Accuracy assessment was conducted by overlaying 507 middens - the ones not used in model development - on the final classified image. Classification agreement was then calculated between model prediction and the reference data. An additional 18 sites were collected and examined (Table 1) in order to assess classification accuracy within the unsuitable class.

ERDAS' accuracy assessment tools were used to calculate three types of classification accuracy (Story and Congalton 1986): 1) overall accuracy, 2) producer's accuracy, and 3) user's accuracy. Overall accuracy represents the accuracy of the overall product (the map), but it does not indicate how the accuracy is distributed across the individual classes. In contrast, producer's accuracy examines errors of omission, thus something is on the ground that is not on the map. Lastly, user's accuracy examines errors of commission, thus something is on the map but is not on the ground. Also calculated was the Kappa statistic (Lillesand and Kiefer 1994), which is an

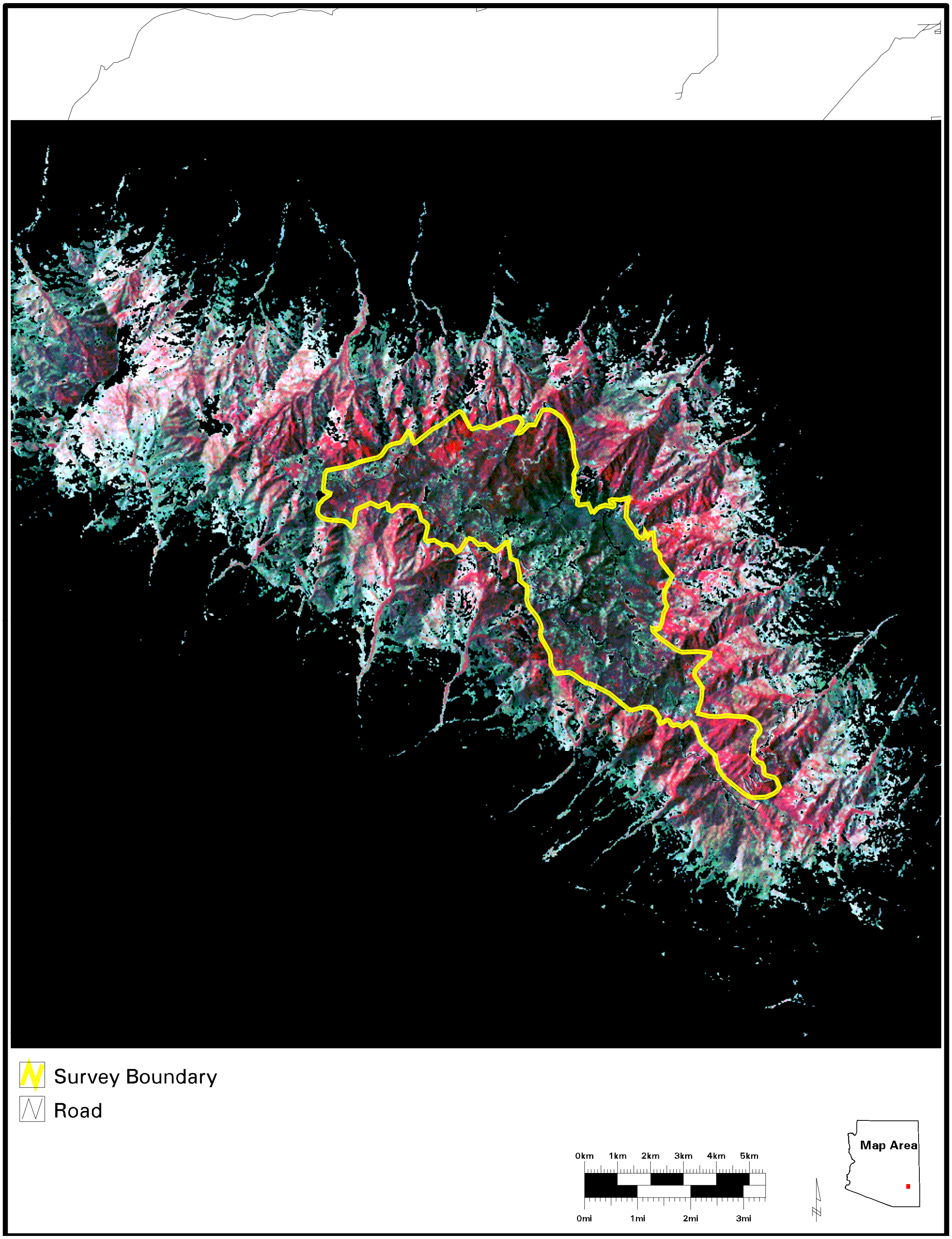

Figure 9. A TM image after an NDVI mask was applied (compare with Figure 5).

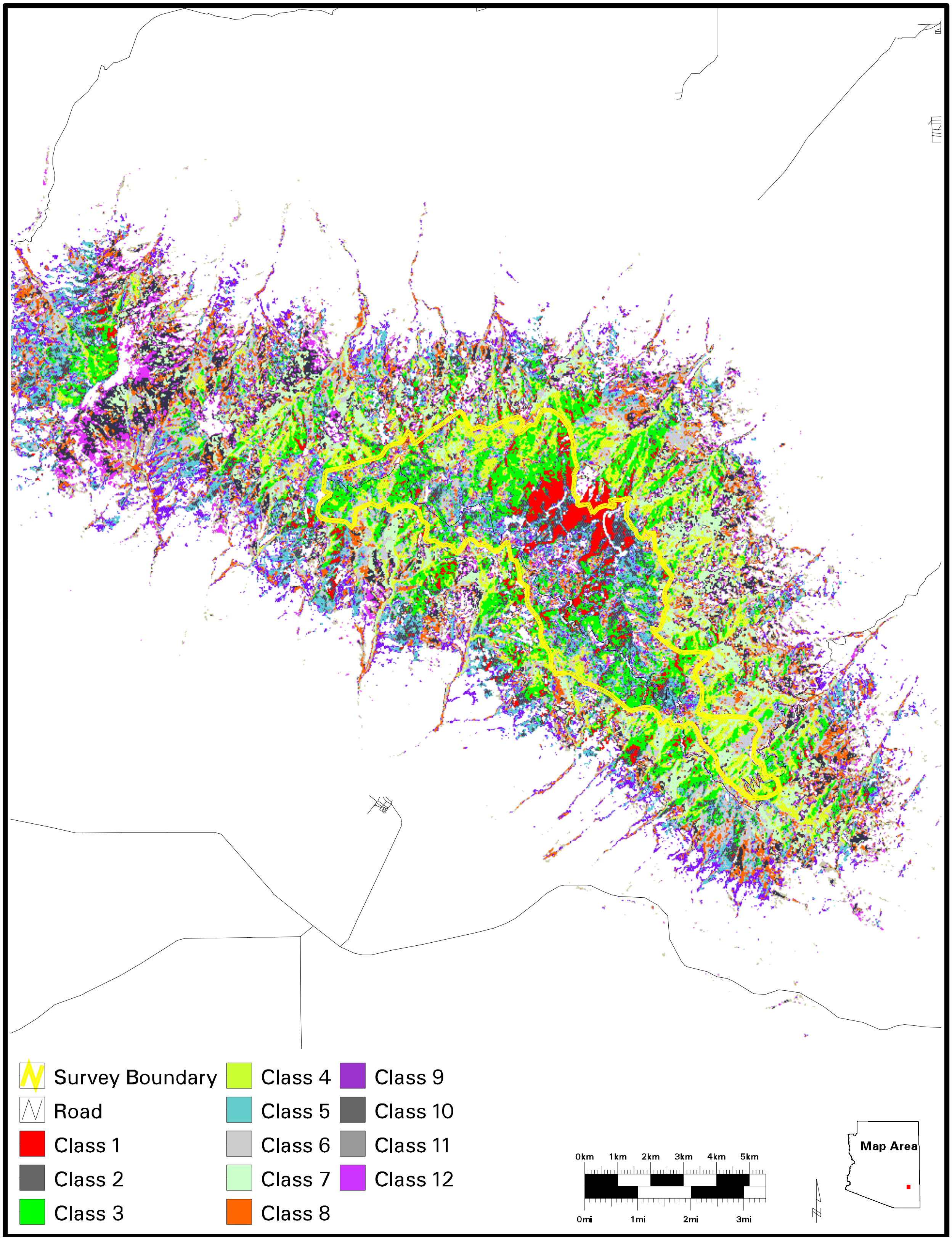

Figure 10. The results of an unsupervised classification of the 6-band TM image (Fig. 9), showing the 12 spectral classes, with the survey boundary and roads overlaid.

indicator of the extent to which the percentage correct values of an error matrix are due to true agreement versus chance agreement. The Kappa statistic and overall classification results usually vary from one another because they use different portions of an error matrix, but both pieces of information are good to compare and contrast.

Table 1. The 18 sites visited for determining accuracy of the unsuitable class.

SITE	EASTING	NORTHING	ELEVATION	SITE NAME
110716e	599441	3620146	9250	Chesley Flat Meadow
110717c	597251	3619448	8750	Spot fire north of Riggs Lake
110717a	597329	3619206	8750	Inlet to Riggs Lake - meadow and alder
110717b	597038	3618992	8500	Edge of Riggs Lake, south side.
110716b	600247	3618943	9250	Meadow
110716d	599913	3618935	9250	Spot burn on road
110716a	600847	3618429	9500	Burn east of Soldier Creek campgroud
110715a	603219	3617600	9250	Post Creek rock outcrop
110718b	603161	3617113	9000	Burn west of Post Creek
110623a	605731	3614855	9000	Hospital Flat meadow
110622a	605854	3614213	8750	Treasure Park meadow
110621c	606534	3613251	8750	Snow Flat meadow
110621d	606500	3613204	8750	Edge of lake at Snow Flat
110720a	611507	3612439	2000	Oak/pine forest along road
110621b	607600	3612366	8750	Aspen/oak thicket
110621a	607867	3612238	8750	Oak/aspen thicket
110620a	608648	3611225	8750	Gambel oak/shrubs
110719b	610591	3610635	7500	Parking lot at 2nd gate (7th switchback)

Conducting the accuracy assessment outside the survey boundary was difficult compared to inside the survey boundary, due to the lack of existing survey data. Consequentially, random points were generated outside the survey boundary, but within the potentially suitable class (Fig. 11) for field visits. Nineteen sites were visited and attribute data collected (Table 2). A GPS coordinate was collected where feasible (10 sites), but dense canopy prevented a GPS location to be collected at all sites. An external antenna probably would have alleviated the problem and should be carried in the future. To determine if we actually visited the correct point in the field, the 10 GPS points were overlaid onto the original random points back in the office and compared. Eight of the field sites inspected were within 230 feet (70 m) of the random points, which was sufficiently close to believe we inspected the correct feature in the field (considering image positional error). However, sites seventeen and twenty were over 656 feet (200 m) off and were not used in the analysis (i.e. we inspected the wrong locations). The nine locations that did not have a GPS location were used in the accuracy assessment anyway, since the accuracy rate for inspecting the correct feature was 80 percent (8 out of 10).

Lively discussions ensued at each random site between MGRS biologists, namely, was it squirrel habitat or not. In the strictest sense, any area that was mixed-conifer, ecotone, or spruce-fir qualified as suitable since those habitat types contained the squirrel middens within the survey

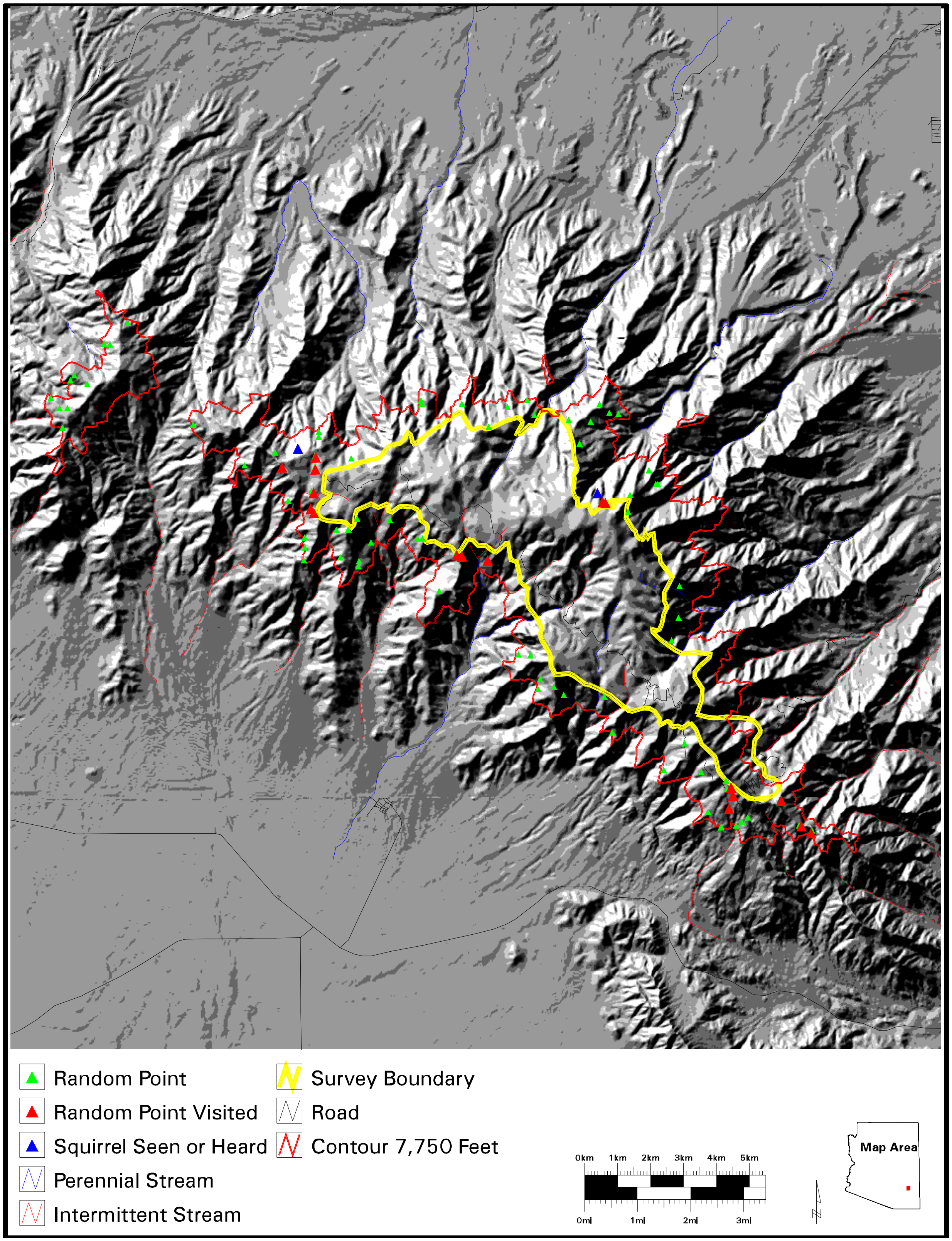

Figure 11. The 19 random points used in accuracy assessment outside the survey boundary are displayed.

Table 2. Random point coordinates and attributes collected outside the survey boundary.

ID	EAST	NORTH	OFF[1]	ELEV	SLOPE	ASPECT	SERAL[2]	POTENT[3]	EVIDENT[4]	SPECIES[5]
17	609527	3610098	270	8840	20	210	PO	Low	No	WP,PP,GO
20	609470	3610350	240	9080	10	190	MX	Low	No	DF,WP,PP
14	596332	3620623	NA	8250	45	1	OG	High	Yes	DF,WF
88	605422	3619273	NA	9500	20	3	OG	High	Yes	DF,CBF,ES
50	605572	3619003	NA	10000	30	352	MX	Low	No	ES,DF,CBF,ASP
63	605662	3618973	NA	10000	50	1	MX	Low	No	CBF,ES,ASP
30	601312	3617353	NA	8750	25	70	OG	Medium	No	DF,WP,PP
54	596872	3620354	40	8750	8	228	MA	Low	No	DF,WF,WP,PP
72	596801	3619272	70	8750	31	194	PO	Low	No	DF,WP,PP
80	595852	3620053	NA	8750	5	205	MX	Low	No	DF,WP,PP
49	596722	3618793	NA	8250	48	320	MX	Low	No	DF,PP,GO
90	602092	3617233	NA	8250	31	272	MX	Low	No	DF,APS,WP,PP
60	596820	3618669	8	8500	32	285	MX	Low	No	DF,WP,PP,GO
6	601155	3617390	58	9000	20	294	MX	Low	No	DF,ASP,GO,WP
24	596859	3619992	63	8750	12	260	PO	Low	No	SP,PP,DF
36	611002	3609943	NA	8250	20	68	MX	High	No	DF,WF,GO
23	611611	3609171	70	8000	10	50	MX	Low	No	DF,WF,PP,GO
19	611899	3608963	35	7750	15	230	MX	Low	No	DF,PP,SO
61	609412	3609703	NA	8000	20	90	MX	Low	No	DF,WP,PP,WF,GO

[1]The distance between the random map coordinate and the GPS position taken in the field.
[2] Seral Stage (PO = pole; MX = mixed ages; OG = old-growth; MA = mature)
[3] Low = little to no squirrel habitat; Medium = moderate squirrel habitat; High = lots of good habitat.
[4]Squirrel sign present (heard, seen, midden)
[5]WP = white pine; PP = ponderosa pine; GO = Gamble oak; DF = Douglas-fir; WF = white fir; CBF = corkbark fir; ES = Englemann spruce; ASP = aspen

boundary. However, quantitative criteria to rank MGRS habitat potential outside the survey boundary had not yet been developed. Until an in-depth analysis is conducted of the midden database, and habitat criteria defined, conducting an accuracy assessment outside the survey boundary will remain largely qualitative. Ideally, when a site was visited outside the survey boundary, a squirrel would be seen or heard - which did happen at a couple of sites. However, sites that had no evidence of squirrel use required a judgment call on habitat suitability.

At each random point, data were collected on elevation, slope, aspect, seral stage, site potential, evidence of squirrel presence, and tree species (Table 2). Seral stage was denoted as pole (young trees), mature (trees were good sized, but clearly not old-growth), old-growth, and mixed ages. A qualitative habitat suitability ranking was developed by MGRS personnel and assigned to each site visited: 1) low = little to no potential, 2) moderate = habitat did not look too bad and probably could support squirrels, and 3) high = very good habitat present, or squirrels heard or seen. Qualitative measures of squirrel habitat used to rank the squirrel habitat included: presence or absence of standing snags or downed logs, the density of the canopy, the relative lushness of the site, presence of large cone bearing trees, slope, and aspect.

RESULTS

FIRE CHANGE DETECTION

The results of the fire change detection estimated that 2.6 percent (1.2 mi^2 (3.21 km^2)) of spectrally suitable habitat for the MGRS burned in the Clark Peak fire. Within the survey boundary, 3.2 percent (0.46 mi^2 (1.19 km^2)) of spectrally suitable habitat burned, and 2.6 percent (0.8 mi^2 (2.02 km^2)) outside the survey boundary. The change detection analysis did not include spectrally unsuitable habitats for MGRS (like oak thickets). Thus, the total size of the fire was somewhat larger than that reported (Fig. 7).

TOPOGRAPHIC ANALYSIS

The relationships between the three topographic variables and midden frequencies are displayed in Figures 12A-C. Middens were sparse between 7,750 (2,362 m) and 9,000 (2,743 m) feet (Fig. 12A), occurring only on north and east aspects (classes 1 and 2). While data were not standardized by area, it appeared that the heaviest concentrations of middens were above 9,000 feet, extending all the way to the top of the mountain. Concerning aspect, the north slopes of the mountain contained the greatest numbers of middens, east and west slopes contained similar numbers of middens, and south aspects the fewest (Fig. 12B). Note in Figure 12B how the number of middens within each aspect class increased steadily from south to north. Regarding slope (Fig. 12C), classes 1 – 2 (0 – 20 degrees) had the most middens, with a rapid drop in midden frequency in slope classes 3 and 4. There were very few middens observed above 30 degrees, and none observed above 40 degrees.

NORMALIZED DIFFERENCE VEGETATION INDEX ANALYSIS

The relationships between NDVI (in 12 classes) and midden frequency are displayed in Figure 12D. Very few middens were observed below NDVI Class 8, and a visual inspection of the NDVI classification (Fig. 6**)** revealed that classes less than 8 largely comprised the lower flanks of the mountain. Since the NDVI classes were created with an unsupervised classification, reference data were not used to define them. However, site investigations helped qualitatively define the NDVI class contents as: classes 1 - 3 contained rock outcrops, semi-desert grassland, meadows, water features, and bare soils; classes 4 - 7 contained oak woodlands, pinyon-juniper, and pine-oak communities; and classes 8 – 12 were mixed conifer, ecotone, and spruce-fir series. Please note on Figure 6 the vegetation inversions extending down the canyons of the mountain are conifers below their normal elevation boundary, likely due to the cooler micro-climate adjacent to the creeks. Since NDVI classes below 8 were unsuitable habitats for MGRS, they were masked-out in all subsequent image analyses. After masking, NDVI was again included as the 6^{th} band in the unsupervised classification based upon its clear importance as a predictor variable.

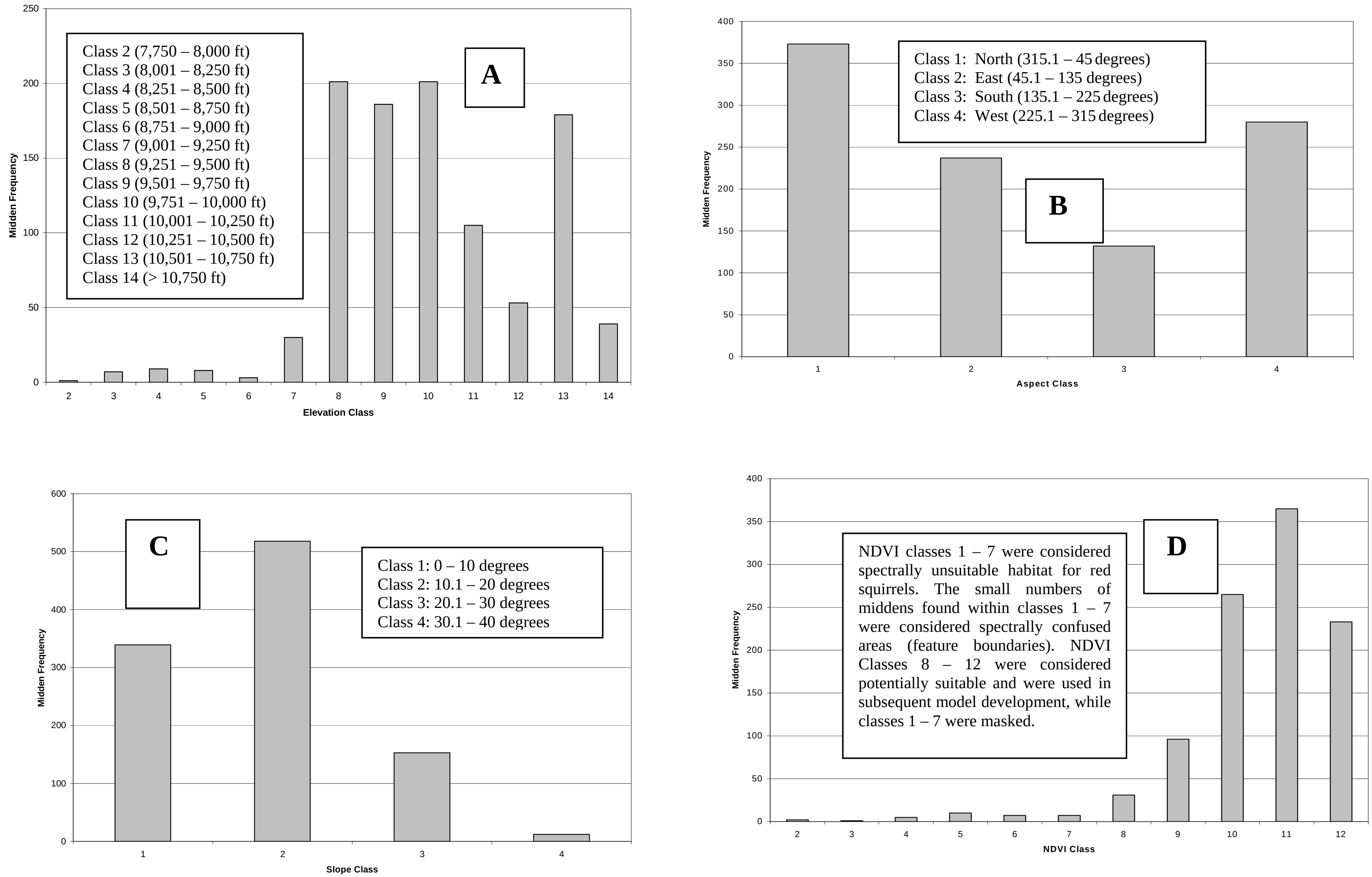

Figure 12. Relationships amongst topographic variables, NDVI, and middens.

The relationships among the randomly selected middens and the 12 spectral classes are shown in Figure 13. Spectral classes 1 – 6 contained 91 percent of the middens (n = 457), while classes 7 – 12 contained only 9 percent (50). A close inspection of the middens (when overlaid on the image) revealed the majority of middens found in classes 7 – 12 were along feature boundaries, such as roads and meadows (spectrally confused areas). A more in-depth discussion on spectral confusion and spatial error can be found in the discussion. Spectral classes 7 – 12 were aggregated into a single class and labeled unsuitable MGRS habitat. In subsequent analyses and discussion, the term suitable habitat referred to spectral classes 1 – 6.

Relationships between the 6 suitable classes and the habitat types (series) contained within them are show in Figure 14. Recall that the reference data for this analysis were derived from the midden database, so the midden locations did not represent a random sample of the forest. However, it was the only source of accurate data for this analysis. Spectral Class 1 was the only class that contained a relatively pure habitat type (88.5 percent spruce-fir). In contrast, the other 5 spectral classes had substantial mixing of two or more habitat types. This was not surprising since many sites contained conifer species indicative of two series. Given the mixing of tree species at such a localized scale, it became obvious that even a higher resolution image might not be able to accurately classify the habitat types. Therefore, for purposes of simplifying the model and the resultant accuracy assessment, spectral classes 1 – 6 were aggregated into a single suitable class (Fig. 15). This caused no conflict with the project objectives of identifying potentially suitable MGRS habitat or identifying a meaningful survey boundary. It also made the accuracy assessment much simpler, since there were only two classes to consider: suitable or unsuitable.

Table 3 lists the amount of habitat (suitable and unsuitable) within three zones: Zone 1 is within the survey boundary, Zone 2 is outside the survey boundary but above 7,750 feet (2,362 m), and Zone 3 is below 7,750 feet. The significance of Zones 2 and 3 is there have not been any MGRS middens found within them. However, Zone 2 is located at an elevation where MGRS have been found within the survey area, so its potential is higher than Zone 3, which is at an elevation where middens have not been found. There was a total of 47.2 mi^2 (122.1 km^2) of spectrally suitable habitat on the Pinaleno Mountains: 14.1 mi^2 (36.5 km^2) of spectrally suitable habitat within Zone 1, 12.0 mi^2 (31.1 km^2) within Zone 2, and 21.1 mi^2 (54.6 km^2) within Zone 3.

ACCURACY ASSESSMENT WITHIN THE SURVEY BOUNDARY

Overall classification accuracy was 92.2 percent (Table 4), with 92.6 percent of the randomly selected middens correctly classified (Producers accuracy; Table 4). Concerning unsuitable habitat, 83.3 percent of the unsuitable locations were correctly classified (Producer's accuracy).

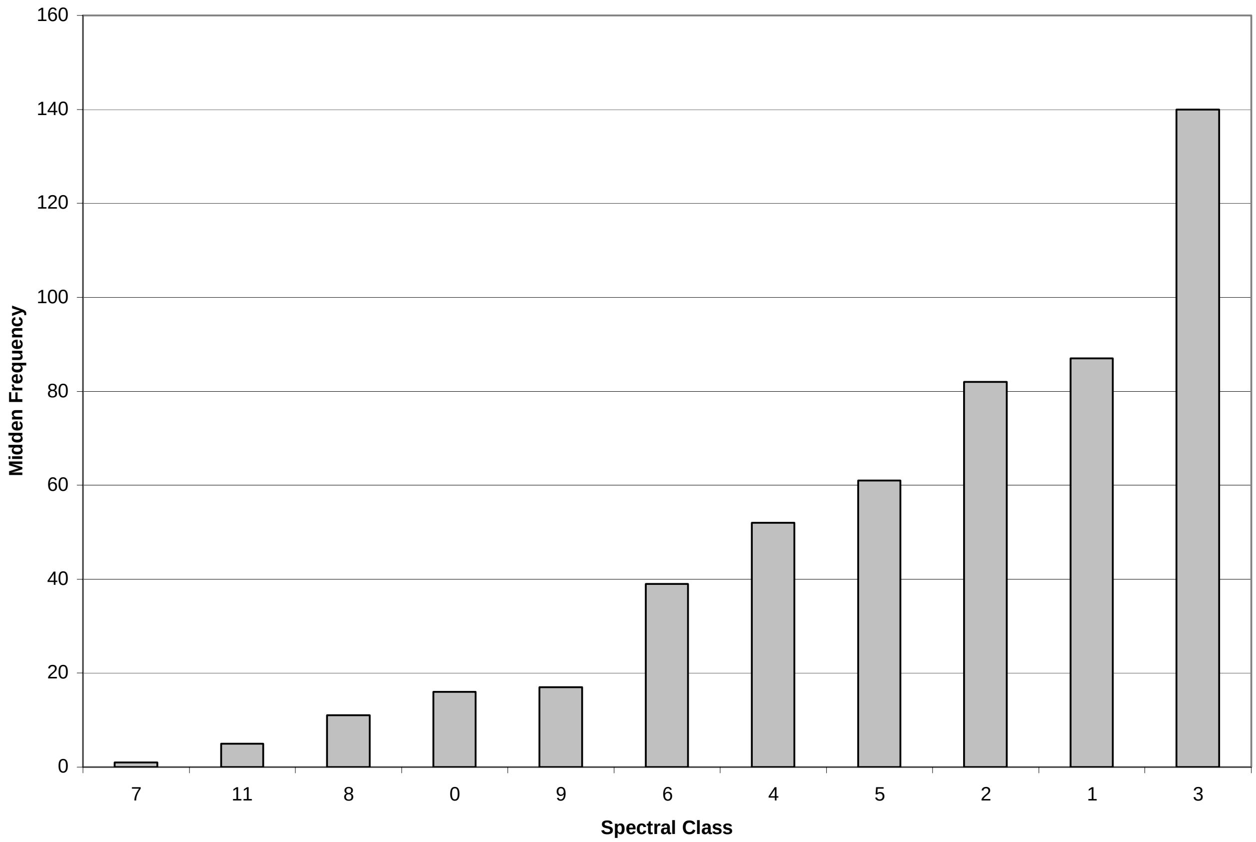

Figure 13. The frequency of middens within each spectral class; classes 1 – 6 were considered spectrally suitable, while the other classes were considered spectrally unsuitable.

Table 3. The amount of spectrally suitable and unsuitable habitat within each zone.

FREQUENCY[1]	ZONE[2]	SUITABLE[3]	AREA (M^2)	AREA (HA)	AREA (KM^2)	AREA (AC)	AREA (MI^2)
818	1	1	11778149	1177.8	11.78	2909.2	4.55
258	1	2	36434682	3643.5	36.43	8999.4	14.06
820	2	1	29242813	2924.3	29.24	7223.0	11.29
724	2	2	31095838	3109.6	31.10	7680.7	12.00
1141	3	1	785769994	78577.0	785.77	194085.2	303.31
2127	3	2	54636697	5463.7	54.64	13495.3	21.09
Totals			948958173	94895.8	948.96	234392.7	366.30

[1] The number of vegetation polygons (areas or contiguous patches).
[2] Zone 1 is within the survey boundary, Zone 2 is outside the survey boundary but above 7,750 feet (2,362 m), and Zone 3 is below the 7,750 foot contour (no middens found below this point by the cooperators).
[3] Spectrally Unsuitable = 1; Suitable = 2.

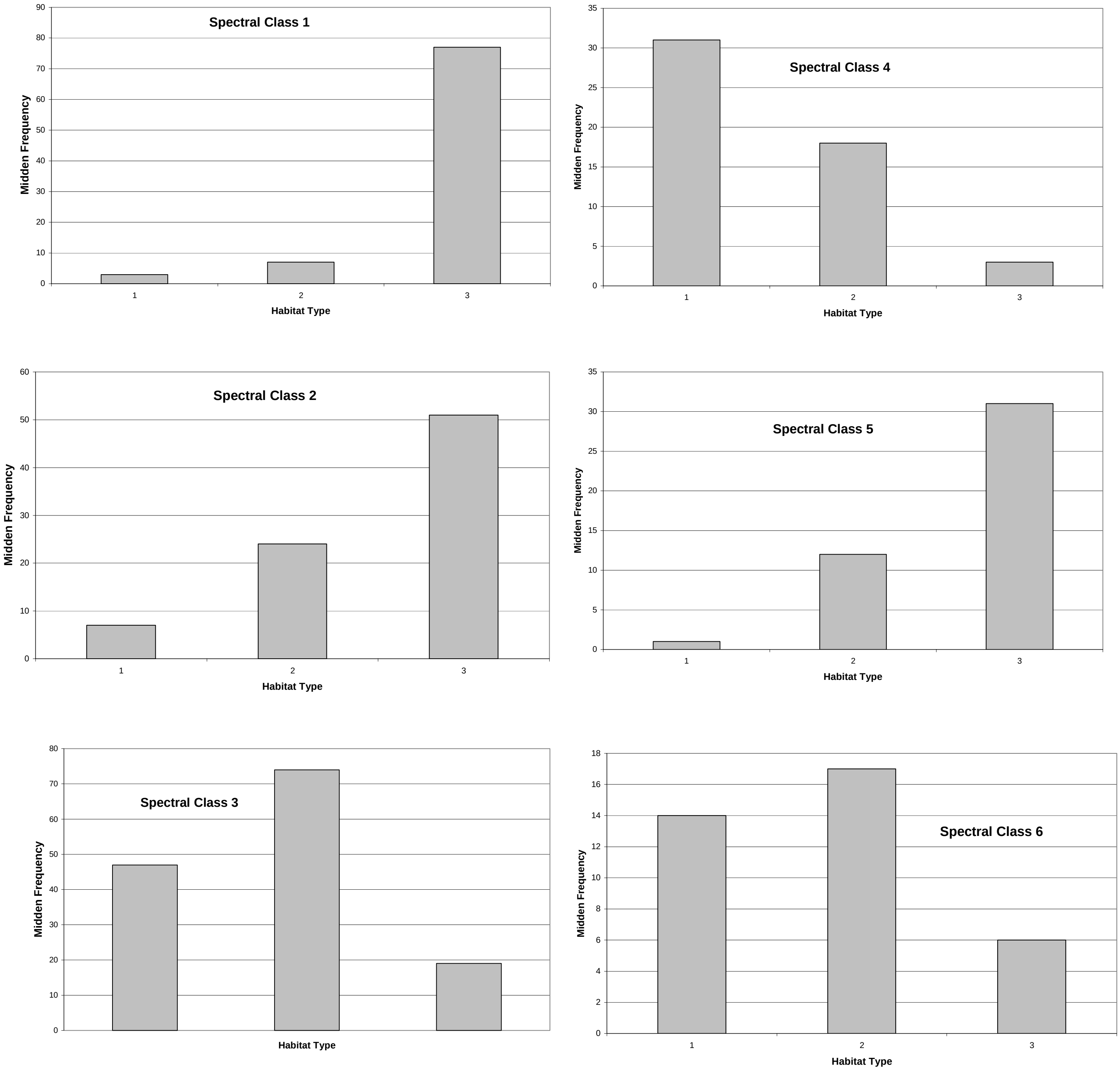

Figure 14. Relationships between habitat types and spectral classes, determined by using the randomly selected midden data as reference points (habitat type 1 = mixed-conifer, 2 = ecotone, and 3 = spruce-fir).

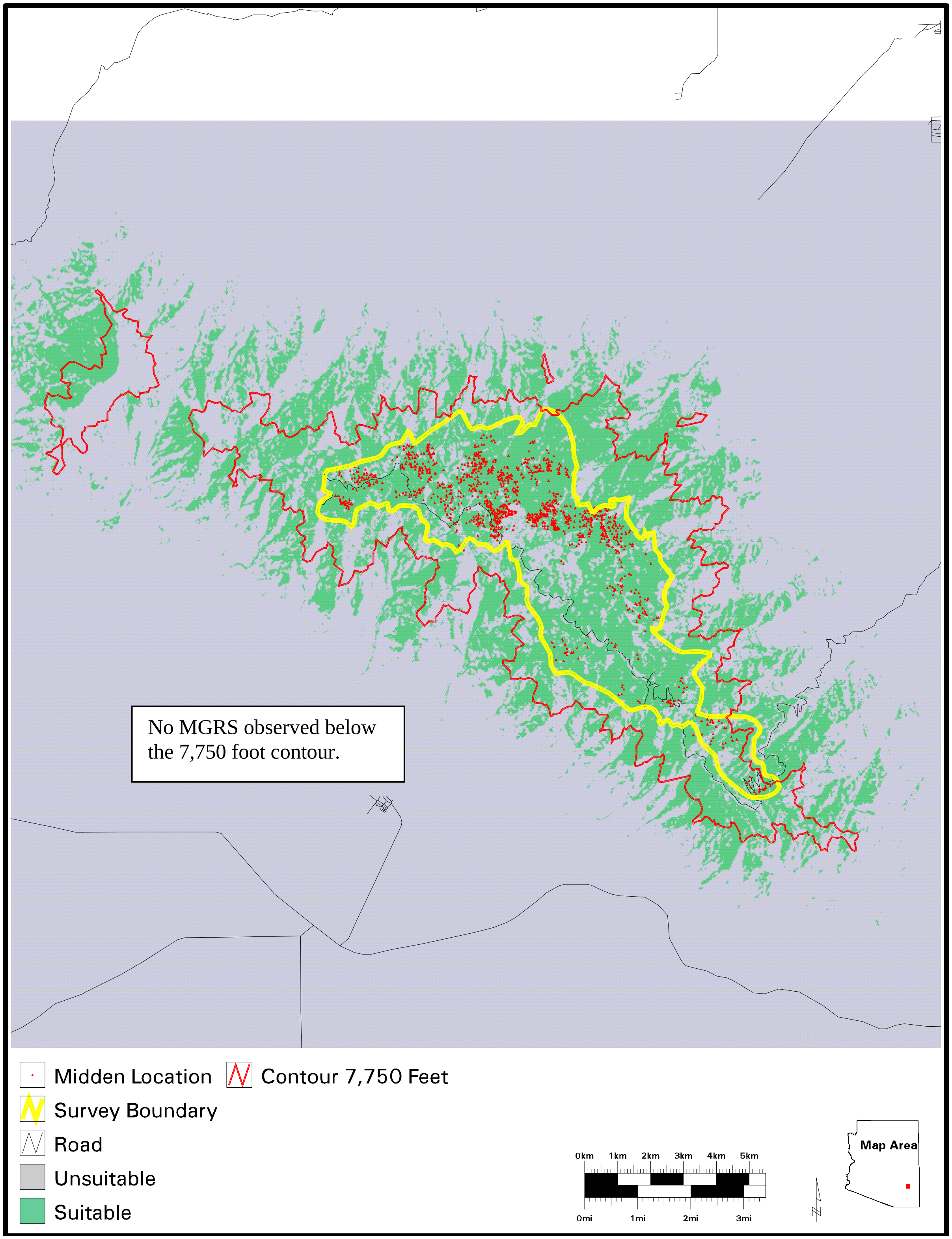

Figure 15. A habitat suitability (pattern recognition) model for the MGRS (suitable refers to spectral properties of the forest canopy and not to micro-habitat features).

Most errors within the suitable and unsuitable spectral classes appeared to be related to spatial (positional) rather than spectral (classification) error. All misclassified locations were less than 1 pixel from a feature in question. All of the 18 locations used to test the unsuitable classification were collected within meadows, burn areas, rock outcrops or pine/oak/aspen thickets (Table 2). Field notes were used to help interpret the sources of error. Given the 1 pixel (30 m) positional error of the image, some misclassified sites were probably correctly classified. A more in-depth discussion of classification error can be found in the discussion.

Table 4. An error matrix with the results of the accuracy assessment; twenty-three middens were removed because they burned up in the Clark Peak fire.

	REFERENCE	CLASSIFIED TOTAL	NUMBER CORRECT	PRODUCER'S ACCURACY	USER'S ACCURACY
Class 1	18	51	15	83.3	29.4
Class 2	484	451	448	92.6	99.3
Totals	502	502	463		

Kappa statistics: Class 1 = 0.27; Class 2 = 0.81%; Overall = 0.40

The overall Kappa statistic was 40 percent, meaning that the classification reduced errors over a completely random process by 40 percent. Correspondingly, Class 1 Kappa was 29.4 percent, and Class 2 Kappa was 99.3 percent. The Kappa statistics must be viewed with caution, because the large difference in sample size between Classes 1 and 2 caused the statistics to be unbalanced. For example, while only 7.4 percent of Class 2 middens were incorrectly classified, they jumped ship into Class 1 (since the errors are not independent) and lowered Class 1's user's accuracy to 29.4 percent. This large change in Producer and User's accuracy would not have occurred if the sample size for Class 1 was more proportional to Class 2. This situation can be improved in the future with more samples from Class 1. Of primary importance is the extremely high accuracy within Class 2, which is spectrally suitable habitat. Again, these high percentages will probably decrease as more Class 1 samples are collected, but preliminary results are promising.

ACCURACY ASSESSMENT OUTSIDE THE SURVEY BOUNDARY

All of the random points examined outside the survey boundary contained a key cone-bearing species for MGRS, although some trees were not mature or producing cones. While the potential existed for each site examined, seral stage and aspect prevented good habitat formation at most sites. Every random site contained Douglas-fir (*Pseudotsuga menziesii*), except site #63, which was located at an elevation of 10,120 feet (3,085 m), had a north aspect, and contained corkbark fir (*Abies lasiocarpa*) and Englemann spruce (*Picea englemannii*). The habitat potential of the sites indicated that the pattern recognition model worked, in as much as it identified potentially suitable habitat.

Four of the 17 sites contained good or moderate habitat, with MGRS seen or heard at sites #14 and #88. Two of the four sites faced east, and two north. The ground slopes of the moderate to good sites were between 20 and 45 degrees, and contained old-growth or mixed-aged forests.

Also, two of the sites were located at a relatively low elevation (8,250 feet [2,515 m]). At site #88, an adult red squirrel was observed clipping cones from a mature Englemann spruce and running off with the cones; we pursued the squirrel but could not find the squirrel's cone stash. Another squirrel was observed several hundred meters away (not at a randomly selected site) with a cone in its mouth, but no midden was found. Nevertheless, the activities of the squirrels suggested cone stashing and probably middens in the vicinity.

Eight sites were inspected with a south or west facing aspect and all had low quality MGRS habitat. Douglas or white fir occurred at every site, but the sites tended to be open, steep, hot, and contained few quality snags or large downed logs. Also, the south and westward slopes appeared to be less lush compared to the randomly selected sites on the north and east slopes at comparable elevations. All of the sites had components necessary to be classified as mixed-conifer, but some had isolated pine and oak scattered throughout. Thus, many of the south and westward facing sites were transitional (ecotone) vegetation communities, making a clear-cut classification difficult.

Discussion

Classification and Error

The results of the habitat suitability modeling were very good, with 92.6 percent of the randomly selected middens correctly classified. The misclassified middens (7.4%) were errors of omission, since they should have been classified as suitable, but were not. Classification errors within the suitable class were partly due to the classification errors within the unsuitable class, since errors in one class result in errors in the other class with which it was confused (Aronoff 1993). In contrast, classification errors within the unsuitable class were errors of commission, since the map said they were suitable when they were not. The high accuracy of the suitable class indicates it will form a good base map for midden sampling or identifying new areas to search.

Detailed notes were collected at 18 unsuitable locations and were used in interpretation of the accuracy assessment. When the classified image was overlaid on a rectified topographic map, positional error of 1 pixel became apparent. Positional accuracy is the expected deviance in the geographic location of an object in the data set (i.e. a map) from its true ground position (Aronoff 1993). One measure of positional accuracy commonly used in photogrammetry is the root mean square error (RMS), which is similar to the standard deviation of positional error. For Thematic Mapper data, RMS of 1 – 2 pixels is common (98.4 – 196.8 feet). Thus, overlaying the midden locations onto the classified image caused problems, since the midden data had only 7 – 16 feet (2 – 5 m) spatial error (post differential correction), resulting in misalignment of the reference data with the correct spectral class. Field observations revealed unsuitable areas correctly classified on the map, so misclassification occurred when the GPS data were overlaid onto the classified image.

Re-registering the TM image lowered the RMS from 2 to 1 pixels, but positional error could not be completely eliminated. However, classification error can be minimized through prudent use of the suitability maps, since classification errors were largely restricted to feature edges. Thus, MGRS surveyors need to be cautious when working around the edges of suitable or unsuitable habitat. Features smaller than 1 pixel (98.4 feet or 30 m) won't be clearly distinguishable on the suitability map either. Perhaps the best way to reduce classification error is to acquire higher resolution imagery, since the smaller cell size would reduce spectral confusion and reduce positional error.

MODIFYING THE SURVEY BOUNDARY

The current survey boundary appears to skirt the mountain too high on the north and east flanks (Fig. 4). Given the number of middens observed down to 7,750 feet, it stands to reason that if the survey boundary were lowered, there would be more middens discovered on similar aspects. The spectrally suitable areas (Fig. 15) could be used to zero in on areas to be surveyed outside the survey boundary; areas like West Peak, Ladybug Peak, or Mt. Graham. Two historic sightings of red squirrels, one in the vicinity of West Peak in the early 1960s, and another at 6,750 feet in the Ash Creek drainage in 1914 (Spicer and others 1985), help validate the potential outside the current survey boundary.

There was little evidence to support substantially altering the boundary on the west and south slopes of the mountain. Results are still preliminary, with relatively few sites investigated outside the survey boundary; however, we generally found poor quality habitat at sites with west or south aspects. All sites did contain Douglas or white fir, both of which can produce cone crops for squirrels; but the sites tended to be fairly open, had poor cone production, and had a lot of potential for heating during summer months. In contrast, random sites with north and east aspects had denser forests than south/west sites at comparable elevations; much of the forest was old-growth and mixed-conifer, with slopes alternating between 20 and 45 degrees. At site #88, a squirrel was observed clipping and hoarding green cones from Englemann spruce and Douglas-fir at an elevation of 9,500 feet (2,911 m; Fig. 16). Furthermore, near site #14, which also had a northward aspect, a red squirrel was heard in an old-growth forest at an elevation of 8,250 feet (2,515 m). We have yet to find any middens outside the survey boundary, but no sweeps have been conducted yet. There might also be middens located below the surface, since much of the north slope appeared to be talus covered with vegetation; cracks were evident in many places, offering ample opportunity for the squirrels to stash their cones. More analyses and investigation needs to occur before we can rule out any of the spectrally suitable areas, or to modify the current survey boundary.

CONCLUSIONS

- A habitat suitability model developed from the spectral characteristics of the forest canopy worked very well in identifying potentially suitable MGRS habitat.

- The survey boundary appears inadequately placed on the north and east sides of the mountain, since middens have been found as low as 7,750 feet (2,362 m), but the survey

Figure 16. An image of a red squirrel found at random point 88, located at about 9,500 feet on the north side of Mt. Graham (the squirrel is at the end of the diagonal log at about mid-picture).

boundary largely skirts the 9,000 foot (2,743 m) contour.

- Searchers of northward facing slopes outside the survey boundary saw and heard red squirrels at two sites, but did not see middens. However, MGRS middens might be found if the spectrally suitable areas are thoroughly searched.

- There is currently little evidence to support moving the survey boundary on the south and west sides of the mountain. However, this could change if middens are found lower down the south and west flanks.

- The habitat suitability model should prove useful in the development of a plot-based sampling methodology, or in searching for undiscovered middens.

- The Clark Peak fire burned an estimated 3.2 percent of the spectrally suitable MGRS habitat within the survey boundary and 2.3 percent outside the survey boundary.

- Misclassification occurred primarily along feature boundaries where two objects overlapped within the same cell, resulting in spectral confusion. Also, features that were too small, or less than 30 m, could not be accurately classified.

- Misclassification occurred when a highly accurate GPS receiver was used in conjunction with a coarse-resolution (30 m) satellite image, resulting in field data being incorrectly associated with map features.

RECOMMENDATIONS

- Conduct field surveys to systematically confirm or deny the quality of the sites.

- Investigate potentially suitable habitat outside the survey boundary, particularly where the aspect is north or eastward, and slopes less than 30 percent.

- Collect more samples in spectrally unsuitable habitat in order to improve the accuracy assessment in this category.

- Acquire higher resolution imagery for the Pinaleno Mountains, to reduce positional error and improve classification accuracy.

- Conduct an analysis of the midden database to establish habitat criteria for MGRS. This information could then be used to help assess the potential of spectrally suitable habitat.

- Continue to use remotely sensed imagery to monitor the spectrally suitable habitat of the MGRS.

- Conduct a change detection every few years in order to identify changes in MGRS habitat.

- Assess the influence of individual and combined variables on midden distribution with a plot-based sampling design. Plots would allow us to standardize the data by area searched, and to collect absence data. Presence/absence data would in turn allow for more sophisticated analyses and modeling, such as logistic regression. A pilot study should be conducted in order to determine if plot-based sampling is feasible.

ADDENDUM

This report presented findings based upon satellite imagery from 1993 – 1997. The choice of the imagery was due to affordability and availability. Since the completion of this report, free satellite imagery became available for October 1999, from the Arizona Regional Image Archive (ARIA), located at the UA. An inspection of the imagery revealed a marked decline in habitat quality in the spruce-fir portion of the mountain, largely on the northward slopes of Mount Graham. The suspected agents in this decline are insects, which are defoliating and burrowing into the trees. Unfortunately, an investigation and analysis fell outside the timeline for this report, but a follow up analysis will be performed, with the results presented in the not too distant future.

LITERATURE CITED

Aronoff, S. 1993. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Canada.

Avery, T.E. and G.L. Berlin. 1992. Fundamentals of Remote Sensing and Airphoto Interpretation. Fifth Edition. Macmillan Publishing Company, New York.

Dunster, J. and K. Dunster. 1996. Dictionary of natural resource management. UBC Press, Vancouver, Canada.

Environmental Systems Research Institute, 1992. Cell-based modeling with GRID. Environmental Systems Research Institute, Redlands, CA.

________ 1994. Understanding GIS: The ARC/INFO Method, Version 7 for UNIX and OpenVMS. Redlands, California: ESRI.

Froehlich, G.F. and N.S. Smith. 1990. Habitat use by the Mt. Graham red squirrel. In: Krausman, P. R. and N. S. Smith (ed.), 1990. Managing wildlife in the Southwest (pp. 118 - 125). Arizona chapter, The Wildlife Society, Phoenix.

Hurn, J. 1989. GPS: A Guide to the Next Utility. Trimble Navigation Ltd., Sunnyvale, CA.

Jensen, J.R. 1983. Biophysical Remote Sensing. Annals of the Association of American Geographers 73(1):111-132.

Lillesand, T.M. and R.W. Kiefer. 1994. Remote sensing and image interpretation. John Wiley & Sons, Inc. New York.

Minckley, W.L. 1968. Possible extirpation of the spruce squirrel from the Pinaleno (Graham) Mountains, south-central Arizona. Journal of the Arizona Academy of Science 5:110.

Pereira, Jose M.C. and R.M. Itami. 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel. Photogrammetric Engineering & Remote Sensing 57 (11):1475–1486.

Schrader, S. and R. Pouncey. 1997. ERDAS Field Guide. Fourth edition. ERDAS, Inc, Atlanta, Georgia.

Spicer, B.R., J.C. deVos, Jr. and R.L. Glinski. 1985. Status of the Mount Graham red squirrel, *Tamiasciurus hudsonicus grahamensis* (Allen), of Southeastern Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Story, M. and R.G. Congalton. 1986. Accuracy assessment: a user's perspective. Photogrammetric Engineering and Remote Sensing 52(3):397-399.

United States Forest Service. 1988. Mount Graham Red Squirrel – An Expanded Biological Assessment. Coronado National Forest, Tucson, Arizona.