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Montane Meadow and Open Area Encroachment in the Lincoln Forest, Sacramento Grazing Allotment

NM STATE UNIVERSITY

Range Improvement Task Force
Cooperative Extension Service / Agricultural Experiment Station
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INTRODUCTION

The Region 3 U.S. Forest Service (USFS) Sacramento District Lincoln National Forest, located in south central New Mexico, was designated as a forest reserve in 1902. Woolsey (1911) and Plummer et al. (1904) described the area as containing significant openings with extensive grass-dominated understories with approximately 20–70 trees per acre. Garrett (2001) reports that current conditions of the Lincoln National Forest are primarily dense forest and woodland stands with densities at or above 200 trees per acre and fuel loads in excess of 20 tons per acre. Many of the major forest openings, more commonly known as meadows, have been significantly reduced or altogether eliminated due to tree and woody species encroachment. Of the total forest area, meadows occupy a fraction of the landscape, but "their beauty and stark contrast with the surrounding forest make them favorite destinations. One only needs to step from a tunnel of dense conifers to a bright oasis of grasses and wildflowers to know that mountain meadows are precious patches of diversity, havens of distinction" (Thompson, 2007).

In its most casual use, *meadow* refers to all vegetated but treeless portions of an otherwise forested landscape. However, meadows take many forms and occur on diverse landscapes.

> Often, they occur where soils are too thin and dry to support trees—along ridgetops—or, where soils are permanently saturated—in poorly drained depressions, such as those found on landslide deposits and glacial landforms. These types of meadows are at low risk to conifer encroachment. Meadows also occur in less extreme environments—on mesic or moist slopes, where soils are productive and well drained—conditions that typically support an abundance of trees (Thompson, 2007).

These are the major forest openings that are giving way to tree encroachment. Garrett's

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report indicates that this phenomenon has occurred as a result of single-species management imposed on Region 3 by adjudication on the Mexican spotted owl court case and other environmental lawsuits. This has impeded multiple-use management, particularly in the timber sector. No matter the cause, the loss of mountain meadows needs to be addressed. Many species rely on them. They are home to various communities of plants that cannot survive under the forest canopy. Deer, elk, and cattle depend on them for forage. Insects, butterflies, and moths rely on meadow flowers for pollen and nectar. Predatory birds use meadows for hunting grounds.

This report evaluates aerial and satellite imagery records of the Lincoln National Forest by decade over a 60-year period from the 1940s through early 2000s. Through digital analysis of the images and field verification utilizing satellite ground positioning system (GPS) equipment, tree habitat and forest open areas were identified. Results were then compared decade-to-decade to determine if woody species encroachment has occurred and to what extent encroachment has affected the habitat.

OBJECTIVE

The objective of this study was to create and evaluate a georeferenced pictorial baseline for the Lincoln National Forest of current (2005) ground-level images and of archived aerial images from the 1940s to 2002. The set will be used to determine if tree encroachment has occurred over time in the montane meadows and open forest areas of the prey base habitat for the endangered Mexican spotted owl (MSO).

BACKGROUND

Modern computer technology has expanded diagnostic capabilities in spectral analysis of landform surface images, both in real-time and of archived satellite images and aerial photography. Several software programs—including ArcView, ArcMap, ENVI, Terramodel, and ERDAS Imagine—have been developed and refined to examine and compare habitat changes through time to detect trends. These programs could be useful tools for land managers and policy makers, enabling better administrative decisions.

This technology has also led to more efficient utilization of labor in the field by allowing technicians in the laboratory to examine large areas in a matter of hours instead of spending months in the field. Project areas can now be more easily identified in the laboratory, resulting in more efficient deployment of ground teams for research, thus making more efficient use of a limited resource base.

These software programs also evaluate large photographed areas faster and more effectively than did the older dot grid matrix averaging methods, reducing the human subjective error common to the dot grid matrix method. The image is spectrally and mathematically evaluated at the pixel level with discernment beyond the capacity of the human eye. Stronger and faster computer chips have revolutionized this aspect such that large agricultural and habitat land images that previously would have tied up resources for months or years can now be evaluated and results returned in a matter of weeks.

New Mexico State University's Range Improvement Task Force (RITF) embarked on a project to use this technology to examine changes in rangeland characteristics over time and under various management practices. The first project selected was measuring tree encroachment over time in open areas after timber harvest and in montane meadow habitat areas of the prey base of the endangered Mexican spotted owl. Initially, the only images available for vegetation evaluation were satellite infrared images from 1972 to 2002 with pixel equivalence ranging from 15 meters to 10 meters to the pixel across that era.

A search for other archived aerial images of the area was initiated when a retired forest ranger made the RITF aware of their existence. Their location was unknown, as many years had passed since the collection was last seen. In the fall of 2003, independent of this three-year investigation, the photographs were discovered by Forest Service personnel cleaning out a storage area, one week before contact was made by the RITF in quest of these images. The collection comprises hundreds of high-definition aerial black-and-white images in 10-year intervals dating from the late 1960s back to the early 1940s. An agreement was made between the RITF and the Region 3 USFS, Lincoln National Forest, to have the collection scanned and digitized at high resolution for evaluation.

The different scales of the satellite images and the aerial photographs were standardized through computer software. The importance of this collection is the expanded ability it grants researchers to examine the changes in montane meadows and open areas over a 60-year period. Minor changes may escape detection in localized areas for a period of time or due to scale of the image pixels. However, over extended periods of time, habitat trends become apparent if there are cumulative effects from these minor-scale changes. What follows is a description of this process as applied to 11 study plots of approximately 1,000 acres (405 hectares) each. These sites are known as Areas of Interest (AOIs) in the Lincoln National Forest.

REQUIREMENTS

As with any computer software, image analysis programs require properly trained personnel to get them to yield accurate results. This is further complicated by the lack of a single software capable of the analytical tasks required by project researchers. As a result, during the course of this project the technicians have learned and utilized Terramodel, ArcView, ArcMap and ERDAS Imagine. ERDAS Imagine 8.6 is being described as a working example.

Landform images are large and occupy substantial amounts of memory on the computer during evaluation. Large capacity hardrives, memory cards and high RAM are strongly recommended, as the image and evaluation process can easily overwhelm the capacity of a computer and crash the program. This can result in loss of data or, at times, loss of the entire image being evaluated. Always maintain a backup of the original on a CD or another hard drive to avoid data loss. The computer chosen for this project was a Dell workstation equipped with two 80-gigabyte (Gb) hardrives, 2 Gb of RAM and 2 Gb of memory. A stand-alone large-capacity tape backup (in this case a Sony AIT Drive 100 Gb) was used and is recommended for additional security of the original files.

A high-definition flatbed scanner was acquired to convert the aerial black-and-white photographs to digital images. A Hewlett Packard Scanjet 4600 series flatbed scanner was used for this project. For maximum definition and evaluation, the aerial photographs were scanned at 1,200 dots per inch (DPI), which resulted in an average size of 110,000 kilobytes per image. The images were saved in the JPEG format. Each scan and nomenclature input took approximately 20 minutes.

The scanned images require rectification and registration for useful analysis to occur. A template set of 1-meter–scale rectified and registered digital orthoquad maps of the project area was acquired. These were acquired from the Region 3 USFS, Lincoln National Forest, in the BIL format. These maps were used to align and orient the scanned images to the proper scale and facilitate the examination of changes in the landscape over time.

IMAGE METHODOLOGY

The scanned photographs and the orthoquad images are in two formats: JPEG and BIL (BIL is not directly usable in ERDAS Imagine). ERDAS Imagine does have the capacity to convert BIL, JPEG, and many other formats to the IMAGE format. Converting the imagery to the IMAGE format is the first step in equalizing the formats for evaluation.

Once the imagery has been converted in ERDAS Imagine, two viewing screens are opened showing the rectified template image (Figure 1) and the unrectified scanned aerial image (Figure 2). To equalize formats, in the first view screen, navigate to the folder with the rectified map image being used as the template and open it. In the second screen, navigate to the folder with the scanned aerial image being rectified and open it. Landscape features are visually matched to the rectified orthoquad map.

On the toolbar in the unrectified aerial image, click on the “raster” button and then click on the “geometric correction” button. A series of windows will open, requiring input on the constraints within which the rectification is to be done. Once the parameters have been set, the windows are arranged so that all fields can be viewed simultaneously (Figure 3).

Starting in one corner of the aerial image, identical land features are located and have georeferenced points located in both images. The close-up view windows allow for relatively accurate placement of the points. This is done in a serpentine fashion evenly distributed across the images until a minimum of 18 to 20 points have been located on both images. Once the image has been sufficiently covered with reference points, the “rectification” button is activated and the software converts and orients the aerial image to the template orthoquad image. This image is opened in a different viewer for verification of the accuracy of the operation (Figure 4). Should the rectified image not match the template image as desired—or should it be distorted, rendering it useless for evaluation—the image is eliminated and the process begins anew until the image is properly rectified.

AREA OF INTEREST (AOI) DETERMINATION

Decisions of which areas to investigate were held to two basic criteria: 1) AOI must have montane meadows and other forest open areas; 2) AOI must have cloud-free images throughout the data series from 1940–2004.

To determine the meadow areas, the Lincoln National Forest, Cloudcroft District, provided a 2005 map of the Sacramento Allotment Summer Pasture Meadow Sites (Figure 5). From these meadows, all image sets from 1940 through 2004 were examined for cloud-free areas and 11 AOIs, each of approximately 1,000 acres (approximately 2 sq mi), were developed. Subsequent calculations will be based on this figure.

Each AOI map polygon was then developed for evaluation. This allows for subsetting of the image by clipping out the cloud-free image with the AOI polygon, which then allows for uniform evaluation of the specific area across all images contained within the AOI (Figures 6 and 7).

Once the image had been rectified and subset, the function of pixel spectral identification and classification could proceed. ERDAS Imagine has a spectral analysis function that allows the software to separate the various spectral frequencies by pixel (in the gray tone or color value bands), depending on the parameters as defined by the technician. The classification can be either unsupervised, allowing the software to determine the classification assignments, or supervised, allowing the technician to determine the classification assignments. Both methods allow for the technician to assign the number of iterations, or times the image is mathematically evaluated pixel by pixel, for best category assignment of the pixel to a classification. It was determined that eight classifications derived from six iterations best fit the requirements.

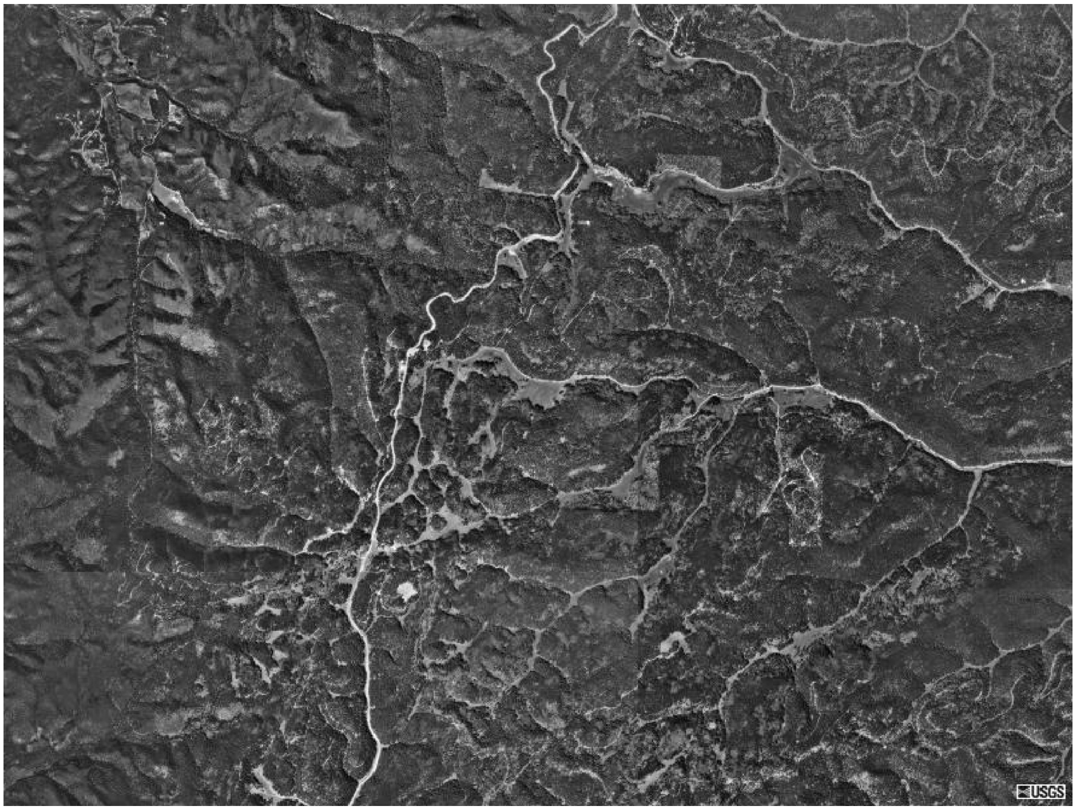


Figure 1. **Rectified Orthoquad Map Template**

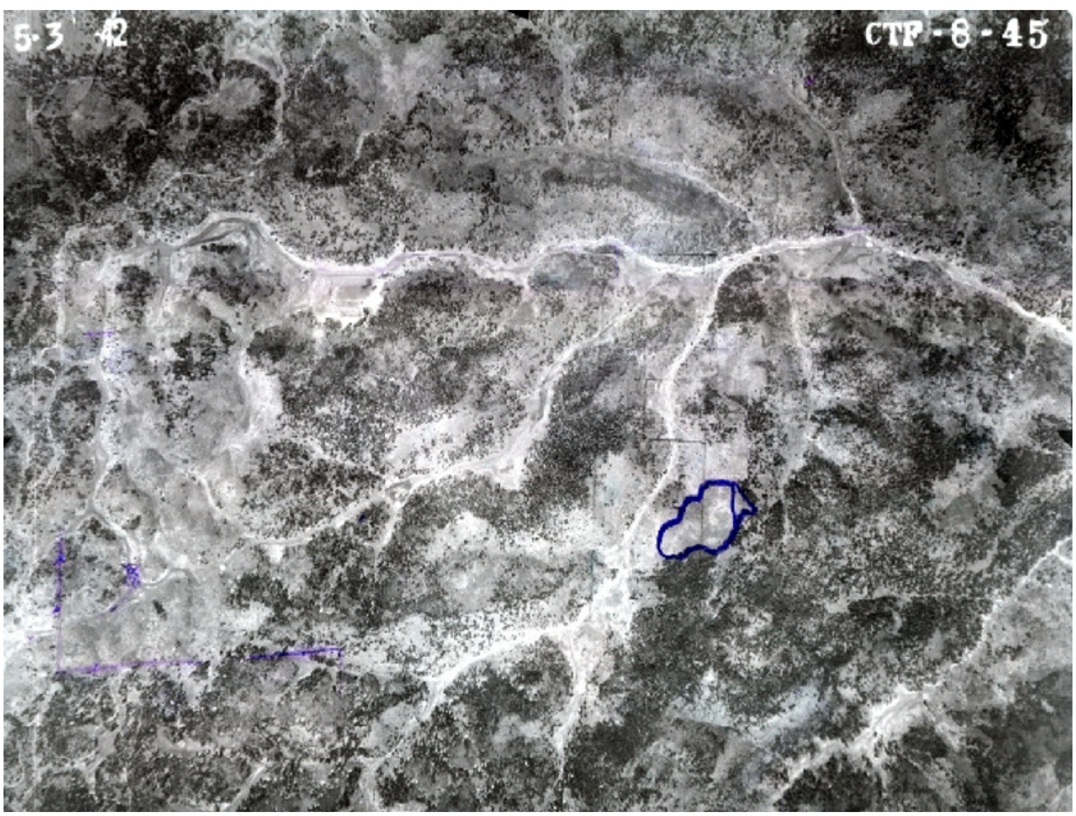


Figure 2. **Unrectified Scanned Aerial Image**

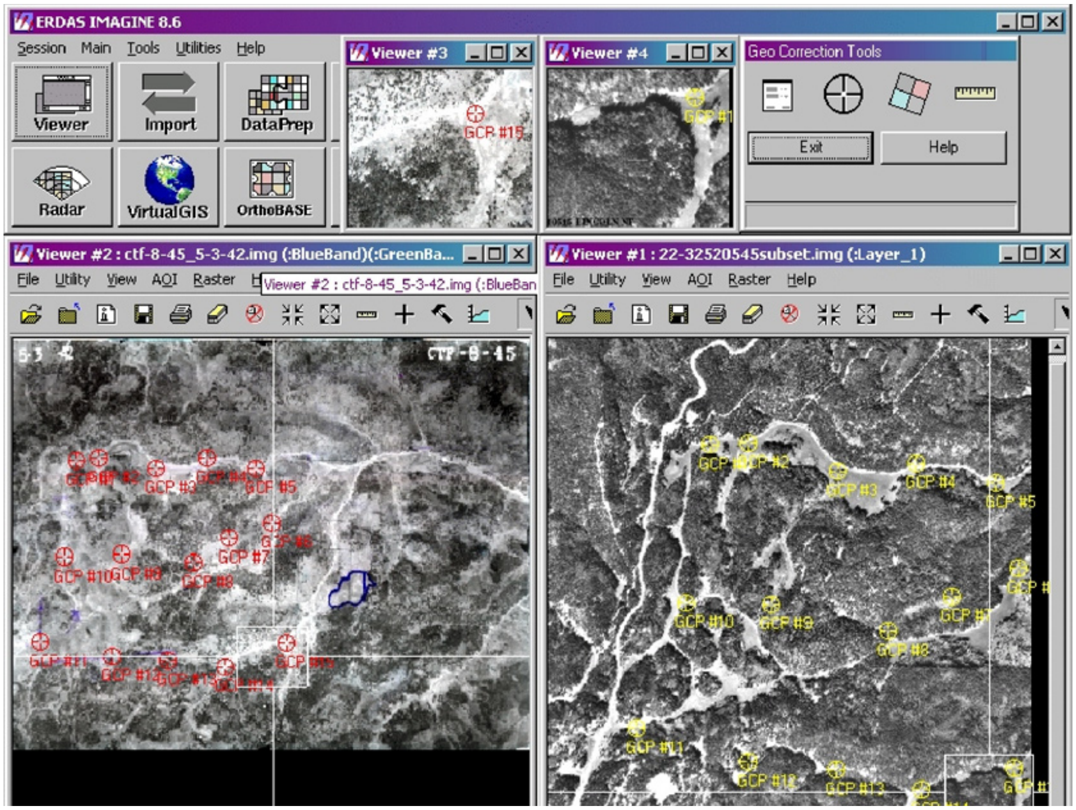


Figure 3. **Geometric Correction of Unrectified Image**

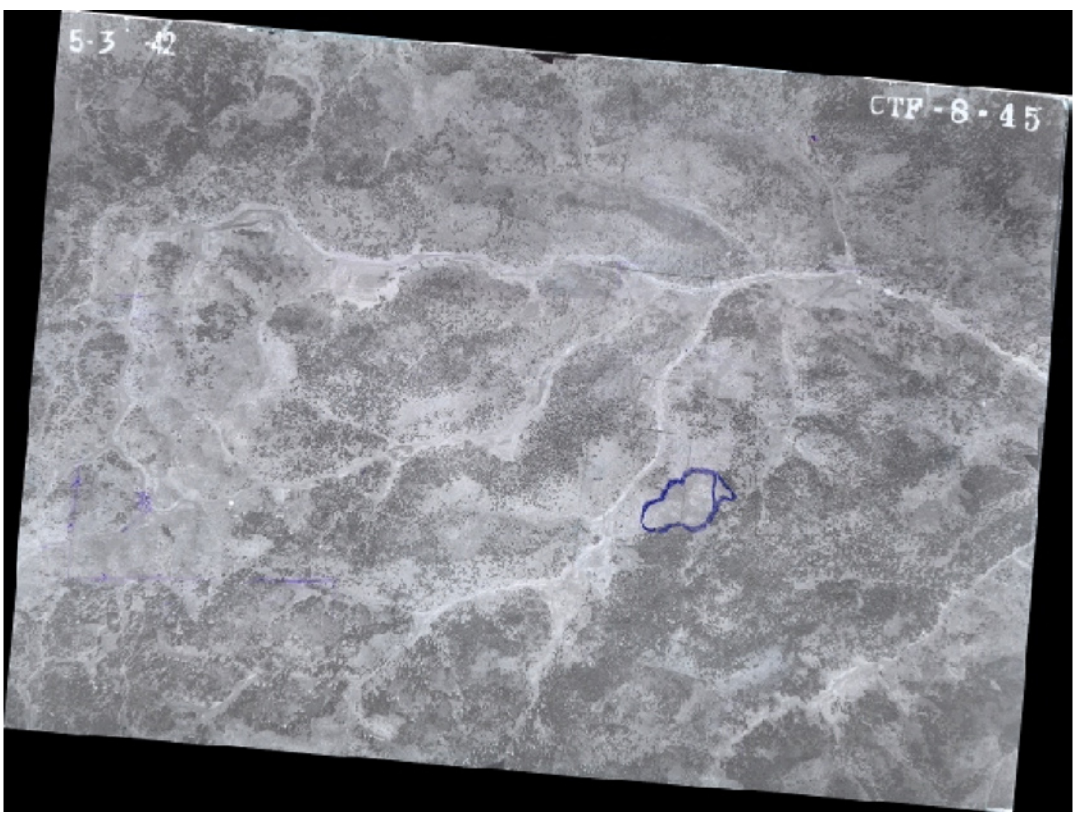


Figure 4. **Geometrically Corrected Rectified Image**

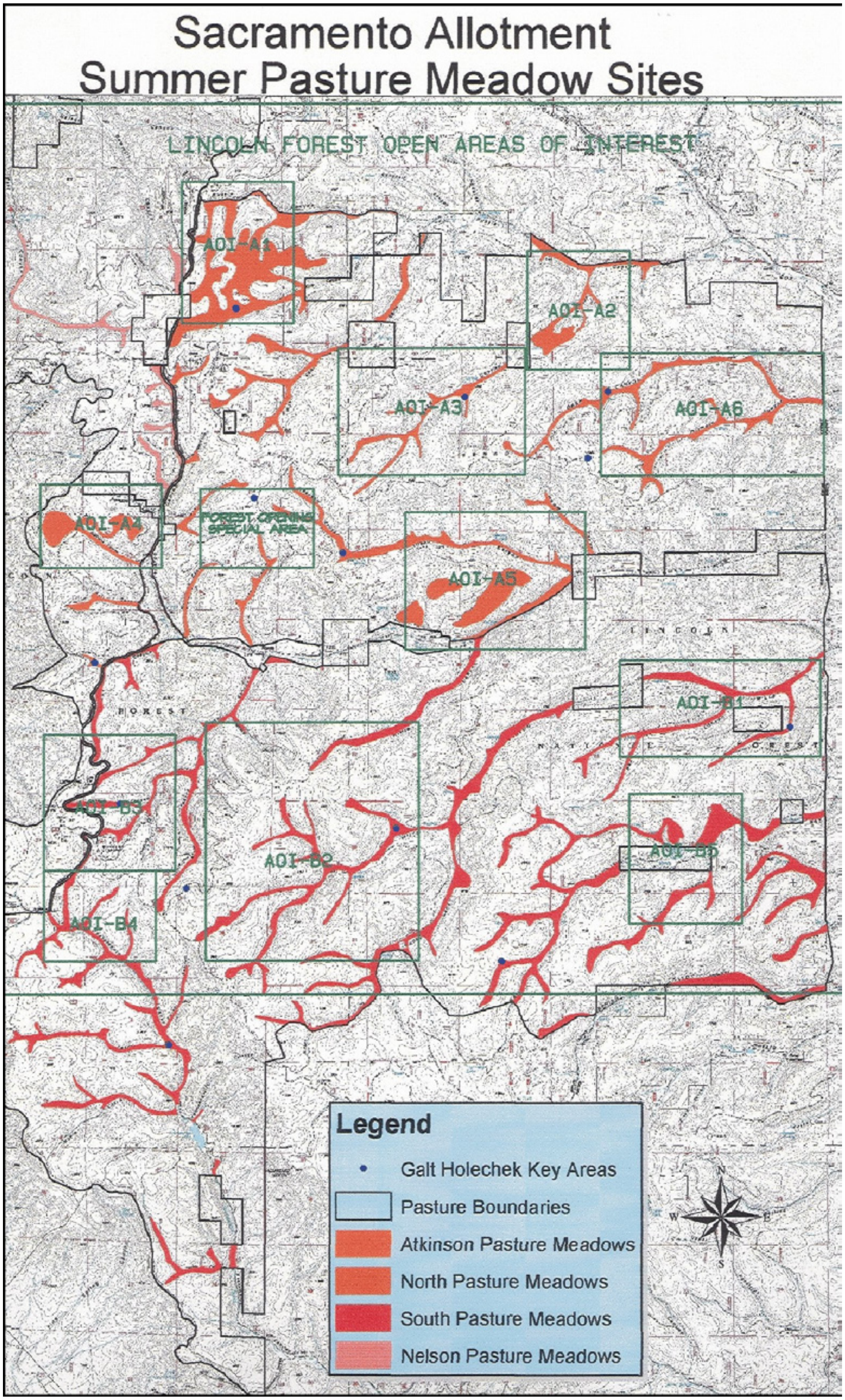


Figure 5. **2005 USFS Region 3 Cloudcroft District Meadows Map Showing Areas of Interest (AOIs)**

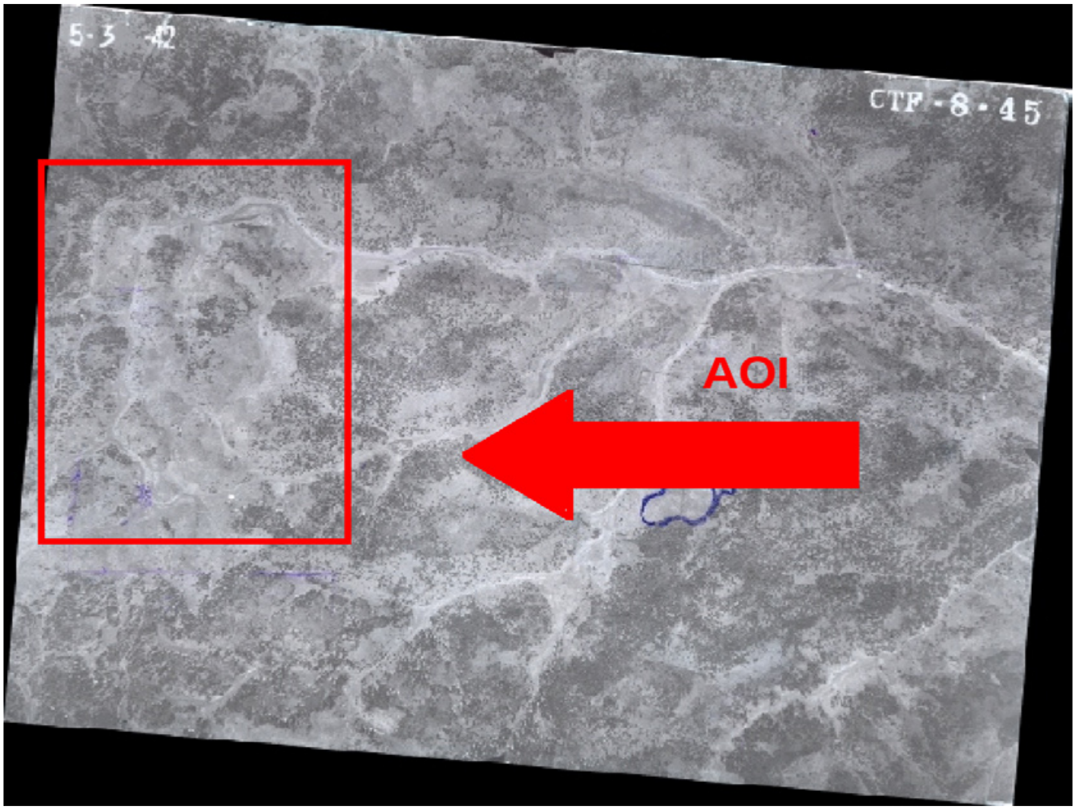
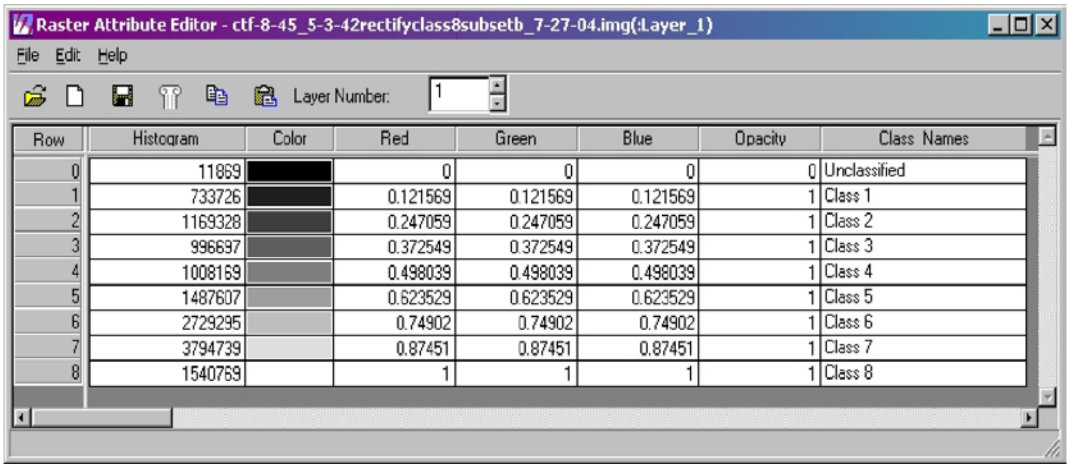


Figure 6. **Area of Interest to Subset (AOI-A1)**

Figure 7. **AOI-A1 Subset**


Raster Attribute Editor - ctf-8-45_5-3-42rectifyclass8subsetb_7-27-04.img(:Layer_1)

File Edit Help

Layer Number: 1

Row	Histogram	Color	Red	Green	Blue	Opacity	Class Names
0	11869		0	0	0	0	Unclassified
1	733726		0.121569	0.121569	0.121569	1	Class 1
2	1169328		0.247059	0.247059	0.247059	1	Class 2
3	996697		0.372549	0.372549	0.372549	1	Class 3
4	1008169		0.498039	0.498039	0.498039	1	Class 4
5	1487607		0.623529	0.623529	0.623529	1	Class 5
6	2729295		0.74902	0.74902	0.74902	1	Class 6
7	3794739		0.87451	0.87451	0.87451	1	Class 7
8	1540769		1	1	1	1	Class 8

***Figure 8*. Attribute Editor and Pixel Gray Tone Assignment**

Once this was accomplished, the classified image and the attribute editor were opened in a viewer and compared side by side with the original AOI image (Figure 8). The color band was changed individually from the gray tone to a color tone, after determining which gray band tone was assigned by the computer to the various land attributes in the image (Figure 9). Brown was assigned to the areas covered by trees, green to the areas covered by meadows, yellow to bare ground attributes such as roads and bare rock, and black to indicate no data values. This changes the colors in the image, which is then saved as a rectified recolored AOI (Figure 10). While this does not change the classification mathematical elements, it does provide a visual record for ease of viewing by interested parties.

This process was repeated for each image across all data sets by year. This AOI clipping and classification procedure was repeated on the infrared satellite images (Figure 11). One readily apparent difference was in the pixel quality between the AOI images (Figures 10 and 12). This was due to the difference in the scale of the original data image sets. Once all data image sets have been evaluated, a visual side-by-side preliminary result comparison is possible (Figures 12 and 13). The actual pixel evaluation is done mathematically to show vegetation areas as a percentage of coverage per image; the area percentages are then compared between the points in time data sets. The final AOI classification set of the preliminary results is seen in Figure 14.

EVALUATION METHODOLOGY

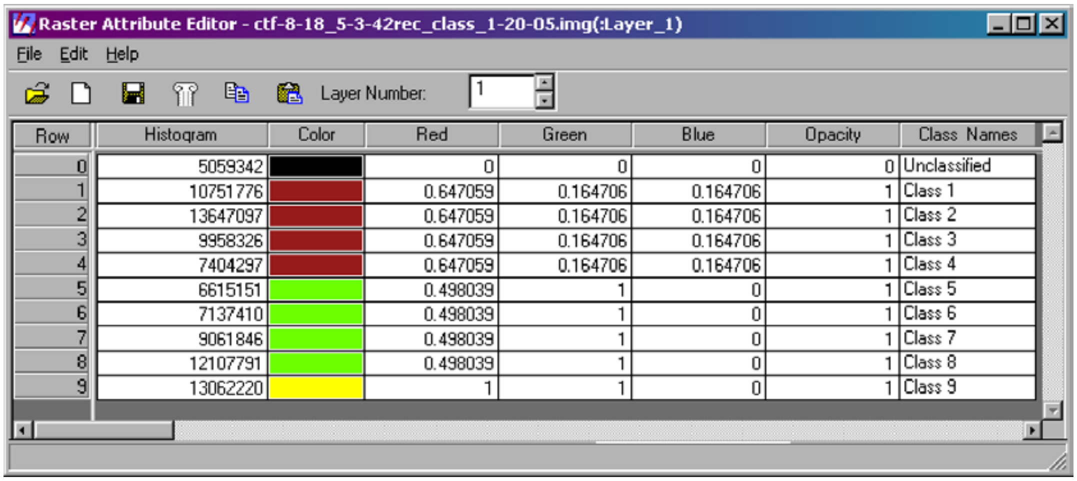
While a visual set of images can give a sense of change, it cannot render an empirical evaluation. As can be seen in Figure 8, there is a left-hand column called “Histogram” with numerical values. This is the pixel count of the number of pixels that correspond to the various classified spectral designations in the image evaluated. These are extracted and placed in a common spreadsheet format for evaluation. For this project, Microsoft Excel was used.

As a comparison, the manual dot grid method was used on the same scanned A0I images. The results are tabulated in Table 4.

Each AOI is evaluated individually for the pixel percent area covered by trees, meadows, bare ground, and no data. Note the difference in image quality from one year’s data set format to the other in Figures 13 and 14. The time frame of the scanned black-and-white images is the 1940s thru the 1960s, the orthoquad is the 1990s, and the infrared is the 2000s.

This evaluation produced the percentage of area coverage displayed in Table 1.

Results when the 11 AOIs are averaged by classification are shown in Table 2.


Raster Attribute Editor - ctf-8-18_5-3-42rec_class_1-20-05.img(:Layer_1)

File Edit Help

Layer Number: 1

Row	Histogram	Color	Red	Green	Blue	Opacity	Class Names
0	5059342		0	0	0	0	Unclassified
1	10751776		0.647059	0.164706	0.164706	1	Class 1
2	13647097		0.647059	0.164706	0.164706	1	Class 2
3	9958326		0.647059	0.164706	0.164706	1	Class 3
4	7404297		0.647059	0.164706	0.164706	1	Class 4
5	6615151		0.498039	1	0	1	Class 5
6	7137410		0.498039	1	0	1	Class 6
7	9061846		0.498039	1	0	1	Class 7
8	12107791		0.498039	1	0	1	Class 8
9	13062220		1	1	0	1	Class 9

Figure 9. **Attribute Editor and Pixel Color Tone Assignment**

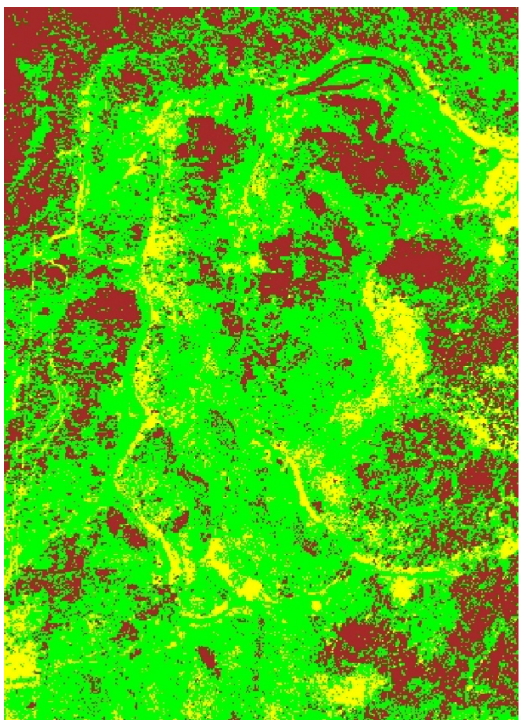


Figure 10. **Rectified and Recolored Classified AOI-A1**

Classification averages initially confirm the visual evaluation of tree encroachment into montane meadows and open areas. Table 3 shows the percent change between each year series. The numerical values demonstrate the tree/meadow occupancy levels from one decade to the next and the overall trend across the 60-year period for these AOIs (Figure 15). One note of interest is the relative decline in the amount of bare ground during the same period.

While the actual percentages of the dot grid method approximate the information derived from the software, the numbers obviously disagree as to how much area is covered by which vegetation classification. The most immediate problems are:

1) The subjective judgment of the technician as to which dot entry falls on which classification type on marginal interface areas.
2) The inability to visually distinguish between rock outcropping, dirt roads and other bare ground land features that visually mimic meadows in the black-and-white photographs.

To determine the trends over time, the base data were evaluated by four basic time groups: 1940 through 2000, 1940 through 1990, 1950 through 1990, and 1990 through 2000. These groupings were based on the major change points of the generated graph (Figure 15). The trend line slope formulas are tabulated in Table 5 and illustrated in Figures 16–19.

DISCUSSION

When the data are examined in this fashion, all time sets show a steady increase in the area covered by trees, while all but one of the meadow time sets show a steady decline in area covered by meadows. All show a decline in area covered by bare ground. When the time period of 1950 through 1990 is examined, the tree and meadow area coverage remains relatively stable. The most dramatic change in trends was from 1990 through 2000, during which trees increased in area coverage by 12.1% while meadow area coverage decreased proportionately, by 11.7%. The rate of change in tree coverage was 14 times greater in the decade from 1990 to 2000 than from 1950 to 1990.

This drastic increase in tree area coverage occurred during a short 10-year period compared to the previous relatively stable 40-year time period. This 40-year stable period occurred during a time when the Lincoln Forest

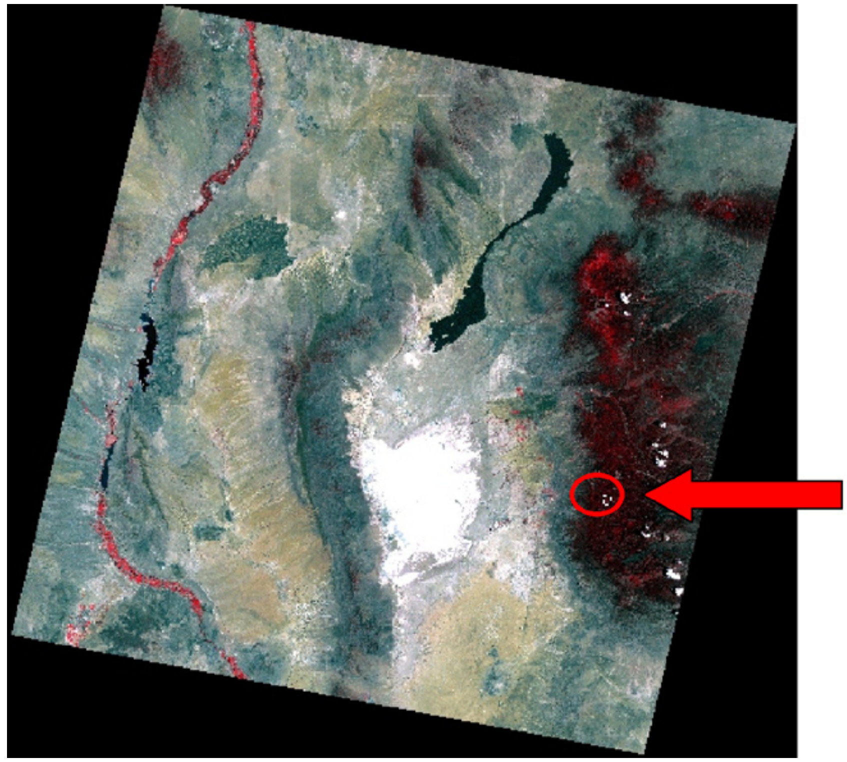


Figure 11. **Satellite Infra-red Image**

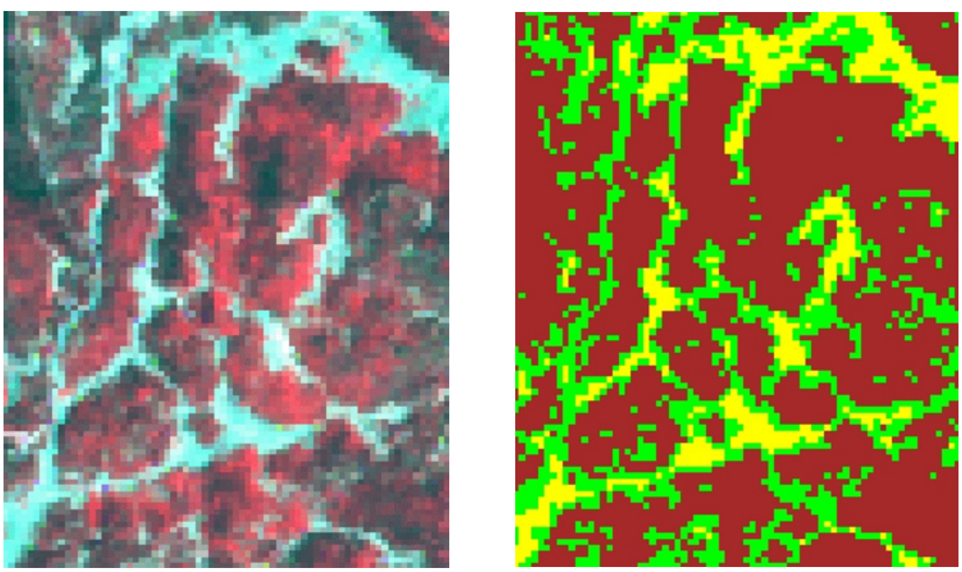


Figure 12. **Infra-red Subset and Recolored Classification AOI-A1**

Table 1. Percentage of AOI Coverage by Classification, from 1940 through 2000

PRIMARY AOI CALCULATIONS								
MEADOW		PIXEL PERCENT						
		1940	1950	1960	1970	1980	1990	2000
AOI-A-1 ACRES 1122	NO DATA	0.06%	0.05%	0.05%	0.00%	0.00%	0.00%	0.00%
	TREES	23.49%	50.83%	53.08%	45.73%	40.67%	44.75%	62.41%
	MEADOWS	65.55%	45.29%	34.16%	44.14%	54.27%	49.13%	26.41%
	BARE GROUND	10.90%	3.83%	12.71%	10.13%	5.06%	6.12%	11.18%
AOI-A-2 ACRES 1238	NO DATA	0.08%	0.05%	0.04%	0.00%	0.00%	0.00%	0.00%
	TREES	21.75%	45.93%	40.52%	44.60%	59.62%	43.81%	64.41%
	MEADOWS	59.88%	43.92%	53.93%	49.74%	37.09%	49.67%	31.28%
	BARE GROUND	18.29%	10.09%	5.51%	5.67%	3.29%	6.52%	4.31%
AOI-A-3 ACRES 897	NO DATA	0.09%	0.06%	0.09%	0.00%	0.00%	0.00%	0.00%
	TREES	21.28%	38.75%	50.24%	45.11%	51.81%	48.37%	60.81%
	MEADOWS	44.77%	49.48%	43.26%	45.83%	44.57%	45.38%	34.68%
	BARE GROUND	33.85%	11.70%	6.42%	9.06%	3.62%	6.25%	4.51%
AOI-A-4 ACRES 1757	NO DATA	0.02%	0.03%	0.03%	0.00%	0.00%	0.00%	0.00%
	TREES	45.17%	47.75%	44.31%	53.76%	52.07%	53.72%	62.34%
	MEADOWS	35.28%	40.57%	42.12%	37.30%	42.41%	36.21%	31.15%
	BARE GROUND	19.53%	11.65%	13.54%	8.94%	5.52%	10.08%	6.51%
AOI-A-5 ACRES 946	NO DATA	0.10%	0.07%	0.09%	0.00%	0.00%	0.00%	0.00%
	TREES	55.29%	39.35%	40.66%	55.88%	48.44%	46.19%	54.78%
	MEADOWS	34.06%	47.06%	48.35%	37.37%	44.29%	46.54%	38.05%
	BARE GROUND	10.56%	13.51%	10.90%	6.75%	7.27%	7.27%	7.17%
AOI-A-6 ACRES 1652	NO DATA	0.00%	0.03%	0.02%	0.00%	0.00%	0.00%	0.00%
	TREES	36.22%	50.40%	34.48%	59.52%	48.63%	43.80%	58.09%
	MEADOWS	45.80%	38.49%	54.69%	35.98%	45.64%	49.72%	37.06%
	BARE GROUND	17.98%	11.08%	10.80%	4.50%	5.73%	6.49%	4.86%
AOI-B-1 ACRES 691	NO DATA	0.05%	11.63%	0.04%	0.00%	0.00%	0.00%	0.00%
	TREES	30.39%	34.67%	39.31%	48.94%	46.82%	40.58%	55.15%
	MEADOWS	47.04%	42.05%	50.55%	47.16%	48.16%	54.85%	39.37%
	BARE GROUND	22.52%	11.64%	10.10%	3.90%	5.02%	4.57%	5.48%
AOI-B-2 ACRES 1789	NO DATA	0.05%	0.03%	0	0.00%	0.00%	0.00%	1.09%
	TREES	45.79%	40.38%	0	55.35%	57.83%	46.35%	55.46%
	MEADOWS	36.85%	45.42%	0	35.83%	35.04%	46.91%	37.42%
	BARE GROUND	17.31%	14.17%	0	8.83%	7.13%	6.74%	6.03%
AOI-B-3 ACRES 843	NO DATA	0.00%	0.04%	0.02%	0.00%	0.00%	0.00%	0.00%
	TREES	37.28%	50.54%	46.90%	50.46%	64.43%	39.06%	57.60%
	MEADOWS	46.98%	30.67%	41.42%	43.57%	32.63%	54.23%	35.52%
	BARE GROUND	15.75%	18.75%	11.67%	5.97%	2.94%	6.71%	6.88%
AOI-B-4 ACRES 344	NO DATA	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
	TREES	37.97%	50.51%	50.53%	47.33%	60.22%	47.11%	47.11%
	MEADOWS	45.57%	36.84%	41.71%	45.56%	8.89%	49.33%	49.33%
	BARE GROUND	16.45%	12.64%	7.75%	7.11%	30.89%	3.56%	3.56%
AOI-B-5 ACRES 640	NO DATA	0.00%	0.07%	0.06%	3.70%	3.70%	3.70%	0.00%
	TREES	25.36%	48.29%	37.52%	48.54%	27.78%	51.85%	62.41%
	MEADOWS	47.02%	44.63%	48.57%	37.57%	65.61%	36.77%	28.57%
	BARE GROUND	27.62%	7.01%	13.85%	10.19%	2.91%	7.67%	9.02%

was managed for multiple uses. Multiple use management in the period since 1990 has been compromised by the single-species Mexican spotted owl restrictions imposed on Region 3 by an environmental lawsuit. This court action restricted multiple use management, especially in the timber sector, halting the removal of biomass through selective timber harvesting.

A separate study, conducted in 2000, of the Region 3 USFS timber sales and harvest records by forest, showed that the Lincoln National Forest average annual rate of harvest from 1971 to 1989 was approximately 12,703 MBF (thousand board feet). In the decade following this 20-year period, from 1990 to 1999, annual rate of harvest fell 76% to approximately 2,995 MBF. Unlike

Table 2. Total AOI Pixel Averages by Classification, 1940 through 2000

	AVERAGE AOI PIXEL PERCENT			
YEAR SERIES	NO DATA	TREES	MEADOWS	BARE GROUND
1940	0.04%	34.61%	46.12%	19.22%
1950	1.20%	45.19%	42.03%	11.58%
1960	0.04%	43.72%	45.82%	10.41%
1970	0.37%	50.45%	41.83%	7.35%
1980	0.37%	50.81%	41.39%	7.43%
1990	0.37%	45.88%	47.26%	6.49%
2000	0.11%	58.01%	35.57%	6.31%

Table 3. Total Pixel Percent Change by Decade

	PIXEL PERCENT CHANGE BY DECADE			
YEAR SERIES	NO DATA	TREES	MEADOWS	BARE GROUND
1940 - 1950	1.16%	10.58%	-4.10%	-7.65%
1950 - 1960	-1.45%	-2.03%	4.48%	-1.00%
1960 - 1970	0.42%	6.07%	-3.23%	-3.26%
1970 - 1980	0.00%	0.37%	-0.44%	0.08%
1980 - 1990	0.00%	-4.93%	5.87%	-0.94%
1990 - 2000	-0.26%	12.13%	-11.69%	-0.18%
1940 - 2000	0.07%	23.40%	-10.55%	-12.92%

Table 4. Meadow and Open Area Coverage by Dot Grid Method

Year Base	TREES	MEADOWS	BARE GROUND
1940–2000	0.0281x	-0.0091x	-0.0185x
1940–1990	0.0228x	-0.000060x	-0.0226x
1950–1990	0.0085x	0.006x	-0.0132x
1990–2000	0.1213x	-0.1169x	-0.0018x

PRELIMINARY RESULTS

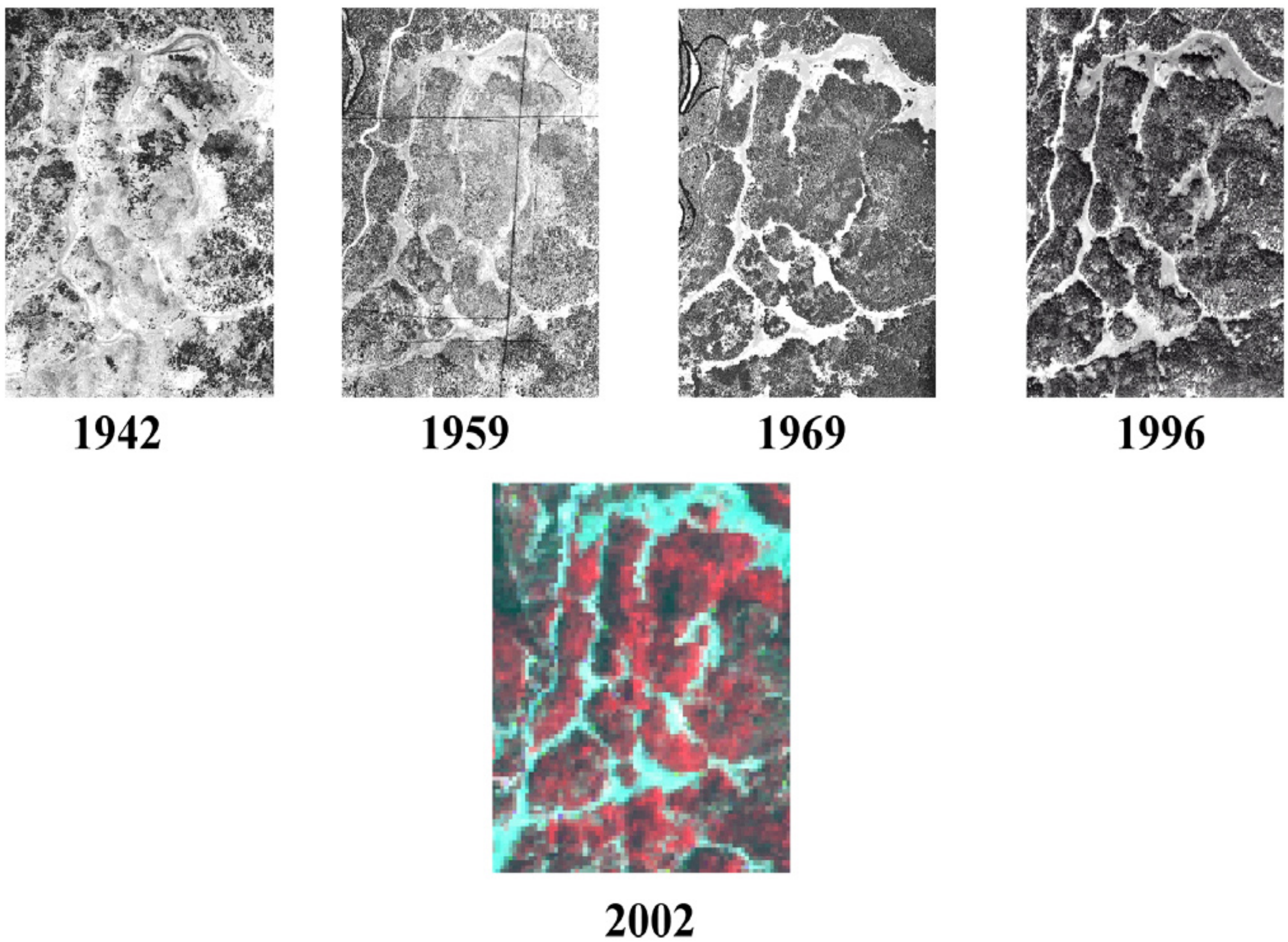


Figure 13. **Initial AOI-A1 Classified Image Sets**

rock, trees continue to grow and regenerate, which accounts for the 12% annual increase in encroachment.

When all of the Region 3 forests in New Mexico were compiled for timber harvest evaluation, it was discovered that New Mexico harvested timber declined 82% (138,485 MBF) in the time period 1986 through 1999. This reduction of approximately 10,653 MBF per year has resulted in an estimated 1,419,405 MBF (about 1.4 billion board feet) buildup of unharvested timber in New Mexico forests. Of this buildup, almost 92% has occurred since 1990, with 78% of the accumulation occurring since 1992 (Frost, 2000). A 2001 report by L.D. and P.J. Garrett of M3 Research evaluated forest conditions over a 100-year period and noted many other studies on the Lincoln National Forest, going back to 1904.These studies indicate that the historical density of this forest at 8,500 to 9,500 feet elevation (AOI study area elevation) was approximately "40–70 trees per acre" (p. E-10) with cumulative fuel loads at "2–6 tons per acre" (p. E-11) and that current densities have increased to approximately "227 trees per acre…an average increase of over 170 trees per acre" (p. E-20). The report concluded that "cumulative fuel loads now exceed 20 tons per acre, or four time the levels of the presettlement period" (p. E-20).

With regard to meadows and open areas, the report states that:

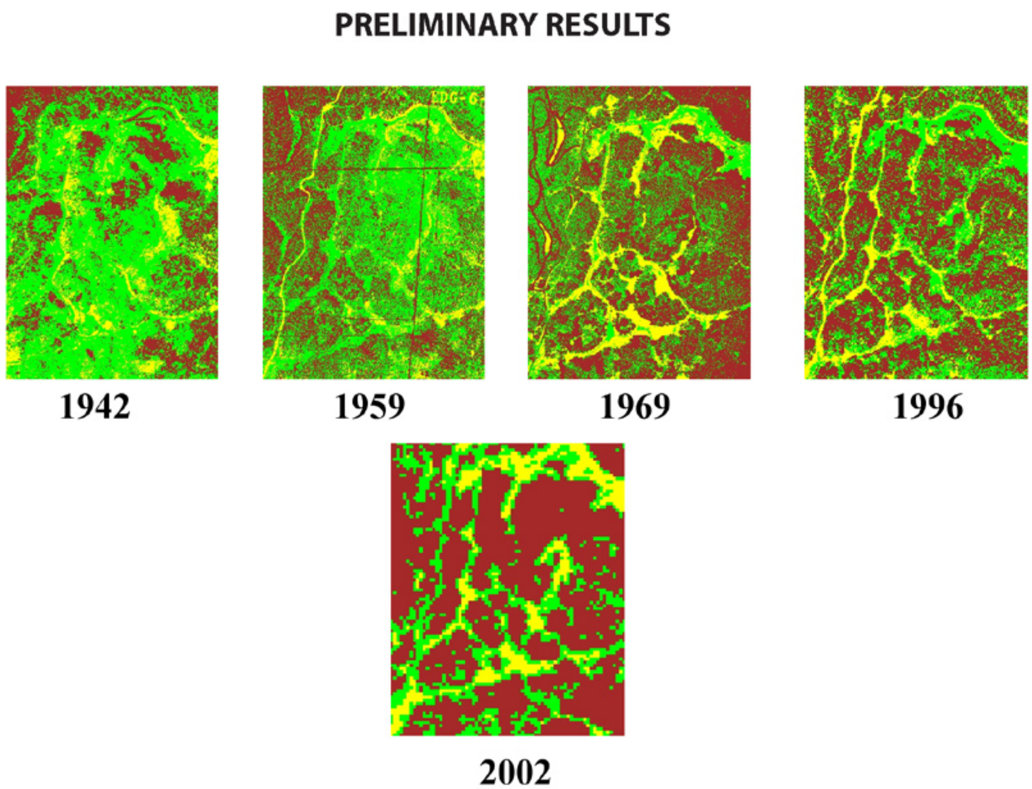


Figure 14. **Final AOI-A1 Classified Image Sets**

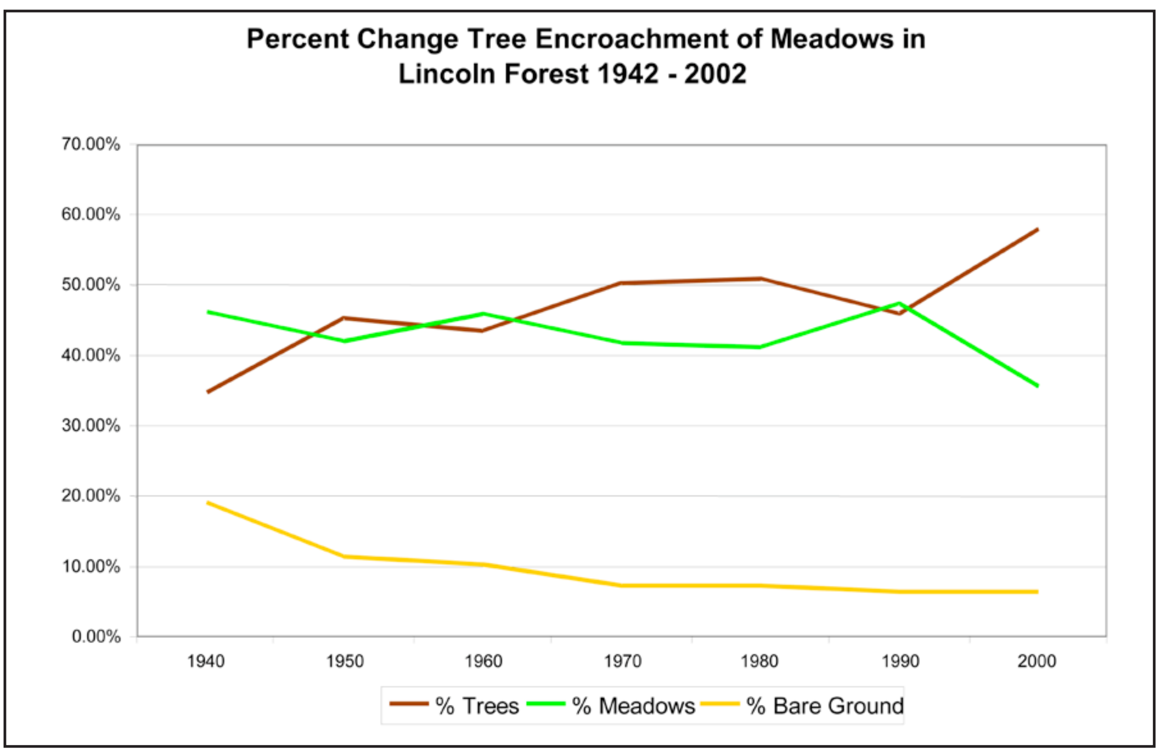


Figure 15. **Pixel Values Classification Graph**

Table 5. Trend Line Slope Formulas

Year Base	TREES	MEADOWS	BARE GROUND
1940–2000	0.0281x	-0.0091x	-0.0185x
1940–1990	0.0228x	-0.000060x	-0.0226x
1950–1990	0.0085x	0.006x	-0.0132x
1990–2000	0.1213x	-0.1169x	-0.0018x

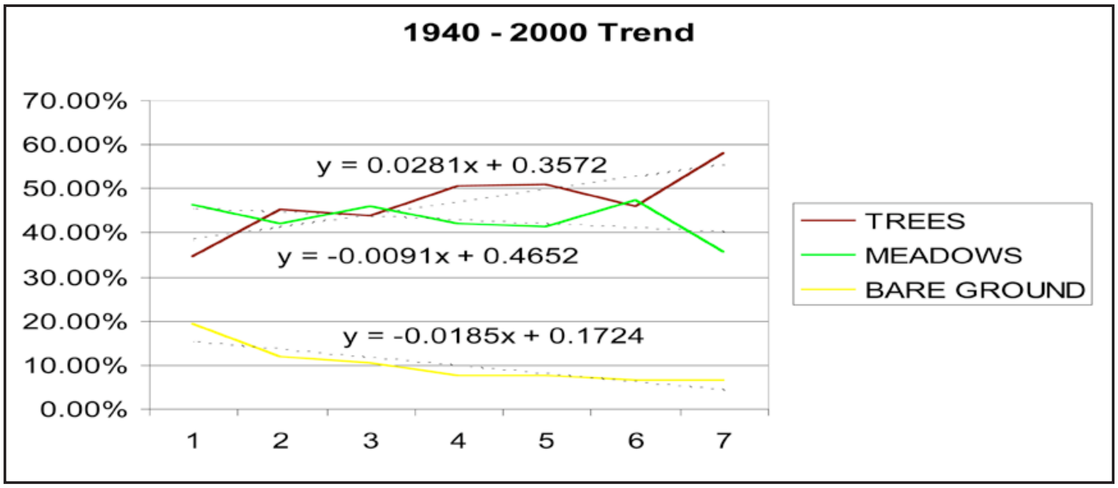


Figure 16. **1940 to 2000 Trend Line Formula Graph**

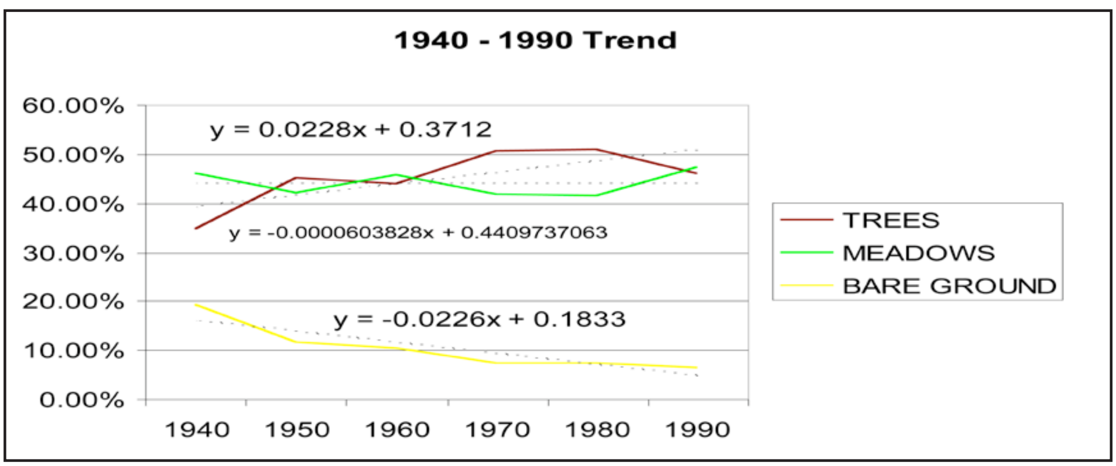


Figure 17. **1940 to 1990 Trend Line Formula Graph**

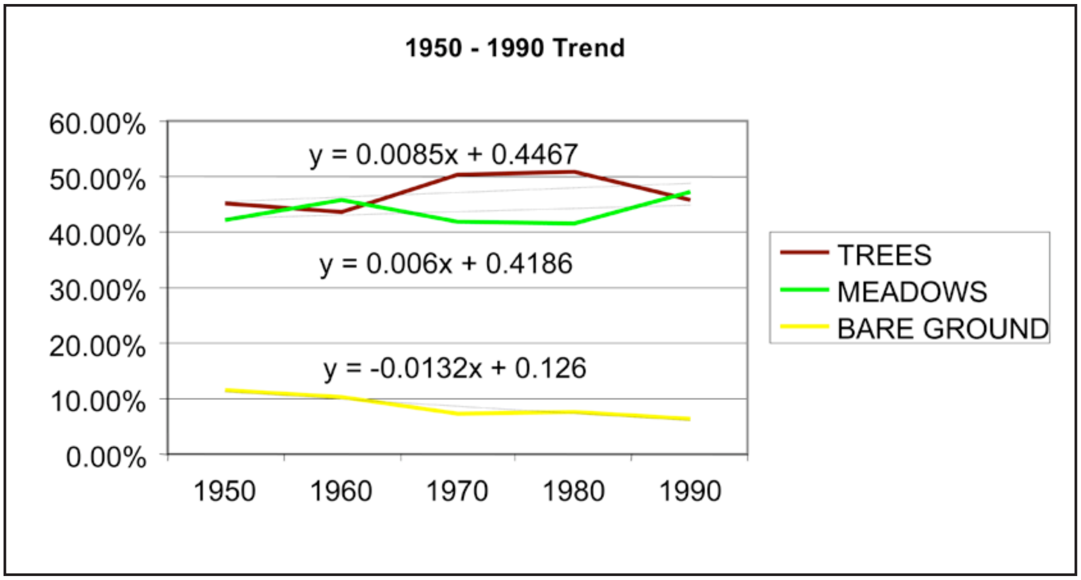


Figure 18. **1950 to 1990 Trend Line Formula Graph**

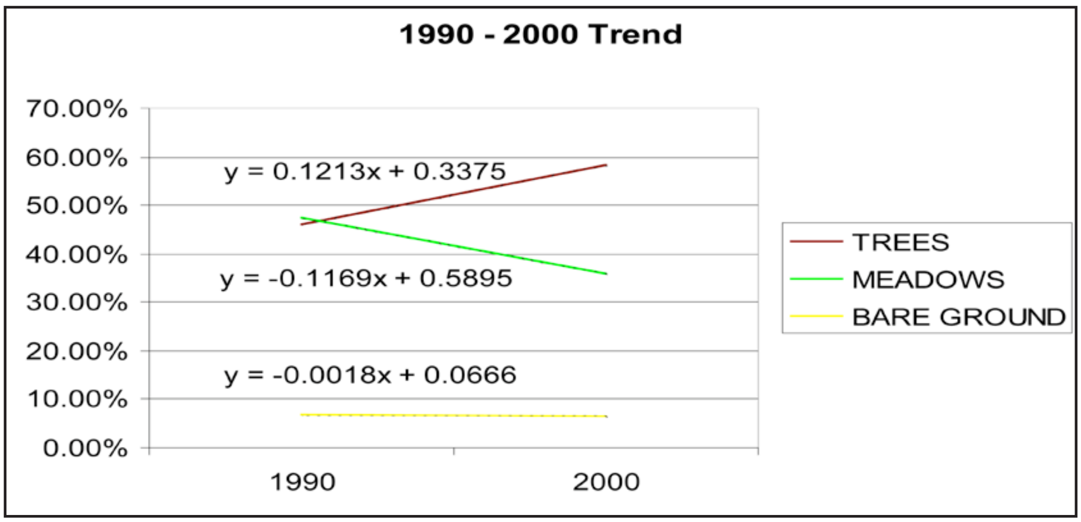


Figure 19. **1990 to 2000 Trend Line Formula Graph**

> Openings have been encroached upon in all areas. Presettlement period small openings of 1–20 acres are often not identifiable today. Larger parks and glades greater than 100 acres are decreasing in size due to encroachment. On-site water deficits and loss of openings are causing declines in wetlands, seeps and springs, water recharge and contributions to instream flows. In combinations these factors have reduced on-site biodiversity. (p. E-20)

They summarize the causes of this phenomenon with this statement:

> Appropriate thinning and timber stand improvements regimes were not implemented in the 1960s–1990s at the levels necessary to reduce tree densities, favor the original species balance, or through time replace the old growth structures. In

> part, some of these options were not available to the USDA Forest Service due to extensive environmental opposition to management treatments since the 1970s. (p. E-13)

More recently, this situation has been aggravated by the MSO restrictions imposed on Region 3 by the MSO environmental opposition that restricted timber harvest. Given the pattern of encroachment and biomass accumulation observed statewide, the likelihood is that tree encroachment into open areas and loss of biodiversity is occurring throughout Region 3 forests at a rate equal to that demonstrated in the Lincoln National Forest. Projecting this rate into the future, it is clear that unless management practices are adjusted open areas will continue to decline, forage carrying capacity for all animals will decline, biodiversity will continue to decline, and the excessive accumulation of biomass will enhance the likelihood of catastrophic wildfires. In the worst case scenario, wildfires potentially could destroy forest habitat beyond reasonable recovery.

FIELD VERIFICATION

Upon completion of the image analysis, preparation for conducting field verification of the open areas in the AOIs was initiated. Over a 15-week period during the summer and fall months of 2005, each AOI's meadow and open area tree line was surveyed by foot utilizing satellite ground positioning equipment. The GPS unit recorded the technicians' movements in the field as they trekked along the leading growth edge of the existing tree line where it encountered meadows and open areas. Tree line was determined by the outermost tree or tree groups of seedling size or larger (greater than two inches diameter). When the seedling clusters were widely scattered from the tree line towards the open areas, the average density edge of the seedlings was walked, allowing the outlier individual seedlings to be counted for the small open areas just inside the tree line. The following images (Figures 20–22) are examples of this decision process. The red line shows the GPS-recorded path taken along the observed tree line. The large red arrows show the individual seedlings treated as outliers.

A digital camera recorded the existing condition of the forest at the time of the survey during the summer and early fall months of 2005. Images were taken using a Sony Cyber Shot 3.2 digital camera at locations along the tree line route deemed to be the best representative vantage points of current conditions. A GPS reading was taken to locate and reference the photo points for later mapping and for revisiting of the location for future comparisons. Images were taken by starting from an easterly direction, turning 360 degrees, and taking adjacent images in a manner that left some overlap of the previous image, until the collection of images completed a circle recording the tree line conditions (approximately 12 images per photo point). This was done approximately every 500 to 1,000 yards (457 to 914 meters) across all AOIs. The following appendices show each AOI photomap with photo points as located in the field (Appendix B). The photo point index (Appendix C) lists the corresponding photo image sets taken at each point. These correspond to the photo images contained on the CD, which can be obtained by contacting the RITF coordinator at 575-646-2841. Instructions for using the index in combination with the maps and CD image sets are contained in Appendix B.

When the recorded GPS data sets of the tree lines were overlaid on the rectified aerial images and the rectified meadows map provided by the USFS Cloudcroft District office, this example image of AOI-A4 was developed (Figures 23–24).

CONCLUSION

Computer technology can enhance land resource evaluation and aid in on-the-ground management. Computer equipment and software advances allow resource agencies to evaluate historical aerial photographs and satellite images with relative side-by-side equality. This technology also enhances the detection and observation of landscape and habitat trends across time, allowing a higher degree of accuracy and confidence by minimizing subjective human error.

This study of meadow and open areas demonstrates not only that the trees have encroached into the montane meadows but also at what rate, at what point in time the changes occurred, and to what degree encroachment occurred across 60 years. The standard dot grid matrix method, traditionally used, also can detect these landscape attribute changes across time; however, it is hindered by the subjective nature of human observation. The dot grid method should not be discarded altogether in favor of exclusive reliance on computer technology. It should be kept as a spot check and balance verification of this technology. Also, field ground truthing should always be employed for verification or contradiction of what is found in the laboratory, as static images only record a point in time on a dynamic landscape. What is in the image of yesterday does not necessarily represent what is on the ground today, as changes have occurred since the image was made.

Habitat area of the meadow prey base for the Mexican spotted owl had remained relatively stable over the 50-year period between 1940 and 1990, during which all AOIs were studied, and has declined significantly since the 1990s. A comprehensive study using the technology can potentially demonstrate how extensively this habitat degradation has occurred and during which time periods the degradation was more pronounced. When coupled with the history of the administration of the area, implications for management policy outcomes can be assessed.

Figure 20. **GPS Recorded Tree Line Showing Outlier Seedlings**

Figure 21. **GPS Recorded Tree Line Showing Outlier Seedlings**

The completion of this study will also aid in future resource decisions as to how to augment management to change the direction of this habitat alteration and other rangeland degradation. The compiled data set could now be potentially correlated with other data sets such as logging, grazing, wildlife, or other records, to determine relationships.

Figure 22. **GPS Recorded Tree Line Showing Outlier Seedlings**

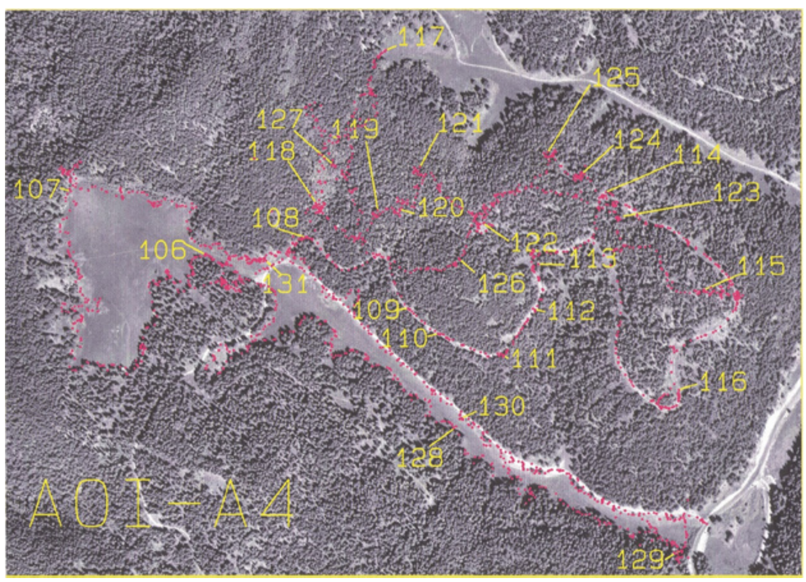


Figure 23. **Recorded GPS Route and Photo Points as Overlaid onto Rectified Aerial Image of AOI-A4**

One tremendous potential of this image set analysis technology, opening the door for further research, is the flexibility of the image data sets once established. At any time in the future, the image AOIs can be changed in location and size, increased or decreased in number, or completely redone, creating new ones for examination of the images from the perspective of a different query. This can be done at any time without having to go back into the field and attempt to reestablish or duplicate field examinations, as is the case with current investigative practices. This gives resource managers and researchers a tool to use in ways not yet imagined.

Figure 24. **Recorded GPS Route and Photos Points as Overlaid onto USFS Meadows Map of AOI-A4**

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Frost, Richard. August 14, 2000. *New Mexico Forest Fire Situation*. Testimony presented to House of Representatives Natural Resource Committee. Field Hearing. Taos, New Mexico.

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Thompson, Jonathon. June 2007. *Mountain Meadows—Here Today, Gone Tomorrow? Meadow Science and Restoration*. *Science Findings*. Pacific Northwest Research Station/USDA Forest Service.

Woolsey Jr., Theodore S. 1911. *Western Yellow Pine in Arizona and New Mexico*. (Bulletin 101). Washington, DC: U.S. Department of Agriculture, Forest Service.

APPENDIX A: INHERENT PROBLEMS

While this mapping technology has enhanced evaluation qualities, it is not without problems. Some of the factors to consider while conducting this type of investigation are summarized below.

Age – The age of the photograph to be scanned affects the quality of the image because colors can fade, the paper can yellow and crack, water damage can alter spectral quality, and bug holes can remove pertinent information. Some of this can be accounted for in the software program but not very much. The problem area(s) can be clipped out of the image and left blank, but these clipped areas will have to be removed on all subsequent images to maintain equality of evaluation from one image set to another.

Capacity of computer – The capacity of the computer affects the functionality of the program being used. If the image is large enough, and most are, some software programs, such as Terramodel, cannot handle the magnitude of the calculations, causing the system to lock up or crash altogether. Larger memory chips and drives can be installed on existing systems, but experience has shown that this is, at best, a short term fix, as cumulative files and project demands soon outstrip the computer's capacity. Obtaining a stand-alone computer system that is designed to handle large files and calculations solves this problem.

Capacity of software – Several programs exist for map making and spectral modeling. Not all of them perform the same functions, so the outcome of the project design and the file formats being used dictate the software to be obtained. Until a program is developed that combines all these functions, in most cases the best solution is to install multiple map-making and spectral modeling programs on a computer with sufficient capacity to support them, and to make sure technicians are trained in their use.

Clouds – Cloud cover in the image prevents the spectral information on the ground from reaching the camera or sensing tool. The software reads the spectral information as white, which could be added to the bare ground category or possibly to the unclassified category. Either way, clouds interfere with evaluating the spectral information on the ground under them. They can be clipped out of the image and left blank, but these clipped areas will have to be removed on all subsequent images to maintain equality of evaluation from one image set to another. If this occurs across several images in a mosaic, the quality of the information will diminish.

Glare – Photographic highlights (especially on glossy photographs), known as glare, give false spectral information of the image, known either as false positives or as false negatives. Large bare ground areas of meadows were problematic in this area on some of the photographs that were scanned, as the time of year was before the grass had greened up for the season or was not greened up due to drought. On a few of the scanned photographs, some areas with trees had so much glare that the software designated them as meadows or bare ground. Attempts to use other software programs to lighten or darken the problem photographs failed, as the program darkens and lightens the entire image, rendering the results of classification questionable (meadows became treed areas in some cases). The best results come from a photograph that is uniform across the entire image, but this is difficult to expect of archived historical photographs.

Ground truthing – What you see may not be what you get. Photographs and images represent a static point in time. The project area may have changed in some attribute, such as vegetation type, or by anthropomorphic alternation of the surface since the latest image on file. Sometimes land features may be mimicking what is being examined. Consequently, once the project area has been laid out and developed, a GIS field team needs to be sent out to verify the specific attributes being studied. Without this validation, the results of the study will be an armchair educated guess.

Mosaic of images – To create the largest image possible of these archival photographs, all of the images taken in the same year will be pieced together by the rectification and registration assigned to the images. The rectification method used here requires numerous points of human input per image. This works well in areas where street corners are convenient reference points through time. However, obvious points in natural areas become confusing when decades of growth or lack of growth, or physical attribute alterations (such as logging) change the landscape as seen from above. Multiple points per image across multiple photographs scanned means potentially multiple opportunities for some degree of human error to occur. If this is not controlled, any results derived or inferred from the classification will be compromised.

Resolution – When working with different formats, the area covered by pixel can vary greatly. When doing comparisons between formats, the scale between images and source materials can vary greatly. For example, the pixel scale of the scanned photographs is approximately one meter per pixel, while the satellite images range from 10 to 15 meters per pixel. This reduces any comparisons between formats to a percentage of area coverage rather than a direct pixel-by-pixel comparison.

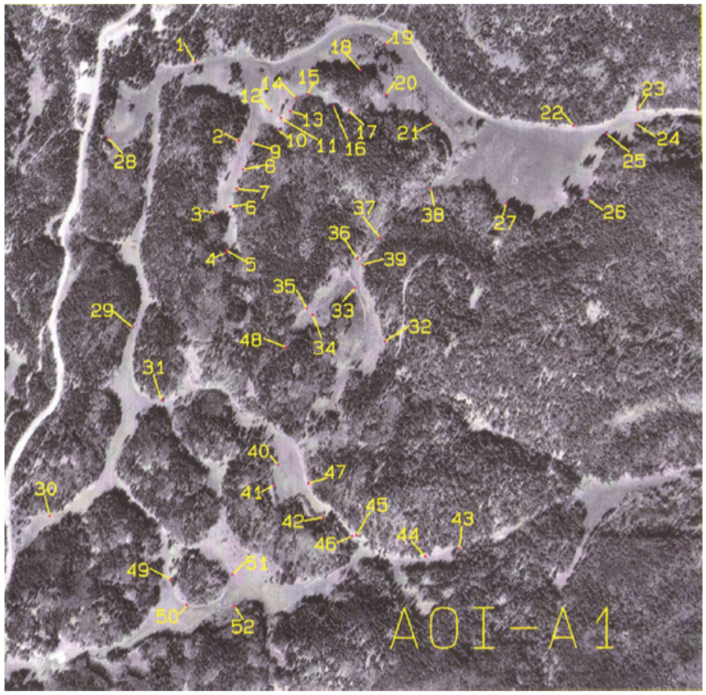
Rectification – When rectifying raw images, placement of the alignment points is critical. Should the image being rectified not align properly, the target attributes to be classified will be misrepresented. The misalignment can either make the attribute larger, make it smaller or make it disappear altogether due to coverage from an adjacent image during the mosaic overlay process.

Writings and drawn objects – On archived aerial photographs, drawing or writing directly on the image alters the spectral information and, much like a cloud, cannot be removed (see 1959 and 1969 in Figures 13 and 14). This can be clipped out of the image and the area left blank, but these clipped areas will have to be removed on all subsequent images to maintain equality of evaluation from one image set to another. If this occurs across several images in a mosaic, the compound quality of the information derived will diminish.

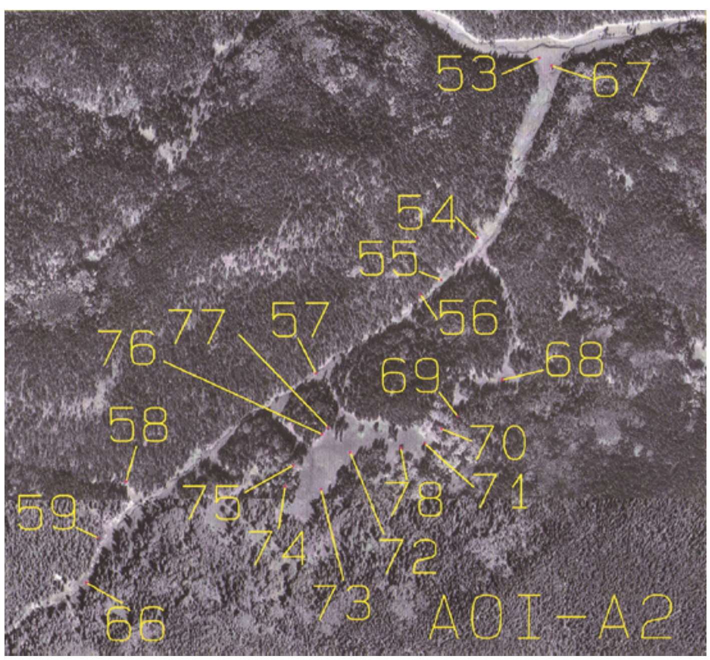
APPENDIX B: MAPPED AOIs WITH GEO-REFERENCED PHOTO POINTS

The following images demonstrate the geo-referenced photo points for each of the 11 mapped AOIs. Appendix C contains an indexed list of each AOI and related photo points with the photograph sets taken at each point. All AOI photos are contained on CD sets which can be obtained by contacting the RITF coordinator at 575-646-2841. To view the images, insert and open the CD of the AOI of interest, scroll through the list of images and open the photo images listed for that photo point in a picture viewer.

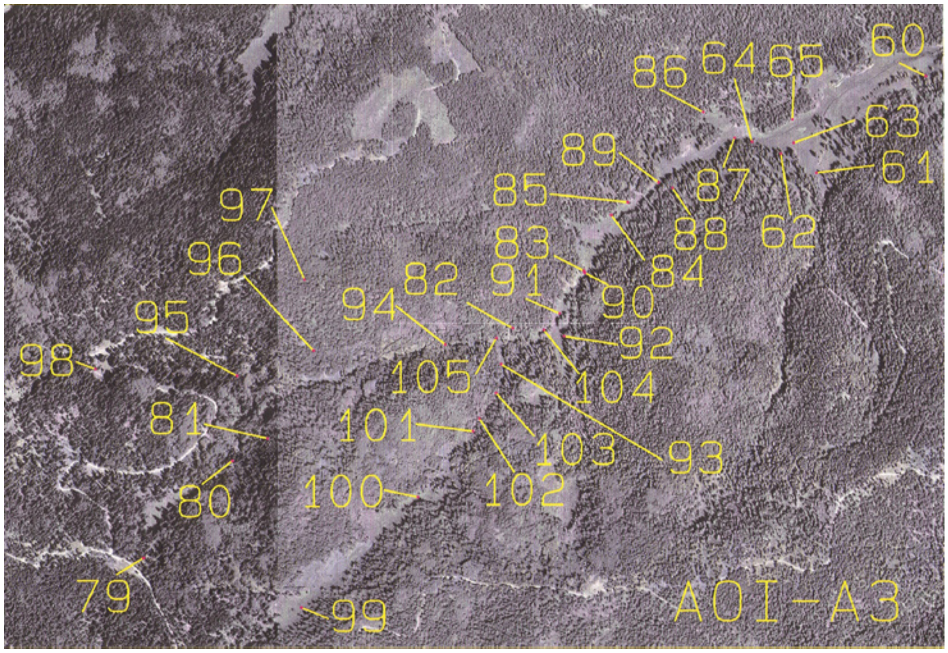
For example, AOI-A1, Russia Canyon, has 52 geo-referenced photo points. The corresponding photo sequence is displayed in Appendix C. In the book sleeve containing the CDs, locate the one labeled “AOI-A1” and load the disc into the CD drive. Using the map in Appendix B for AOI-A1 (page 28), determine which photo point is to be examined and locate the corresponding photo set number(s) from the index in Appendix C. (For this example, AOI-A1 photo point 36 on page 41 contains the image set 825–837). Locate those photo numbers on the CD and open them in the computer’s picture viewing program.



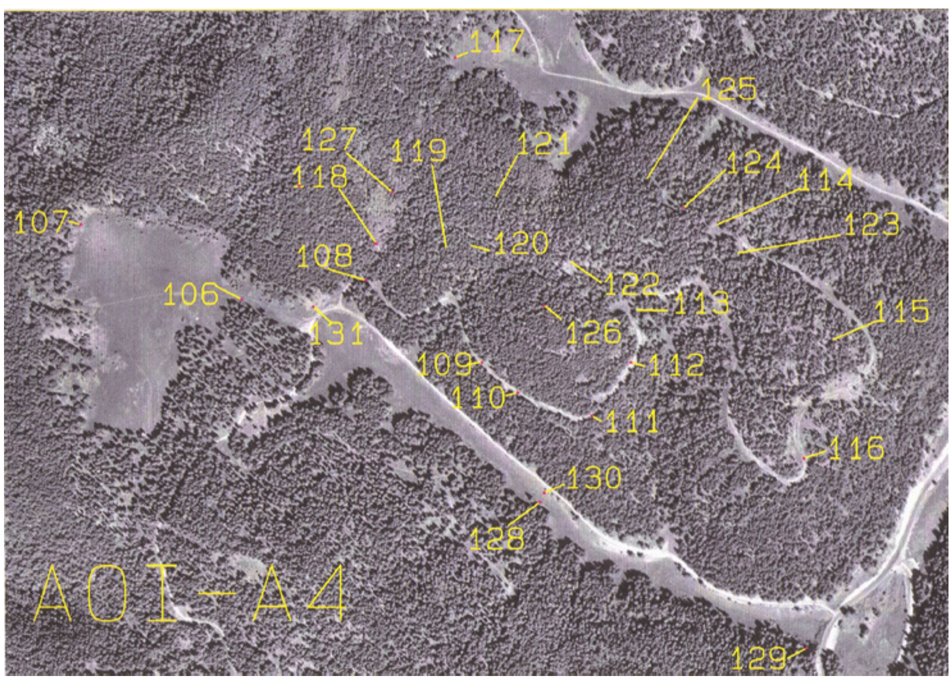
AOI-A1, Russia Canyon



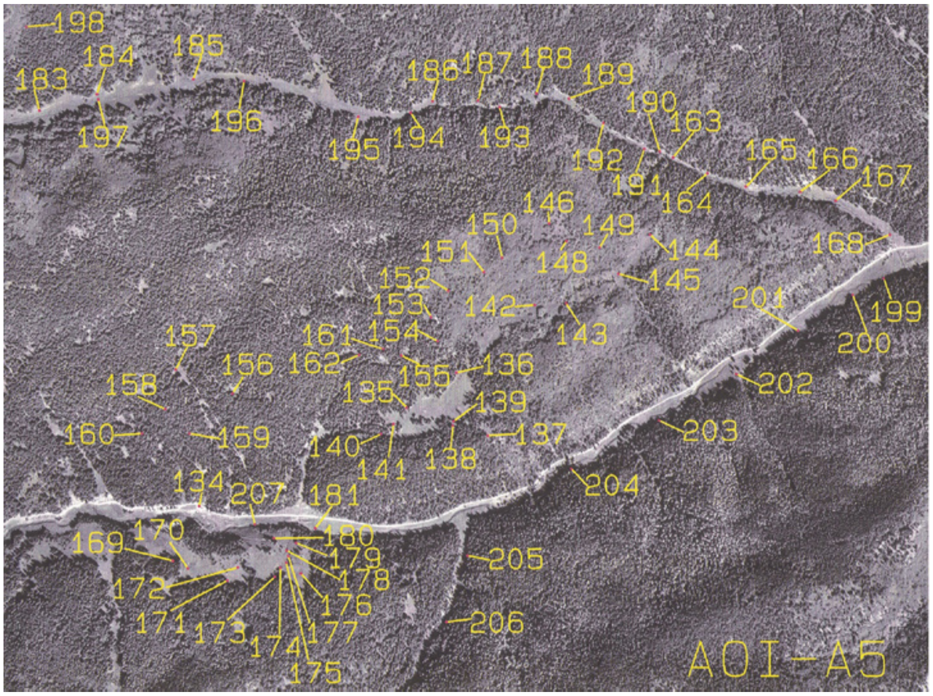
AOI-A2, Lower Lucas Canyon



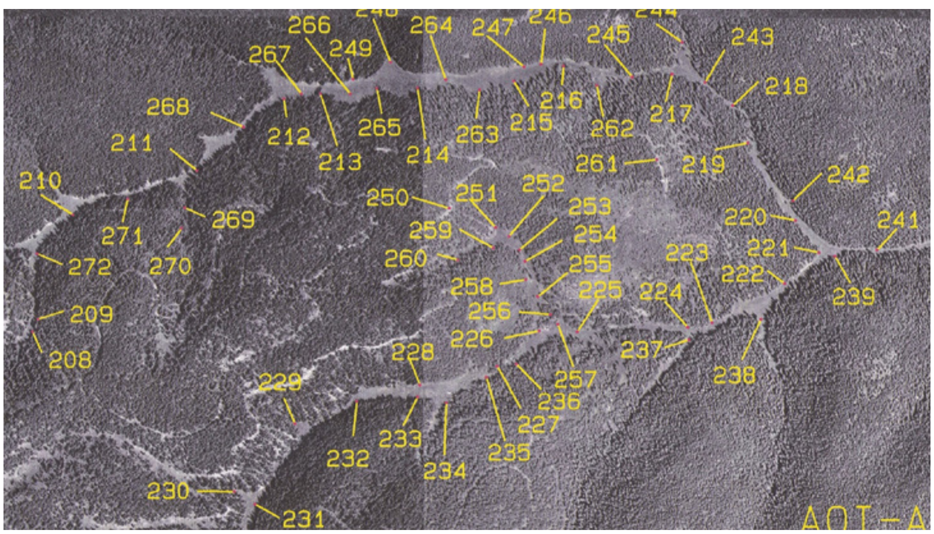
AOI-A3, Upper Lucas Canyon



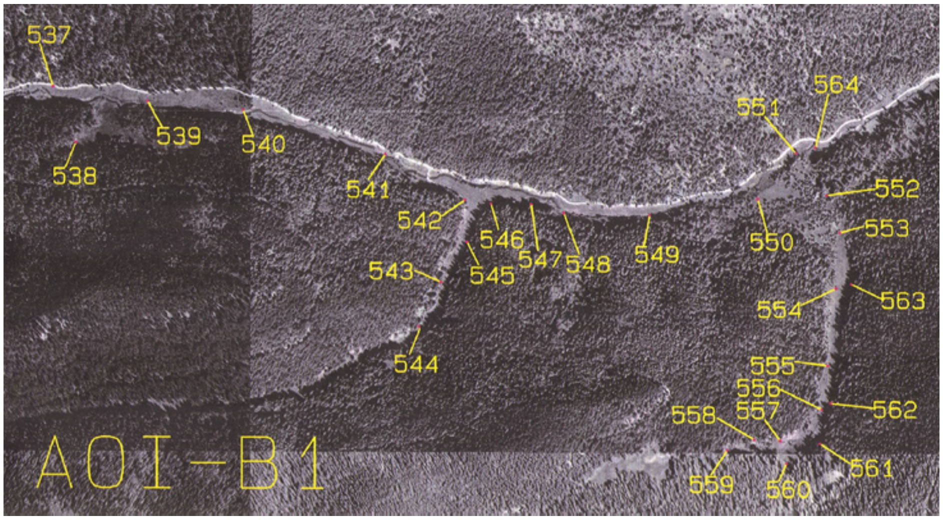
AOI-A4, Atkinson Canyon



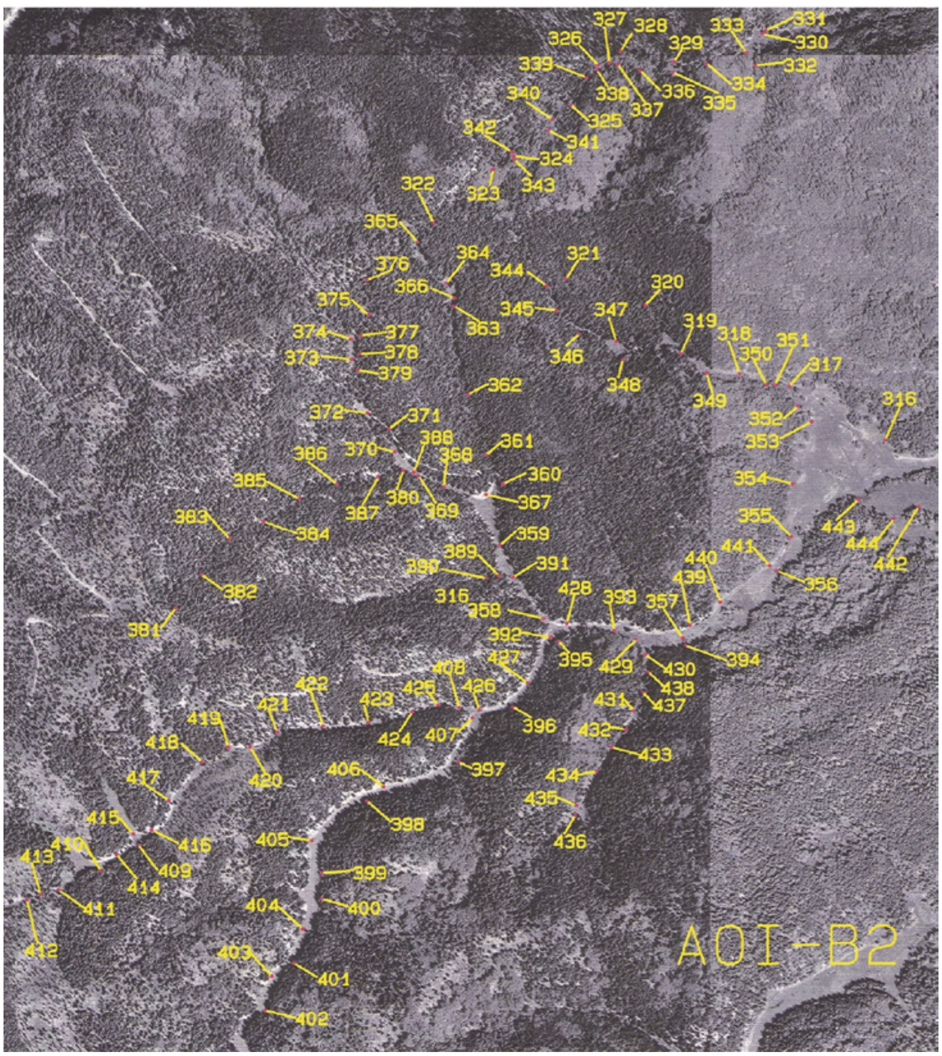
AOI-A5, Bluff Springs



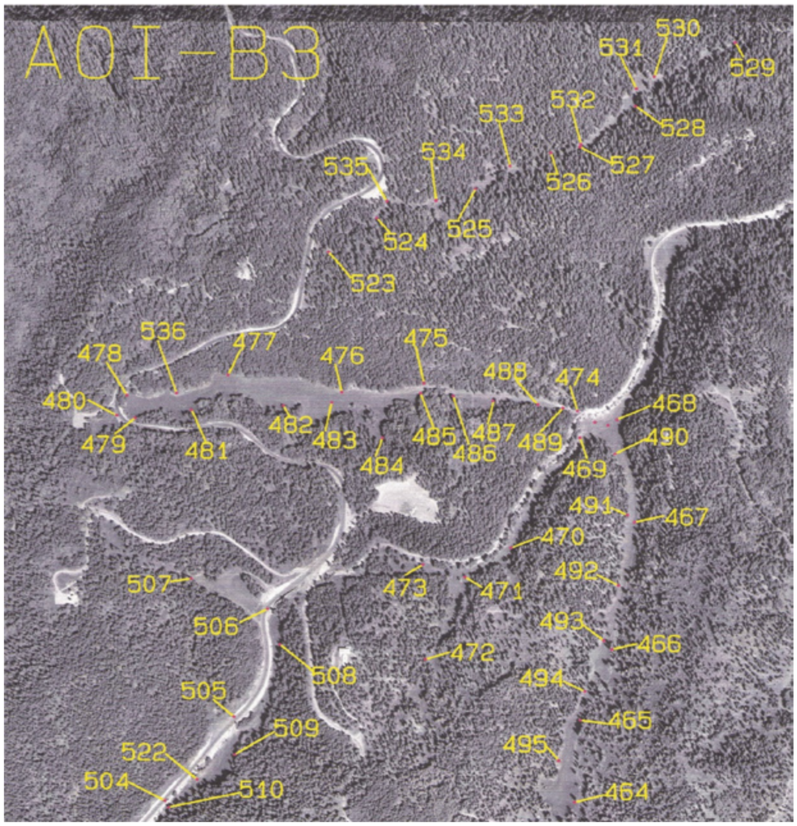
AOI-A6, Dark and Wilmeth Canyons



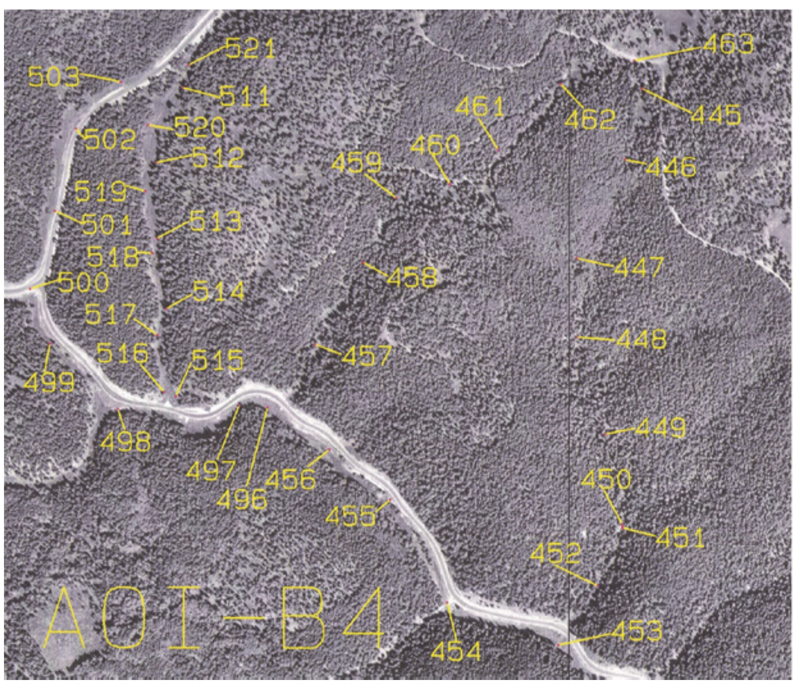
AOI-B1, Bear Canyon



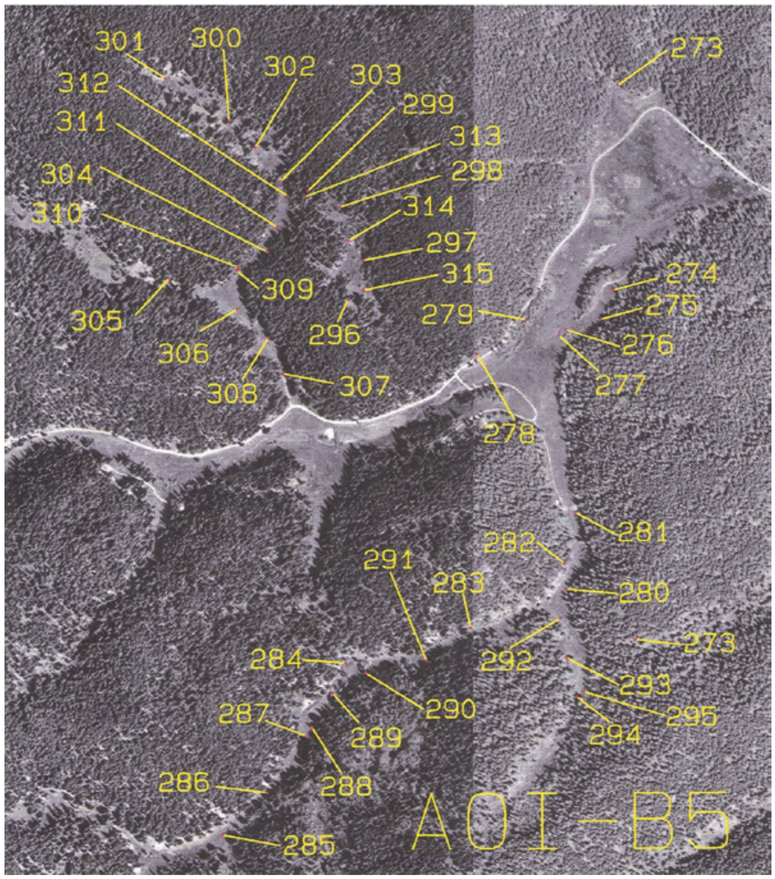
AOI-B2, Willie White and Wills Canyons



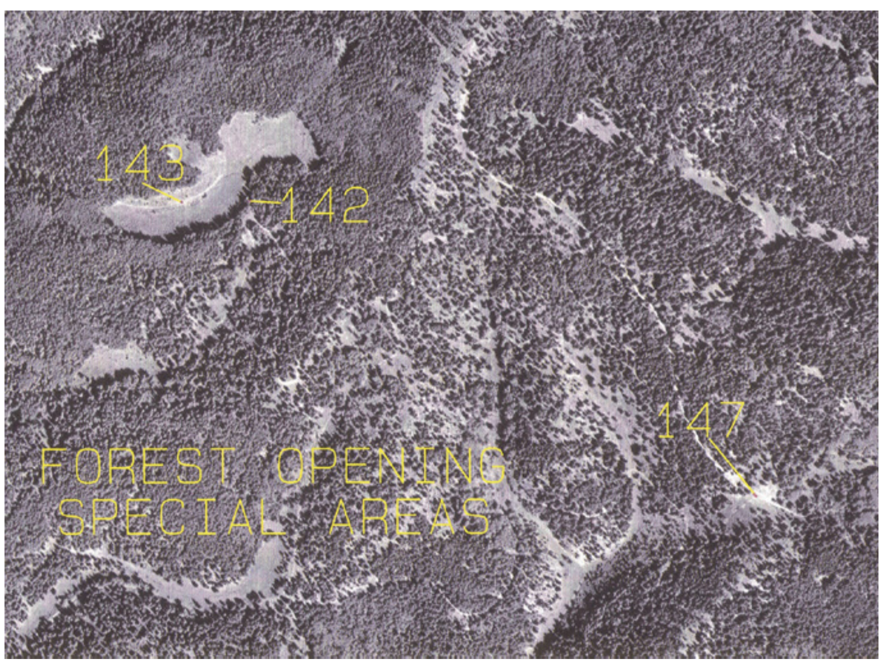
AOI-B3, Cathy and Deadman Canyons



AOI-B4, Sunspot Entrance



AOI-B5, Hay Canyon



Forest Openings Special Areas

APPENDIX C: INDEX OF MAPPED GEO-REFERENCED PHOTOGRAPH GROUPS

Note: Photograph sets are, for the most part, consistent in sequence for the majority of the project; however, several photographs and sets were not included in these data sets due to lack of relevance to the study focus of this project. Thus, there are sequential gaps in the number series that should not be of concern. Also, the field surveys were conducted in a manner conducive to the field conditions and the need for efficiency of collecting data when the surveyors were in adjoining AOIs; thus the geo-photo points do not necessarily follow a consistent sequence within some of the AOIs.

This index lists the AOIs in order, followed by the geo-referenced photo point with the photo sets and individual images taken at those locations. To examine the photographs taken at specific locations, locate the CD labeled to match the AOI map being reviewed and load the CD in a computer with software compatible for reading JPEG and movie files. Locate the geo-referenced point of interest on the AOI map, then the corresponding number in the following index. Locate the photograph number sets in the right hand column and then open the related JPEG or movie on the related CD.

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A1 Russia Canyon	1	552 - 557
	2	558 - 560
	3	561 - 564
	4	566 - 569
	5	570 - 578
	6	579 - 591
	7	592, 596 - 600
	8	601 - 604
	9	605 - 610
	10	613 - 624
	11	625 - 629
	12	630 - 638
	13	643 - 650
	14	651 - 657
	15	662 - 664
	16	665 - 678
	17	679 - 687
	18	693 - 698
	19	699 - 702
	20	703 - 705
	21	716 - 718
	22	722 - 726
	23	727 - 729
	24	730 - 732
	25	733, 734
	26	735, 736
	27	743, 744
	28	745 - 752
	29	753 - 759
	30	762, 763
	31	764 - 772
	32	775 - 780
	33	781 - 793
	34	794 - 808
	35	809 - 822
	36	825 - 837
	37	844 - 849
	38	853
	39	854 - 861
	40	862 - 875
	41	876 - 880
	42	881 - 888
	43	889 - 895
	44	896 - 900

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A1 Russia Canyon Continued	45	906, 907
	46	908 - 911
	47	912 - 924
	48	925 - 927
	49	928 - 936
	50	937 - 943
	51	944 - 954
	52	957 - 968
AOI - A2 Lower Lucas Canyon	53	993
	54	995 - 1000
	55	1002
	56	1004 - 1009
	57	1012 - 1014
	58	1019 - 1027
	59	1028 - 1034
	66	1101 - 1103
	67	1131 - 1137
	68	1138 - 1149
	69	1150 - 1160
	70	1161 - 1174
	71	1175 - 1190
	72	1191 - 1202
	73	1203 - 1217
	74	1218 - 1221
	75	1225
	76	1228 - 1232
	77	1233 - 1235, 1241 - 1245
	78	1249 - 1251
AOI – A3 Upper Lucas Canyon	60	1035 - 1042
	61	1043 - 1059
	62	1060 - 1073, 1763 - 1766
	63	1074 - 1081
	64	1082 - 1092, 1767 - 1774
	65	1093, 1094, 1745 - 1762
	79	1626
	80	1628 - 1639
	81	1640 - 1652
	82	1655 - 1683
	83	1684 - 1696
	84	1702 - 1714
	85	1717 - 1731
	86	1732 - 1744
	87	1775 - 1786
	88	1787, 1788

Area Of Interest	Geo-Reference Point	Photograph Numbers
AOI - A3 Upper Lucas Canyon Continued	89	1789 - 1792
	90	1793 - 1804
	91	1809 - 1823
	92	1827 - 1842
	93	1843 - 1856
	94	1857, 1858
	95	1860 - 1871
	96	1872 - 1883
	97	1886 - 1896
	98	1897 - 1908
	99	2443 - 2456
	100	2458 - 2471
	101	2472 - 2484
	102	2485 - 2496
	103	2498 - 2509
	104	2510 - 2513
	105	2514 - 2528, 2533 - 2535, 2552, 2555
AOI - A4 Atkinson Canyon	106	1270 - 1281
	107	1283 - 1294
	108	1296 - 1307
	109	1308
	110	1309 - 1311
	111	1312 - 1317
	112	1318 - 1324
	113	1325 - 1338
	114	1339 - 1350
	115	1353 - 1365
	116	1367 - 1378
	117	1383 - 1397
	118	1401 - 1413
	119	1414 - 1417
	120	1418 - 1431
	121	1434 - 1443
	122	1444 - 1456
	123	1458 - 1471
	124	1473 - 1487
	125	1488 - 1492
	126	1494 - 1508
	127	1510 - 1522
	128	1547 - 1554
	129	1555 - 1566
	130	1568 - 1577
	131	1578 - 1583

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A5 Bluff Springs	134	1925
	135	1936 - 1947
	136	1948 - 1961
	137	1965 - 1976
	138	1977, 1979, 1982 - 1984
	139	1985 - 1988
	140	1989 - 2005
	141	2006 - 2017
	142	2018 - 2029
	143	2030 - 2043
	144	2047 - 2063
	145	2068 - 2080
	146	2084 - 2095
	148	2109 - 2119
	149	2120 - 2132
	150	2133 - 2145
	151	2146 - 2158
	152	2159 - 2169
	153	2170 - 2182
	154	2183 - 2195
	155	2196 - 2217
	156	2218 - 2229
	157	2230 - 2241
	158	2244 - 2255
	159	2256 - 2267
	160	2268 - 2281, 2283
	161	2285 - 2296
	162	2297 - 2308
	163	2326 - 2337
	164	2338 - 2348
	165	2349 - 2363
	166	2364 - 2376
	167	2377 - 2389
	168	2390 - 2402
	169	2560 - 2572
	170	2573
	171	2574 - 2585
	172	2586 - 2601
	173	2602, 2603
	174	2606 - 2618
	175	2619 - 2621
	176	2626 - 2639
	177	2646 - 2656
	178	2657

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A5 Bluff Springs Continued	179	2662 - 2679
	180	2680 - 2697
	181	2709 - 2726
	182	2735 - 2746
	183	2747 - 2760
	184	2761 - 2773
	185	2774 - 2786
	186	2787 - 2799
	187	2800 - 2822
	188	2823 - 2835
	189	2836 - 2847
	190	2848 - 2860
	191	2861 - 2873
	192	2874 - 2885
	192	2874 - 2885
	193	2886 - 2902
	194	2903, 2904
	195	2905 - 2916
	196	2917 - 2930
	197	2931 - 2950
	198	2951 - 2956
	199	2972 - 2984
	200	2985 - 2988
	201	2991, 2992
	202	2993 - 3008
	203	3009 - 3022
	204	3023 - 3041
	205	3045 - 3064
	206	3065 - 3077
	207	3078 - 3092
AOI - A6 Dark and Wilmeth Canyons	208	3807 - 3819
	209	3820 - 3822
	210	3823 - 3836
	211	3846 - 3858
	212	3859 - 3871
	213	3872
	214	3879 - 3890
	215	3894 - 3907
	216	3911 - 3923
	217	3930 - 3942
	218	3943 - 3956
	219	3957
	220	3958 - 3975
	221	3976 - 3989

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A6 Dark and Wilmeth Canyons Continued	222	3994 - 4007
	223	4008 - 4023
	224	4026 - 4038
	225	4039 - 4043
	226	4044 - 4057
	227	4058 - 4071
	228	4072 - 4078
	229	4083 - 4097
	230	4098 - 4111
	231	4118 - 4138
	232	4139 - 4151
	233	4152
	234	4155 - 4167
	235	4168 - 4179
	236	4182 - 4185
	237	4186 - 4199
	238	4200 - 4215
	239	4216 - 4228
	240	4229 - 4241
	241	4244 - 4256
	242	4257 - 4268
	243	4269 - 4280
	244	4281 - 4291
	245	4292 - 4303
	246	4304, 4306 - 4315
	247	4316
	248	4319 - 4330
	249	4332
	250	4333, 4334
	251	4335 - 4346
	252	4347 - 4359
	253	4360 - 4372
	254	4373 - 4385
	255	4368 - 4398
	256	4399 - 4412
	257	4413 - 4425
	258	4426 - 4438
	259	4439 - 4450
	260	4458
	261	4464 - 4471
	262	4472 - 4483
	263	4484 - 4496
	264	4497 - 4515
	265	4516 - 4530

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - A6 Dark and Wilmeth Canyons Continued	266	4531 - 4550
	267	4551 - 4564
	268	4565 - 4581
	269	4584 - 4601
	270	4602 - 4615
	271	4616 - 4634
	272	4635 - 4647
AOI - B1 Bear Canyon	537	7717 - 7728
	538	7729 - 7743
	539	7744 - 7757
	540	7758 - 7769
	541	7770 - 7782
	542	7783 - 7794
	543	7795 - 7808
	544	7809 - 7820
	545	7821 - 7832
	546	7833 - 7847
	547	7848 - 7860
	548	7866 - 7881
	549	7882 - 7909
	550	7910 - 7922
	551	7923 - 7936
	552	7937 - 7949
	553	7950 - 7964
	554	7965 - 7977
	555	7978 - 7989
	556	7990 - 8006
	557	8007 - 8021
	558	8022 - 8026
	559	8027 - 8046
	560	8051 - 8067
	561	8068 - 8084
	562	8085 - 8101
	563	8102 - 8117
	564	8120 - 8133
AOI - B2 Willie White and Wills Canyons	316	4669 - 4682
	317	4683 - 4695
	318	4696 - 4708
	319	4709 - 4721
	320	4722 - 4733
	321	4734 - 4745
	322	4746 - 4755
	323	4756 - 4768
	324	4769 - 4782

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B2 Willie White and Wills Canyons Continued	325	4783 - 4795
	326	4796 - 4806
	327	4807
	328	4808
	329	4809 - 4813
	330	4819 - 4830
	331	4831
	332	4832 - 4844
	333	4850 - 4861
	334	4864 - 4876
	335	4877 - 4889
	336	4890 - 4902
	337	4903 - 4914
	338	4916 - 4930
	339	4932 - 4944
	340	4945 - 4956
	341	4957 - 4968
	342	4980 - 4992
	343	4995 - 5005
	344	5006 - 5016
	345	5017 - 5027
	346	5028 - 5038
	347	5039 - 5050
	348	5051 - 5064
	349	5065 - 5078
	350	5079 - 5090
	351	5091 - 5106
	352	5107 - 5120
	353	5121 - 5135
	354	5136 - 5147
	355	5148 - 5160
	356	5161 - 5173
	357	5174 - 5187
	358	5188 - 5201
	359	5202 - 5214
	360	5215 - 5227
	361	5228 - 5239
	362	5240 - 5253
	363	5265 - 5279
	364	5280 - 5298
	365	5299 - 5310
	366	5311 - 5327
	367	5330 - 5348
	368	5349 - 5361

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B2 Willie White and Wills Canyons Continued	369	5362 - 5373
	370	5374 - 5387
	371	5388 - 5400
	372	5401 - 5414
	373	5415 - 5429
	374	5430 - 5443
	375	5444 - 5456
	376	5459 - 5471
	377	5472 - 5484
	378	5485 - 5497
	379	5498 - 5511
	380	5512 - 5528
	381	5529 - 5539
	382	5540 - 5550
	383	5551 - 5565
	384	5566 - 5580
	385	5581 - 5596
	386	5597 - 5607
	387	5608 - 5620
	388	5633 - 5643
	389	5644 - 5657
	390	5658 - 5671
	391	5672 - 5684
	392	5685 - 5698
	393	5703 - 5715
	394	5718 - 5735
	395	5742 - 5753
	396	5754 - 5764
	397	5765 - 5777
	398	5778 - 5795
	399	5796 - 5808
	400	5809 - 5820
	401	5823 - 5843
	402	5844 - 5856
	403	5857 - 5872
	404	5873 - 5887
	405	5888 - 5901
	406	5902 - 5916
	407	5917 - 5929
	408	5930 - 5943
	409	5953 - 5965
	410	5966 - 5978
	411	5981 - 5992
	412	6028 - 6042

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B2 Willie White and Wills Canyons Continued	413	6043 - 6058
	414	6059 - 6071
	415	6072 - 6086
	416	6087 - 6100
	417	6101 - 6113
	418	6114 - 6127
	419	6128 - 6141
	420	6142 - 6154
	421	6155 - 6165
	422	6166 - 6177
	423	6178 - 6189
	424	6190 - 6203
	425	6204 - 6216
	426	6217 - 6230
	427	6235 - 6247
	428	6248 - 6259
	429	6260 - 6272
	430	6273 - 6285
	431	6286 - 6299
	432	6300 - 6312
	433	6313 - 6324
	434	6325 - 6339
	435	6340 - 6352
	436	6353 - 6366
	437	6368 - 6380
	438	MOV06381
	439	6382 - 6394
	440	6395 - 6410
	441	6411 - 6429
	442	6436 - 6446
	443	6447 - 6466
	444	6476 - 6481, 6484
AOI - B3 Cathy Canyon	464	6716 - 6726
	465	6727 - 6738
	466	6739 - 6750
	467	6751 - 6752
	468	6763 - 6778
	469	6779 - 6790
	470	6791 - 6801
	471	6803 - 6813
	472	6814 - 6825
	473	6826 - 6839
	474	6840 - 6852
	475	6853 - 6868

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B3 Cathy Canyon Continued	476	6869 - 6880
	477	6881 - 6894
	478	6899 - 6911
	479	6912 - 6923
	480	6924 - 6936
	481	6937 - 6948
	482	6949 - 6960
	483	6961 - 6965
	484	6968 - 6983
	485	6985 - 6997
	486	6998 - 7013
	487	7014 - 7026
	488	7027 - 7043
	489	7044 - 7063
	490	7064 - 7079
	491	7080 - 7093
	492	7094 - 7110
	493	7111 - 7129
	494	7130 - 7145
	495	7146 - 7159
	504	7275 - 7288
	505	7289 - 7299
	506	7300 - 7318
	507	7319 - 7332
	508	7333 - 7344
	509	7345 - 7358
	510	7361 - 7373
	522	7514 - 7527
	523	7549 - 7560
	524	7561 - 7571
	525	7572 - 7581
	526	7582 - 7592
	527	7593 - 7604
	528	7605 - 7616
	529	7623 - 7635
	530	7636 - 7649
	531	7650 - 7661
	532	7662 - 7673
	533	7674 - 7686
	534	7687 - 7698
	535	7699 - 7712
	536	6895 - 6898
AOI - B4 Sunspot Entrance	445	6492 - 6502
	446	6503 - 6513

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B4 Sunspot Entrance Continued	447	6514 - 6525
	448	6526 - 6537
	449	6538 - 6550
	450	MOV06557 - MOV06560
	451	6562 - 6573
	452	6574 - 6585
	453	6586 - 6599
	454	6600 - 6609
	455	6610 - 6622
	456	6623 - 6635
	457	6636 - 6647
	458	6648 - 6659
	459	6660 - 6670
	460	6671 - 6681
	461	6682 - 6692
	462	6693 - 6703
	463	6704 - 6715
	496	7169 - 7181
	497	7182 - 7193
	498	7194 - 7208
	499	7209 - 7221
	500	7222 - 7234
	501	7235 - 7247
	502	7248 - 7260
	503	7261 - 7274
	511	7374 - 7384
	512	7385 - 7397
	513	7398 - 7410
	514	7411 - 7422
	515	7423 - 7434
	516	7435 - 7447
	517	7448 - 7459
	518	7460 - 7474
	519	7475 - 7487
	520	7488 - 7500
	521	7501 - 7513
AOI - B5 Hay Canyon	273	3140 - 3152
	274	3154 - 3166
	275	3169 - 3173
	276	3174 - 3189
	277	3190 - 3204
	278	3205 - 3217
	279	3218 - 3231
	280	3235 - 3246

Area of Interest	Geo-Reference Point	Photograph Numbers
AOI - B5 Hay Canyon Continued	281	3247 - 3271
	282	3272 - 3283
	283	3284 - 3296
	284	3297 - 3309
	285	3310 - 3323
	286	3327 - 3341
	287	3342 - 3354
	288	3355 - 3370
	289	3374
	290	3382 - 3400
	291	3406 - 3427
	292	3429 - 3448
	293	3454 - 3467
	294	3468 - 3479
	295	3480 - 3486
	296	3487 - 3498
	297	3499 - 3511
	298	3512 - 3525
	299	3526 - 3538
	300	3539 - 3551
	301	3565 - 3581
	302	3582 - 3595
	303	3596 - 3608
	304	3609 - 3622
	305	3625 - 3637
	306	3638 - 3655
	307	3656 - 3662, 3364 - 3673
	308	3674 - 3685
	309	3690 - 3702
	310	3703 - 3715
	311	3716 - 3738
	312	3739 - 3751
	313	3752 - 3763
	314	3764 - 3776
	315	3777 - 3790
Special Area: Forest Opening	132	1526 - 1530
	133	1531 - 1543
	147	2096 - 2108

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