Spectral Analysis for Articulating Scenic Color Changes in a Coniferous Landscape

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Abstract

Scenic resources represent a significant economic gain with regard to regional recreation and tourism. Measuring their scope and spatial distribution, however, has proved challenging because scenic amenities relate to both the physical environment and the responses of people interacting with those settings. The reported research addressed the documentation of scenic resources, and presented an integrated approach toward (1) the acquisition and processing of color/change relationships from scanned ground-based photographs, and (2) the creation of computer simulations using the above photographs to illustrate the color shifts measured during image processing. A geographic information system (GIS), the Global Positioning System (GPS), and image processing technologies were applied to insure that the simulated environments displayed high levels of spatial and spectral accuracy. The derived techniques could ultimately provide managers with a cost-effective means to assess scenic change, through the use of indexed color/change data that could be documented, reproduced, and integrated with other quantitative data.

Introduction and Problem Statement

The value of scenic landscapes (e.g., National Parks, National Forests) extends beyond the enjoyment of the individual. They also influence regional economies through their role as destination points for tourism and recreation (Zube, 1973; Daniel, 1990). Because of their value, agencies have striven to quantify both their significance and their spatial distribution (Hull and Buhyoff, 1986; Vining and Orland, 1989). Measuring the scope and extent of scenic resources has proved challenging, however, as they relate to both the physical environment and the responses of people interacting within those settings (Zube *et al.*, 1982; Daniel and Vining, 1983). Strategies for analyzing visual resources have applied techniques that attempt to associate ecologically based variables (vegetation, water) with the more amenity type items (scenic enjoyment, wilderness experience) (Brown and Daniel, 1986). Unfortunately, existing inventory techniques (stand mapping, satellite processing) are not always designed to equate the traditionally managed variables with the more qualitative attributes. Developing procedures that quantify the levels and extent of scenic-based resources, and integrating this material into a unified data source have, therefore, become a desired management goal.

Analytical techniques previously applied to vegetation inventories offer the potential for measuring color shifts in forest conditions. These techniques further suggest methods for identifying the agents or conditions which impact these color combinations. Shifts in the visible spectrum provide clues that an alteration has taken place. Interventions (timber harvesting, construction) increase color contrasts with the unaltered periphery; first, by the initial disruption, and later, through the introduction of plants that thrive in disturbed areas (Palmer *et al.*, 1986). Abrupt events (fire, a clear cut) alter the vegetative edge, creating new scenic relationships. The results are modified color matrices caused by a revised distribution of reflected light from the forest mass and surrounding open spaces. Broad-scale alterations are particularly critical because they potentially represent a significant shift in the quality of the viewer's experience (Hull and McCarthy, 1988).

Recently, managers have applied perceptual testing to gauge the impact of selected change conditions (Daniel and Boster, 1976; Buhyoff *et al.*, 1982). During such testing, subjects were presented a series of ground-based photographs displaying a range of scenic conditions and landscape types. Subjects were asked to render judgments on issues such as the perceived scenic beauty within each scene. To illustrate change conditions, simulation techniques have been applied to this process (Sheppard, 1989). An extension of this effort has been the use of photographic-based computer visualizations using a range of manipulative procedures (Bishop and Hull, 1991; Daniel *et al.*, 1993; Orland, 1993). These computer graphics allow subjects to view a range of impacts or events before proposals are actually implemented. Multiple alternatives can be presented in this way to obtain input regarding the effects of different strategies.

While useful as a tool for illustrating environmental change, scenic visualization has typically produced output that presents a generalized or averaged view of some future condition. This research has attempted to provide a more quantitative approach toward scenic visualization, applying spectral analysis of samples extracted from the forested portions of scanned ground photographs taken at specific times and dates. The extracted color relationships were related to field-observed variability in the forest canopy, which was caused in-part by a known biological change agent. The research further developed methodologies to statistically characterize the extracted data, to insure that the measured change conditions could be reproduced accurately in other, similar scenes. This approach could ultimately provide resource managers with indexed color/change data that could be (1) easily documented and reproduced, (2) integrated with other quantitative environmental data, and (3) utilized over extended time periods.

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Figure 1. General location map of study sites in southern Utah.

Research Objectives

A goal of the research was to develop and test a process for analyzing and graphically portraying color changes in scanned photographs of a coniferous forest. Analytical image processing offers the potential for articulating scenic color variability, and provides a method for relating that variability to known agents of change. Specifically, the study addressed the following questions: (1) Can changes in the health and vigor of forests be measured and then associated with color shifts indicative of those modified landscapes?; (2) How do forest color values change when observed from multiple view angles?; (3) To what extent do issues of time and solar orientation modulate scenic color values?; and (4) Can color relationships be transferred to other scenes to simulate like conditions in those scenes? A research design was developed to facilitate the acquisition and processing of forest color shifts, and the creation of visualizations to depict those measured color shifts. The corollary question of whether observers viewing those simulations respond to the simulations in a consistent and predictable manner will be addressed in a separate paper.

Analysis of Spectral Relationships

The first objective concentrated on developing procedures for measuring color variation within a targeted forest canopy. Variation, in this instance, was limited to the visible portions of the electromagnetic spectrum (0.38μm to 0.72μm). Scanned photographs, taken from surveyed ground positions, were the source of the extracted color data. Four parameters effecting scenic color relationships were reviewed: (1) view angle differentials, (2) solar shifts during a single day, (3) color variation over an extended period, and (4) the visual effects of an outbreak of spruce bark beetle (*Dendroctonus rufipennis*). The beetle, a natural mortality agent of spruce forests, produces a series of visible color transitions as it impacts the tree (Holsten *et al.*, 1991). These color shifts are readily apparent, and provide a means of identifying, through analysis, the stand's status and relative condition. These convenient relationships provided a mechanism for relating physical change to the color transitions visually apparent.

Landscape Visualization

The second objective was to apply the measured color relationships, representing incremental beetle activity, to a program of scenic visualization. These visualizations illustrated the previously documented color shifts indicative of a *Dendroctonus rufipennis* event at various stages of development. To accomplish this objective, the measured color relationships were transferred to portions of other scanned site photographs that presented conditions similar to those where the beetle event was documented. Because the effects of *Dendroctonus rufipennis* were not visible in this second image collection, the transferred color relationships would simulate a beetle event based on the measured spectral ranges from the initial photographs. Developing photo-realistic simulations could provide planners with a means to test alternative resource strategies, in order to assess the visual effects that changes based on those strategies might produce.

Research Sites

The research focused on a segment of coniferous forest in the Cedar City Ranger District of the Dixie National Forest in southern Utah (Figure 1). The Dixie National Forest is a scenically significant landscape. Due to its proximity to Bryce and Zion National Parks and Cedar Breaks National Monument, millions of visitors travel in and through the forest annually (Orland *et al.*, 1993). Studies have documented the expectations among travelers of a pristine, unspoiled experience (Orland, 1992). Because of these expectations, pressure has been placed on managers to maintain high levels of visual quality through appropriate planning decisions. Within the Dixie, two sites, Midway Face and Sidney Valley, were selected for analysis.

Midway Face

Midway Face is a 975-acre mountainous parcel located 20 miles east of Cedar City, Utah. Of its total acreage, 610 acres is coniferous forest while 365 acres is open meadow. The elevation ranges between 9,650 feet (2941 metres) in the northern meadow to 10,150 feet (3094 metres) at the top of the southwestern ridge. Midway Face is oriented along an east-west axis, with dense conifer stands being located on north facing slopes. A 20-acre subset was selected for investigation. The subset is primarily coniferous forest, with Engelmann spruce (*Picea engelmannii*) being the predominant tree species (Munson and DeBlander, 1992). Much of the Engelmann Spruce at Midway Face can be considered mature forest with an estimated age of over 75 years. Its age and uniformity make Midway Face an attractive site for analysis of color transitions in a simplified canopy.

Sidney Valley

Sidney Valley, located about 10 miles to the northeast of Midway Face, has similar environmental and biological characteristics. The site's elevation ranges between 9,750 feet (2971 metres) in the lower meadow and 10,600 feet (3231 metres) at the top of the western ridges. Sidney Valley is relatively narrow with mountainous slopes on both sides. Its axis is approximately 45 degrees north of east. The mountainous slopes to the east and west are populated by dense stands of coniferous vegetation, with Engelmann spruce again being the primary species. Sidney Valley, unlike Midway Face, is relatively inaccessible to the average visitor. An unimproved dirt road to the south is the only vehicular access. While the site was inappropriate with regard to measuring visitor expectations, Sidney Valley's tree composition proved ideal for extracting color and biological data.

Existing Beetle Activity

Since the late 1980s, the forests around Midway Face and Sidney Valley have been experiencing the effects of an outbreak of *Dendroctonus rufipennis* (USDA Forest Service, 1993). Both sites and the surrounding forest had been rated moderate to high risks regarding an extended beetle event (Munson and DeBlander, 1992). Such events are cyclical with a distinct series of color transitions occurring as a result (Schmid and Frey, 1977). A typical event radiates from a central node, producing zones with different levels of beetle activity. Needle discoloration does not always occur during

Table 1. Regression Equations for Four Images (Sid1, Sid3, Mid11, and Mid17) Normalized to the Control, Mid19

Image	Band#	RGB	Slope Band Intercept	Standard Error
Sid1	Band1	Red	(1.111 * x1) + (−35.911)	2.73
	Band2	Green	(1.013 * x2) + (−16.752)	0.81
	Band3	Blue	(0.9357 * x3) + 5.747	4.16
Sid3	Band1	Red	(1.197 * x1) + (−43.376)	0.93
	Band2	Green	(1.097 * x2) + (−21.794)	1.87
	Band3	Blue	(0.9666 * x3) + 6.078	3.26
Mid11	Band1	Red	(1.203 * x1) + (−18.561)	1.72
	Band2	Green	(1.100 * x2) + (−00.854)	2.45
	Band3	Blue	(0.997 * x3) + 21.151	4.37
Mid17	Band1	Red	(1.173 * x1) + (−37.604)	4.22
	Band2	Green	(1.104 * x2) + (−27.115)	5.71
	Band3	Blue	(1.050 * x3) + (−19.395)	4.11

Band# = Band number, RGB = red, green, blue, Slope = slope of regression equation as calculated by SPSS, Intercept = y-intercept of regression equation as calculated by SPSS, Standard Error = standard error per-band as calculated by SPSS, Sid1 = Sidney Valley Photographic Position 1, Sid3 = Sidney Valley Photographic Position 3, Mid11 = Midway Face Photographic Position 11, Mid17 = Midway Face Photographic Position 17, x1 = each Individual Pixel in Band 1, x2 = Each Individual Pixel in Band 2, x3 = Each Individual Pixel in Band 3.

the first year, even though the tree might be dying. After the second or third year, needles discolor to produce a reddish-brown hue. By the fourth or fifth year, needles will have dropped and the tree will appear gray. At the time of this research, Sidney Valley had experienced the greatest beetle activity of the two sites. It was therefore suggested by the Forest Service as being a suitable location for extracting color samples indicative of incremental beetle activity. Midway Face, which had yet to display any visible effects, was selected to receive the color signatures obtained from the Sidney Valley samples.

Data Acquisition

Site Photographs

A photographic inventory was developed for segments of the Midway Face and Sidney Valley scenic viewsheds in the summers of 1993 and 1994. Generally, these photographs were vista-scale, with the forest mass being approximately one-quarter mile from the camera. Prior to the 1993 activities, multiple camera positions were staked and surveyed within three zones at Midway Face and one zone at Sidney Valley. Two referencing techniques were implemented. First, control points at Midway Face were located using Trimble 4000SE Global Positioning System (GPS) equipment. The balance of Midway's points were then located from the GPS positions using a hand-held laser surveying instrument. Sidney Valley's photographic positions were surveyed from one GPS control point, using the same methodologies applied at the Midway Face survey.

A photographic timetable was established for the second and third week of July for both years. Identical photographic techniques were applied to both sites. Photographs were taken from a leveled tripod using an Olympus OM2 35-mm camera with a 50-mm lens, a UV Haze filter, and Ecktachrome 100 slide film. For future color correcting, a Macbeth Color Checker color chart was positioned in each 1994 photograph. The chart was placed at a distance of approximately 15 feet from the camera with an orientation perpendicular to the camera/target bearing. The chart was angled to insure that the color squares would have a full sunlight exposure. Three photographic angles were employed; South 30° East, South, and South 30° West. A hand-held compass was used to determine the correct bearing. Care was taken to photograph both sites on similar dates and times, and under similar meteorological conditions.

Tree Inventory Data

Data for approximately 5000 individually surveyed trees within the 20-acre Midway Face research site were acquired from the Forest Service district office in Cedar City. The information was surveyed in 1992 by Forest Service field crews as part of a 1990 Data Visualization Project (USDA Forest Service, 1993). During that field survey, the following information per-tree was compiled: (1) a tree identification number; (2) the relative distance in feet and degrees from north, from a starting point; (3) each tree's species name; (4) the field-estimated tree height; (5) the trunk diameter at breast height; (6) the estimated elevation, in feet, at ground level; and (7) a live or dead classification.

Data Development

Photo Database

Thirty-eight slides representing a range of camera/target relationships at the two study areas were sent to Kodak Laboratories for digitization and archival storage on a Kodak Photo CD master disk. Of the five resolution options available, resolution 4: 4 x base, (approximately 1,570,000 screen pixels) was chosen for the scenic investigations. This resolution would provide a sufficient pixel density to sample small canopy areas. The digital images were translated from a *.pcd format to a 24-bit *.tif format in Adobe Photoshop, and were then stored. A series of pre-processing operations were then undertaken to prepare the imagery for future analysis. An initial operation removed extraneous black perimeter pixels that were a reflection of the cardboard slide mount. This reduced the files to approximately 1,380,000 screen pixels.

Next, the images were normalized to re-distribute the color ranges within those scenes. This produced a revised collection of images with comparable color relationships, and ensured that the extracted signatures represented the tree's color characteristics and were not a function of time/date issues. Two normalization strategies were employed. The first applied the mean red, green, blue (RGB) color values from pixel samples extracted from each image's color chart. RGB samples from the center portion of the white, black, red, green, and blue color squares were extracted using Adobe Photoshop. Mean RGB values for each sample were generated. The data were then input into a statistical program (SPSS) for regression analysis. One image (Mid19) was designated the control. The other images were regressed to its color properties. The resulting regression equations were then applied to each of the scanned photographs, using image processing software (ERDAS). Regression results for four selected images are given in Table 1.

A second normalization technique was applied to images that were photographed when the Macbeth color chart was unavailable. This approach utilized the mean RGB values of specific site objects (signs, rocks) which were common to both the control image, and the image to be normalized to the control. Samples were extracted from non-shaded central portions of these objects, with a minimum of 16 pixels per sample. Care was taken not to include mixed pixels signifying an edge between two objects. The mean RGB values per sample were extracted, and the resultant data were used in a regression analysis (using SPSS). The sampled images were subsequently regressed to the control scene. Following the methodology described in the first normalization effort, the resultant regression data were used in ERDAS to correct the images to the control (Table 2). Subsequent extraction of red,

Table 2. Regression Equations for Image Mid12 Normalization to Mid13, and for Image Mid28 Normalization to Mid19

Image	Band#	RGB	Slope Band Intercept	Standard Error
Mid12	Band1	Red	(0.956 * x1) + 9.041	4.15
	Band2	Green	(0.913 * x2) + 20.17	3.89
	Band3	Blue	(1.114 * x3) + 7.61	4.90
Mid28	Band1	Red	(1.198 * x1) + (−8.528)	3.66
	Band2	Green	(1.178 * x2) + (−23.759)	4.12
	Band3	Blue	(0.932 * x3) + (−6.595)	4.39

Band# = Band number, RGB = red, green, blue, Slope = slope of regression equation as calculated by SPSS, Intercept = y-intercept of regression equation as calculated by SPSS, Standard Error = standard error per-band as calculated by SPSS, Mid12 = Midway Face Photographic Position 12, Mid28 = Midway Face Photographic Position 28, x1 = each Individual Pixel in Band 1, x2 = Each Individual Pixel in Band 2, x3 = Each Individual Pixel in Band 3.

green, and blue color values and digital analysis of image characteristics utilized the image processing capabilities within Adobe Photoshop.

GIS Database

GIS line and point coverage was developed for the Midway Face study site (Figure 2). Initially, line information was digitized from USGS 1:24,000-scale 7.5-minute maps using AUTOCAD 10.0 on a microcomputer. Site data (contours, roads, streams, trails, forest edges) were placed in individual layers. Next, point data were generated for (1) the coordinates from the photographic survey, (2) the survey control points, and (3) the data for the 5000 surveyed trees. Individual drawing elements were separated and transferred to an ARC/INFO environment, where the data were converted to vector and point coverage. The coverage then underwent a series of transformations to convert it to metric equivalents. Because the tree data were based on an internal coordinate system, it further required a conversion to change it to a UTM relationship. After that conversion, several erroneous tree coordinates were eliminated. This reduced the list to a total of 4473 individual trees.

The GIS coverage was then extended using ARC/INFO's surface modeling module to produce a series of three-dimensional (3D) surfaces for the Midway Face site. An initial strategy was implemented whereby the contours were transformed to point coverage, and the converted points within the tree survey area were removed. These points were replaced with the tree survey's 4473 ground coordinates. To illustrate the 3D form of each tree within the study area, each tree's height attribute was applied to these ground coordinates to elevate the points to simulate the height of each tree. A set of surfaces was then constructed to delineate the location and spatial distribution of selected groups of Engelmann spruce, applying a bump-map type methodology (Gimblett, 1990). Using these surfaces, selected tree masses were later manipulated to simulate a 3D collection of trees in their appropriate geographic registration.

Analysis of Reflectance Characteristics

The normalized images were separated into groups for further processing to investigate any color shifts within each image, due in part to the following: (1) color changes at different times of a day when observed from a single camera/target relationship, (2) color shifts over a 12-month interval, (3) color shifts when observing a forest target from different observer positions, and (4) color transitions within a scene due to the impact of a bark beetle event. In each investigation, pixel samples were extracted from portions of sunlit vegetation in each scene and were analyzed for their RGB color characteristics. Data from individual scenes were compared with corresponding samples from other scenes, or other portions of the same scene, to assess the recorded color changes that took place.

Color Changes at Different Times of Day

Three digital images were selected from the Midway Face site for analysis. The images were captured from the same camera position, using the same camera bearing, but at 10:00 AM, 12:40 PM, and 3:00 PM. Weather conditions remained constant for the entire photographic session; thus, shifts in solar orientation were the primary cause of color variation. Because the goal was to measure scenic color changes as they occurred, no image normalization was conducted. Five pixel samples were extracted from each image. The sampling created clusters of identical size from the same portions of all three images. Care was taken to insure that conforming samples were extracted from the images. The mean RGB color values were recorded, and are presented in Figure 3.

Across the three color regions, the tree samples showed peak reflectance at 12:40 PM. Lowest recordings in all three bands for coniferous vegetation were recorded at 3:00 PM. Generally, the red and green bands displayed higher digital values and larger spectral swings than did the blue band. This verifies similar findings documented during image preprocessing. Because blue reflectance is typically lower than the red or green, it cannot display the variability in digital value as compared to the red or green measurements. For comparative purposes, solar data pertaining to the sun's zenith angle, elevation, and azimuth were computed for the photographic periods. These data illustrated peak elevation and azimuth recordings at the approximate time of the 12:40 sampling interval. This confirmed the noon-time peaks in the sampled reflectance of coniferous vegetation.

Color Changes Over a Twelve-Month Period

Two normalized images, Mid12 and Mid13, were selected to document the RGB changes that occurred within the images' coniferous vegetation over a 12-month period. The images were photographed on 19 July at 10:40 AM in 1993 and at 10:30 AM in 1994. The same camera position and bearing

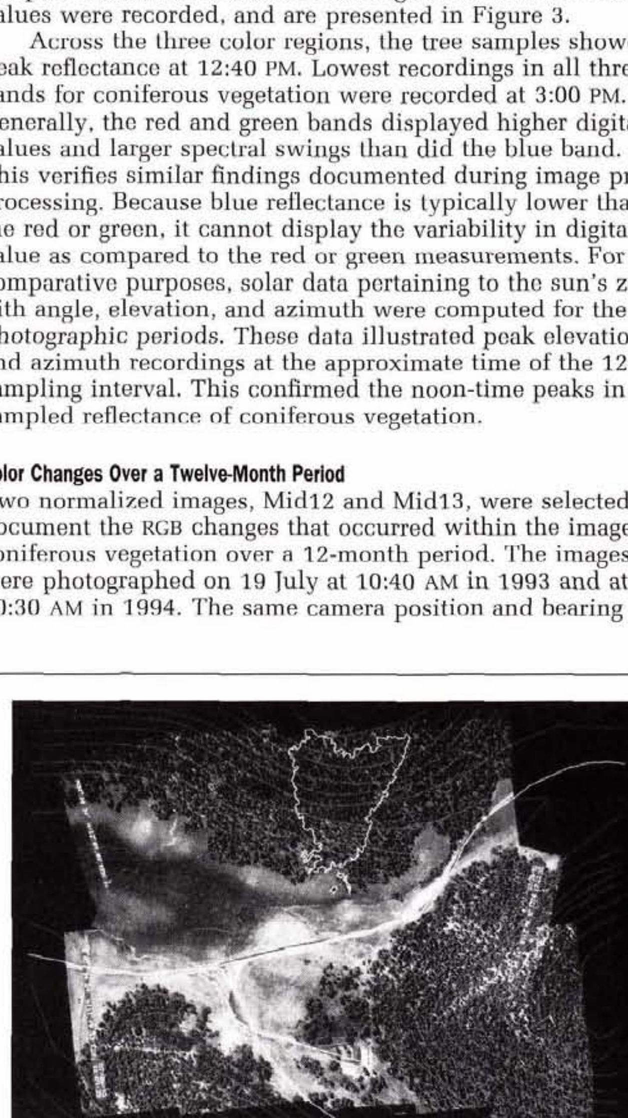
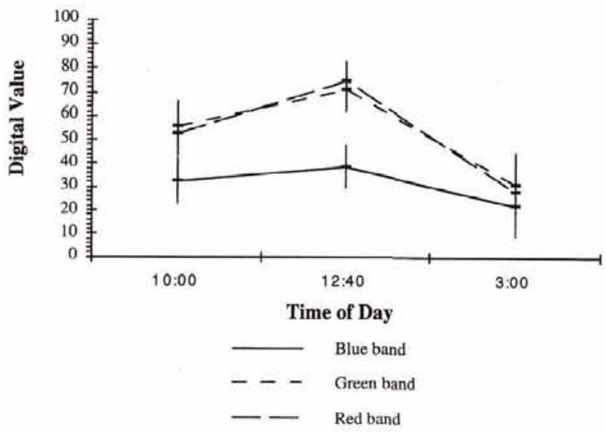


Figure 2. A plan view illustration of the GIS point and line coverage for the Midway Face study site (white irregular boundary) and surrounding landscape, including the 40-metre contours, spot elevations, existing roads, streams, and trails. These data are displayed over an aerial video mosaic (blue, green, and red bands) of the study site and surrounding region.



Summary of Graphed Data for Three Times of Day Investigation

		10:00 AM	12:40 PM	3:00 PM
Blue	Average Mean:	32.56	38.65	21.61
	Standard Deviation:	09.41	08.93	12.91
Green	Average Mean:	55.70	70.96	30.78
	Standard Deviation:	10.36	09.28	13.99
Red	Average Mean:	52.80	74.38	27.72
	Standard Deviation:	09.54	08.35	12.23

Figure 3. Blue, green, and red band mean color values and standard deviations from pixel samples of three scanned photographs from Midway Face, taken from identical camera-target relationships at three time periods in a single day.

was used both years. Rectangular pixel samples of similar size from the same relative portions of both images were extracted and reviewed. While extraction of exact equivalents was not possible, care was taken to insure that corresponding samples, per year, were obtained. A diverse collection of scenic elements from both images was extracted to produce a wide sampling of vegetation. Mean RGB color values per sample, and change relationships are presented in Table 3.

Field observations verified that a minimum of biological change occurred at Midway Face between 1993 and 1994. The mean RGB values (Table 3) generally confirm this finding. While the sample data increased in value from 1993 to 1994, no major shifts in reflectance are evident. More importantly, no major relational changes between color bands are apparent. As previously discussed, insect activity alters tree color relationships whereby the RGB values become more correlated, producing a gray tone in the canopy. The color samples from the 1994 Midway Face imagery did not show a shift towards color correlation. Beetle activity, therefore, had not severely impacted the color relationships over the time interval. A second question to address is the degree of error, per-band, registered during image normalization. The standard error of the regression lines in all three bands exhibited values of approximately four digital values. Spectral gains observed in 1994 might, therefore, be influenced by the margins of error created during image normalization.

Same Target — Different Observer Locations

Two 1994 images, Mid20 and Mid21, were selected to measure the shifts in color values occurring when a target is viewed from two camera points at the same time of day (12:45 PM). Because the goal was to measure the color shifts as a result of view angle differences, normalization procedures to balance the images' color relationships were not implemented. Pixel samples were extracted from sunlit vegetated portions of the two images. The sampling created pixel clusters of similar sizes from equivalent portions of both images. Mean RGB values from the recorded samples, the actual digital shifts, and the percent change between the two observer positions are presented in Figure 4. Differences in camera/target orientations produced measurable changes in the values recorded in all three color bands. Generally, the bearing of South 30° West displayed lower color values than the camera/target orientation of South 30° East.

Color Variation Related to a Bark Beetle Event

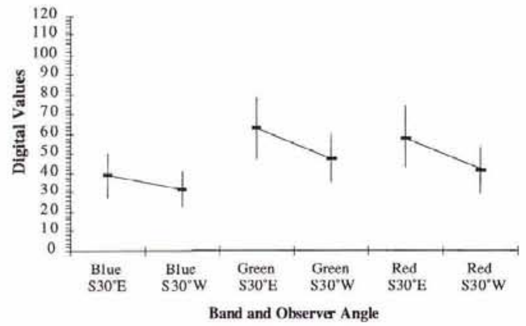
Equating color differentials to environmental events requires both a mechanism to discriminate color shifts, and a knowledge of conditions indicative of those changes. To document the locations of color shifts caused by *Dendroctonus rufipennis*, Forest Service personnel were asked to identify the locations, extent, and estimated age of beetle activity at the Sidney Valley site. After this analysis, two images, Sid1 and Sid3, were selected for articulating color shifts indicative of a beetle event at incremental stages. Both images were previously normalized; therefore, additional pre-processing was not required. The beetle activity, as identified by the Forest Service, was then located within both Sid1 and Sid3. Three general ranges of beetle activity were identified: (1) healthy or visibly unaltered trees, (2) fader trees with infestation at the 1- to 2-year level, and (3) advanced faders with visible damage 3 to 5 years old but not yet losing their main branches (Figure 5).

Pixel samples were extracted from the three ranges, using only the sunlit portions of individual trees. Care was taken not to include woody tree portions or voids with shadows. The mean RGB values were recorded per sample, and averages of the mean values were then computed (Figure 6 and Table 4). Mean color differentials were then computed to produce

Table 3. Mean Color DN Values for 12-Month Investigation

Sample Description	Band	Mid12 (1993)	Mid13 (1994)	Change 93–94	% Change 93–94
1. Left Tree in Tree Island	Red	61.19	65.41	+4.22	6.9%
	Green	76.11	78.68	+2.57	3.4%
	Blue	33.86	38.80	+4.94	14.5%
2. Tree Behind Tree Island	Red	52.13	58.60	+6.47	12.4%
	Green	64.23	68.64	+4.41	6.8%
	Blue	39.38	44.82	+5.44	13.8%
3. Tree East of Tree Island; Lower Right	Red	63.28	64.88	+1.60	2.5%
	Green	80.63	79.13	−1.50	1.8%
	Blue	40.61	44.78	+4.17	10.3%
4. Large Patch of Trees; West of Sample #4	Red	51.25	56.78	+5.53	10.8%
	Green	65.68	68.92	+3.24	4.9%
	Blue	40.82	46.72	+5.90	14.4%
5. Large Patch of Trees: East of Sample #4	Red	48.95	53.69	+4.74	9.7%
	Green	63.93	66.69	+2.76	4.3%
	Blue	39.79	46.07	+6.28	15.8%
6. Large Patch of Trees; West of Tree Island	Red	46.73	52.36	+5.63	12.0%
	Green	61.76	64.63	+2.87	4.6%
	Blue	33.09	38.65	+5.56	16.8%
7. One Tree, East of Snag in Front	Red	52.68	53.79	+1.11	2.1%
	Green	68.97	68.60	−0.37	0.5%
	Blue	35.92	39.09	+3.17	8.8%

Sample Description = general description of location of sample within scene, Band = color band, Mid12 = Midway Face photographic position 12, Mid13 = Midway Face photographic position 13, Change 93–94 = the numeric change in digital values from 1993 to 1994, %Change 93–94 the percent change in digital values from 1993 to 1994.



Summary of Data for Same Target, Different Observer Location Investigation

	Blue Band			Green Band			Red Band		
	S30°E	S30°W	% Change	S30°E	S30°W	% Change	S30°E	S30°W	% Change
Avg. M.	38.87	31.84		62.81	47.43		58.13	41.36	
Std. Dev.	11.75	09.65		15.58	12.29		15.86	12.02	
A% Cng.			-19.43			-22.82			-27.56

Figure 4. The shifts in recorded reflectance per band when identical targets were observed from two different viewer positions. The measurements were acquired from samples of scanned photographs, which were taken at 12:45 PM on 21 July 1994. S30°E = south 30° east, S30°W = south 30° west, % Change = the percentage change of digital value vetween the two view angles, Avg. M. = the averaged means for samples, Std. Dev. = the standard deviation per sample, and A% Cng. = the average percent change for the samples.

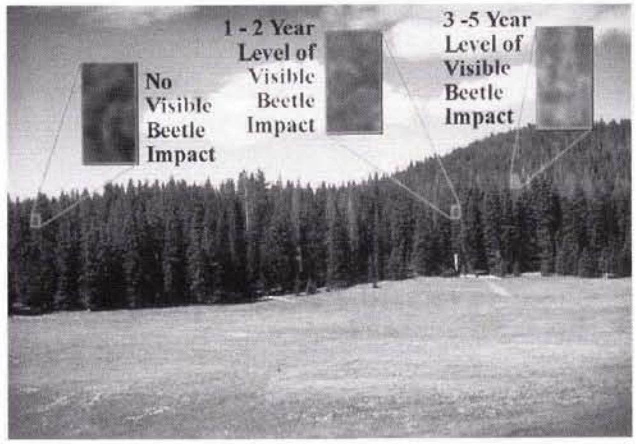


Figure 5. A ground perspective photograph of a scenic view of the study site. Sample data were extracted from this scene that illustrate three general ranges of beetle activity: (1) no visible beetle impact, (2) 1- to 2-year level of visible beetle impact, and (3) 3- to 5-year level of visible beetle impact.

multiplicative factors between (1) the healthy, non- visible beetle levels and the 1- to 2-year level of beetle damage; and (2) the healthy, non-visible beetle levels and the 3- to 5-year level of beetle damage (Table 5). These values represented the statistical changes between the RGB levels of the unaffected and affected samples. In the visualization component, these multipliers were used to simulate color variation representative of the different levels in other, similar landscape scenes.

Development of Reproducible Scenic Simulations

Three inter-related issues were addressed during the data visualization phase: (1) the association of incremental red, green, and blue color ranges to beetle activity levels; (2) the geographic registration of selected color relationships within the image's forested portions; and (3) the final scenic simulation of incremental beetle activity. A two-stage strategy was developed to simulate incremental change, starting at a central point (suggested by Forest Service personnel) within the tree survey area. Color shifts representing a 1- to 2-year insect level, were applied to this central core. Stage two simulated an east-west spreading pattern from this core. In this stage, the center would change from a 1- to 2-year beetle pattern to a 3- to 5-year pattern with crown colors changing to gray tones. As the event spread east and west, the expanded fringe would be given the 1- to 2-year color definition, and the core would be revised to simulate an enlarged section of advanced infestation.

Spectral Association

The first visualization phase applied the RGB corrective multipliers (Table 5) to create revised images with color relationships indicative of 1- to 2-year and 3- to 5-year beetle activity levels. The objective was to manipulate the trees while maintaining the color integrity of the shadows, ground, sky, and voids between trees. Pixel samples of healthy trees were initially extracted from the Sidney Valley image. The mean of each sample's RGB values were generated. Two standard deviations were added and subtracted from this mean to create a maximum/minimum range (based on a digital scale of 0 to 255 per band) of canopy color. These data were then used to isolate tree portions from peripheral elements. The 1- to 2-year corrective multipliers were then applied uniformly to this range to simulate the 1- to 2-year insect color characteristics in the overall forest.

The second visualization task dealt with the 3- to 5-year beetle level. This proved to be problematic as both the colors

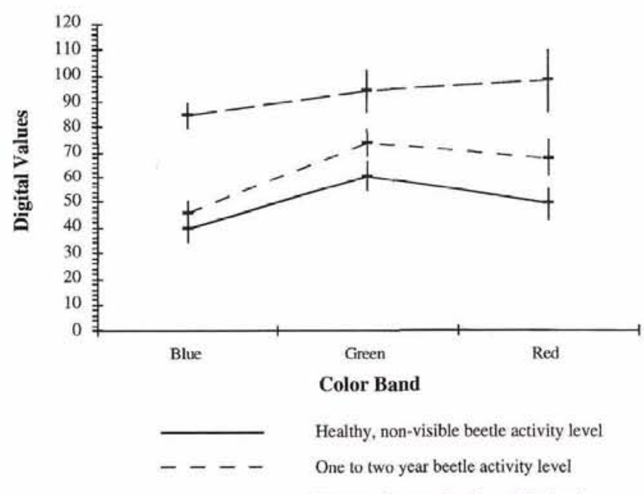


Figure 6. Mean and standard deviation sample data from bands blue, green, and red of the three measured beetle activity levels. The data were obtained from pixel samples of scanned photographs of the Sidney Valley Site.

Table 4. Summary of Sample Data for the Three Increments of Beetle Activity

Sample	Healthy/Non-Visible			One to Two Year Level			Three to Five Year Level		
	Blue	Green	Red	Blue	Green	Red	Blue	Green	Red
Sample1	40.65	56.18	46.53	52.26	72.38	73.46	87.34	99.35	108.78
Sample2	42.19	63.49	53.22	47.78	77.09	71.13	82.27	90.76	100.20
Sample3	31.14	52.96	41.54	46.72	74.80	68.07	81.31	93.57	98.57
Sample4	50.27	70.31	58.60	51.56	79.58	78.37	86.64	90.16	88.87
Sample5	37.10	48.68	36.80	42.46	72.40	64.67	82.60	85.80	85.71
Sample6	32.02	52.73	42.10	47.57	79.63	74.29	80.31	95.75	98.88
Sample7	38.49	64.15	50.13	39.49	71.05	62.29	86.89	90.85	90.71
Sample8	47.70	66.83	55.79	48.48	75.70	68.12	77.82	86.09	84.87
Sample9	37.90	62.16	52.54	48.29	73.42	64.78	85.43	95.35	99.34
Sample10	37.56	63.43	51.58	39.78	63.62	54.14	95.12	114.12	123.52
Sample11	38.11	62.67	48.64	38.87	66.27	58.64			
Sample12	36.16	61.06	50.86	41.53	76.32	65.90			
Sample13	40.65	58.59	49.98	46.37	81.69	78.14			
Avg. Mn.	39.23	60.25	49.10	45.47	74.15	67.85	84.57	94.18	97.95
Std. Dev.	05.35	06.15	06.05	04.55	05.18	07.23	04.86	08.19	11.71

Avg. Mn. = The average value of the sample means, Std. Dev. = The Sample's standard deviation per band and beetle increment.

and their relationships to each other varied from those of healthy trees. An advanced beetle level transforms the canopy, producing a brownish-gray color palette that can not be replicated by applying a uniform corrective multiplier. A different strategy to characterize these color changes was developed. New, smaller samples of unaffected and 3- to 5-year affected trees were extracted from the four normalized Midway Face images (Table 6). From these samples, mean values displayed a shifting proportional relationship between the healthy and the beetle impacted trees. Statistically, green was the dominant color in healthy samples. In 3- to 5-year samples, higher mean values were recorded in all bands; however, the blue and red increased more than the green. This disproportional increase reduced the green's dominance in these samples. Such shifts conform to previous research that predicted higher red reflectance (less chlorophyll absorption) when vegetation is stressed (Heller, 1978; Murtha, 1978; Nelson, 1983).

To simulate a 3- to 5-year color relationship, an additional image processing step was developed. First, the healthy tree pixels were converted to the proportional relationships found in the new samples. Because the green had changed the least from the healthy to the 3- to 5-year level, their relationship was maintained as the control. The red and blue values were then modified, based on the proportions to the green. Mean differences between the green and red, and the green and blue in the 3- to 5-year samples were generated. This produced a multiplier defining the proportional relationships between those colors. The multiplier was applied to the healthy sample's red and blue components to place those pixels in the relationship of the 3- to 5-year trees. The second step raised the overall RGB values of the healthy tree pixels to that of the 3- to 5-year level. A multiplier was developed by dividing the corrected healthy data by the RGB values of 3- to 5-year samples. This multiplier was applied to all tree pixels, thus converting them to a signature association analogous to the 3- to 5-year level. Upon review of the processed images, it was observed that the revised trees seemed artificial with regard to color definition. To rectify these color anomalies, a graduated approach was developed to apply the proportional relationships to the red and blue components (Tables 7A and 7B).

Geographic Registration of Selected RGB Relationships

A series of three-dimensional (3D) surfaces were generated from the GIS line and point coverage. The goals were to develop an articulated surface illustrating the Engelmann spruce within the tree survey area, and then to create a series of perspective views of these data in the same orientation as the scanned Midway Face photographs. The mentioned bump map technique was employed whereby the height attributes from the tree survey were applied to extend the tree points up to their field-estimated heights. In this manner, selected tree masses could be arranged in 3D to illustrate a group of Engelmann spruce with an exact geographic reference. To segregate out only the effected trees for 3D display, Forest Service personnel identified a group of Engelmann spruce centrally located in the study area. This tree cluster was selected as the starting point of the hypothesized beetle event. From that point, projections were made to estimate the position and extent of an event if it were to spread across Midway Face. From these estimations, a series of surfaces were generated to represent the three-dimensional form of the selected trees.

Four DEM perspectives were developed to correspond to the four previously processed images (Mid11, Mid17, Mid19, and Mid28). Each perspective replicated the camera lens, focal plane, and geographic extent of the corresponding image. The grid spacing of the vector DEM was set at 5 metres to provide a surface resolution that represented the terrain's undulation. These perspective views were further divided to include one scene with a central core of Engelmann spruce extended to their projected height, and a second scene which extended that core to the east and west. The views (generated in workstation ARC/INFO) were saved and transferred to a PC platform for future use in Adobe Photoshop.

The revised images with simulated levels of beetle damage were then merged with the associated DEM perspective views. This created a series of composite images, with the DEM wire-frames superimposed over the simulated insect damage (Figure 7). Because the images and the corresponding per-

Table 5. Corrective Multipliers for Simulating the Beetle Increments

1. One to Two Year Multipliers	
Blue Correction	45.47/39.23 = 1.16
Green Correction	74.15/60.25 = 1.23
Red Correction	67.85/49.10 = 1.38
2. Three to Five Year Multipliers	
Blue Correction	84.57/39.23 = 2.15
Green Correction	94.18/60.25 = 1.56
Red Correction	97.95/49.10 = 1.99

The one to two year multipliers were generated by dividing the RGB averaged means of the one to two year samples by the RGB averaged means of the healthy/uneffected samples.

TABLE 6. SUMMARY OF ADDITIONAL RGB PIXEL SAMPLES FROM HEALTHY, UNEFFECTED AND 3- TO 5-YEAR EFFECTED TREES

	3- to 5-Year Effected Trees				Healthy Uneffected Trees			
Sampled Image	Red	Gr.	Blue	Dif.R/B	Red	Gr.	Blue	Dif.R/B
Mid11	78.0	81.1	75.2	02.8	57.9	71.5	50.1	07.8
Mid17	95.8	90.9	79.6	16.2	74.8	84.7	43.8	31.1
Mid19	77.2	76.7	70.4	06.8	59.3	68.1	41.0	18.3
Mid28	90.5	87.6	74.2	16.3	71.8	80.9	50.0	21.0
Avg. Value:	85.4	84.1	74.8	10.53	65.9	76.3	46.2	19.55

Sampled Image = The normalized images from the Midway Face site used to extract additional pixel samples of 3- to 5-year beetle damage and healthy/uneffected trees, Red = Mean red band samples, Gr. = Mean green band samples, Blue = Mean blue band samples, Dif.R/B = The difference in digital numbers between the mean of the red band samples and the blue band samples, Avg. Value = The average of the mean values.

spective views had identical camera-target relationships, image merging produced composite scenes registered to the study's GIS. In this way, the tree groups were positioned on the 3D surface. For the four scenic view points, the following were generated: (1) a composite showing the central core superimposed over the 1- to 2-year simulation, (2) a composite showing the extended tree area superimposed over the 1- to 2-year simulation, and (3) a composite with the central core superimposed over the 3- to 5-year simulation. The new composites were saved for use in the final visualization phase.

TABLE 7-A. TWO-STEP CORRECTIVE MULTIPLIERS FOR SIMULATING THE THREE BEETLE INFESTATION LEVELS: HEALTHY 3- TO 5-YEAR BEETLE LEVEL CORRECTIONS

Image	Mean G/R	Mean G/B	First Cor.R.	First Cor.B.	Sec. Cor.RGB
Mid11	1.039	1.078	1.19	1.32	1.13
Mid17	0.948	1.142	1.20	1.69	1.07
Mid19	0.993	1.089	1.16	1.53	1.12
Mid28	0.968	1.181	1.16	1.37	1.08

Mean G/R = Averaged mean green band value divided by the averaged mean red value, Mean G/B = Averaged mean green band value divided by the averaged mean blue value, First Cor.R. = (the averaged mean green samples of healthy vegetation/Mean G/R) divided by (the averaged mean red samples of healthy vegetagion), First Cor.B. = (the averaged mean green band samples of healthy vegetation/Mean G/B) divided by (the averaged mean blue band samples of healthy vegetation), Sec.Cor.RGB = (the averaged mean red, green, and blue band samples from 3- to 5-year beetle level trees) divided by (the averaged mean green band sample of healthy vegetation/either Mean G/R, the averaged mean green band of healthy vegetation, or Mean G/B respectively).

TABLE 7B. SPECTRAL RANGE FOR APPLYING SECOND CORRECTIVE FACTORS PER BAND

	Mid11		Mid17		Mid19		Mid28	
Range	Mult.	Color	Mult.	Color	Mult.	Color	Mult.	Color
0-30	0.75	R,G,B	0.75	R,G,B	0.75	R,G,B	0.75	R,G,B
31-40	1.31	Red	1.44	Red	1.31	Red	1.36	Red
41-50	1.26	Red	1.39	Red	1.26	Red	1.31	Red
51-60	1.21	Red	1.34	Red	1.21	Red	1.26	Red
61-70	1.16	Red	1.29	Red	1.16	Red	1.21	Red
71-80	1.11	Red	1.24	Red	1.11	Red	1.16	Red
81-90	1.06	Red	1.19	Red	1.06	Red	1.11	Red
91-100	1.01	Red	1.14	Red	1.01	Red	1.05	Red
31-40	1.67	Blue	1.89	Blue	1.67	Blue	1.57	Blue
41-50	1.62	Blue	1.84	Blue	1.62	Blue	1.52	Blue
51-60	1.57	Blue	1.79	Blue	1.57	Blue	1.47	Blue
61-70	1.52	Blue	1.74	Blue	1.52	Blue	1.42	Blue
71-80	1.47	Blue	1.69	Blue	1.47	Blue	1.37	Blue
80-90	1.42	Blue	1.64	Blue	1.42	Blue	1.32	Blue

Range = The image digital range effected by the individual multiplier, Mult. = The multiplier applied to each range, Color = The band manipulated by the specific multiplier, R,G,B = multiplier applied uniformly to all three color bands.

Final Simulation of Incremental Beetle Damage

The composite images were transferred to a PC for final scenic visualization. The original normalized scenes plus the control image were used as the base images for this effort. The image processing strategy was to maintain the integrity of the base images while modifying only those portions that were defined by the DEM perspectives as being areas of simulated change. Generally, the process can be summarized as follows: (1) construct an irregular boundary around the desired tree clusters for both the 1- to 2-year and 3- to 5-year beetle levels/DEM composites; (2) copy this boundary to a clipboard; (3) open the processed images with the two simulated beetle activity levels, and paste the irregular boundary in its appropriate location; (4) using this boundary, isolate and clip the desired tree portions and save these pixels to the clipboard; (5) insert the clipped trees into the appropriate scenes and save as new images; and (6) position the 3- to 5-year beetle levels on top of the simulated trees with the 1 to 2-year beetle levels. Resultant images were made into 35-mm slides using an Agfa Forte film recorder, at a resolution of 4000 horizontal by 2666 vertical screen pixels. Plate 1 illustrates an original scene and a simulated image of damage.

Discussion

Image sampling of scanned photographs provided statistical data to demonstrate significant image change resulting from issues of sun-angle variation, variations due to time of year, dif-

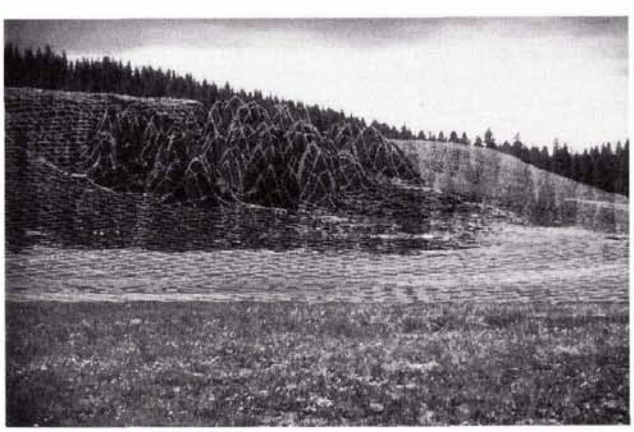


Figure 7. A composite image with the digital elevation model (DEM) wire-frame superimposed over a processed photograph displaying a level of simulated beetle impact.

Plate 1. A dual image of photographic position Img11. The upper image is the normalized scene before any beetle activity has been simulated, and the bottom image displays a simulated hypothetical beetle event spanning a 5-year increment.

ferences in observer-target viewing geometry, and selected environmental change agents. Sampling provided spectral associations, which were later related to field-observed biological changes in the sampled canopies. Data acquired through image processing additionally displayed potential for predicting future events, based on observed color patterns and their scenic associations. In the Utah example, incremental color change was delineated with a measurable degree of consistency. During the scenic visualization component, these measured change conditions were applied to simulate the related biological conditions in other, similar scenes. A set of quantitatively reproducible scenic simulations, illustrating the projected changes to those forested landscapes, was the product of that effort. In the case of change detection based on the bark beetle, spectral analysis was utilized in conjunction with existing maps and GIS data to spatially delineate the color/change relationships associated with the sampled environmental conditions.

The simulated beetle activity was subsequently applied to perceptual testing (Clay, 1995) to determine if untrained observers would rate the simulated scenes showing the different levels of beetle activity on-par with unaltered scenes displaying comparable levels of beetle activity. Results from that testing showed a general reduction in viewer preference that corresponded to a general increase in the amount and severity of the beetle activity visible in the simulated scenes. While additional research is needed to substantiate the preference test results, the recorded correspondence between preference and the simulated levels of beetle activity provides limited support for the methods used to generate the final scenic visualizations.

Conclusions

This research has concluded that considerable care must be taken when developing a photographic inventory for use in a scenic visualization effort. Global Positioning System techniques and GIS registration provided a viable mechanism to locate and catalog each photographic position. This emphasis on accuracy insured that identical camera-target relationships could be maintained throughout the inventory. Additionally, the development of a systematic timetable insured that the acquired photographs could be applied to a controlled sampling exercise that minimized any undesired variation due to solar differentials. While full control over the photography was difficult to achieve, extended care in using identical equipment, film, and processing provided a degree of consistency that rendered the images viable for an image processing effort. Further, the recording of exposures per-photograph, and the screening of each photograph prior to scanning, provided images that were compatible with respect to image brightness and color saturation.

The attention to detail was also extended into the analytical phase. Comparable samples extracted from identical portions of multiple scenes insured that the derived data were valid representations of scenic conditions, and not a function of canopy variation and/or background characteristics. The images' resolution (approximately one-quarter metre squared per screen pixel) allowed for the sampling of discrete portions of individual trees. Isolating trees and tree species, therefore, became possible. Sampling at this detail, however, dictated a greater understanding of the complex shadow patterns within the trees. Previous research (Strahler and Jupp, 1990; Li and Strahler, 1992) addressed similar concerns in a forest condition where voids between the trees created a combined signal of tree reflectance and shadow. While their work was developed at a different scale and view relationship, the analogy could potentially be transferred to the sampling presented here.

The research further concluded that spectral separation requires a consistent level of control to insure that the derived signatures are valid indications of actual conditions, and not a function of processing errors and/or photographic abnormalities. The research has recognized, therefore, the need for extensive image pre-processing to correlate the multiple scenes used during image analysis. This issue is magnified when relating data acquired from multiple platforms at varying distances and angles. Future visualization activities, both ground-based and from aerial sensors, should address issues of color correction and balancing to substantiate the perceptual findings derived from the simulated scenes. Additional improvements in sampling techniques might be achieved by merging remotely sensed data with ground-acquired information. This would allow for data extraction at multiple angles through the application of bidirectional reflectance factors to associate the sample data acquired from different perspectives.

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