The Use of Large-scale Aerial Photography to Inventory and Monitor Arid Rangeland Vegetation

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Abstract:
Interpretation of large-scale color infrared and color aerial photography can be a labor- and cost-effective means to make inventory of and monitor rangelands while maintaining accuracy. Ground measurements of total vegetation cover, tree, shrub and cacti cover at Organ Pipe Cactus National Monument were taken in 1975 and 1984. Estimates of ground vegetation cover made using large scale (1:1200) color and color infrared aerial photography were compared to these ground measurements. High correlation coefficient values exist between color infrared transparency estimates and ground measurements of total vegetation cover (r = 0.972) and shrub cover (r = 0.891). Correlation coefficients were similarly high when matching color prints against ground measurements of total cover (0-976) and shrub cover (0.858). Estimates from color infrared film transparencies corresponded better with ground measurements for both tree and cactus cover, with r values of 0.685 and 0-812 respectively, than the estimates from color print photographs with r values of 0.501 for tree cover and 0.246 for cactus cover.
Keywords: large-scale aerial photography, resource management, rangeland inventory and monitoring, south-western Arizona

Article:

1. Introduction

1.1. RANGELAND MANAGEMENT

Rangelands are a vast and complex resource which occupy approximately 70 million ha (55%) of the coterminous United States, principally in the West (Klemmedson et al., 1984; Poulton, 1975). Rangeland use has increased in response to the growing population of the West, where individuals have further utilized the rangeland for its forage, timber, wildlife, water, minerals, recreation and aesthetic values. Rangeland vegetation must be managed according to recognized goals and objectives issued by governmental agencies; therefore, it is necessary to make inventory of and monitor the vegetation. An inventory is an assessment of what vegetation attributes exist for an area, whereas monitoring detects what vegetation changes have occurred over time. Various techniques are available to make inventory of and monitor rangeland vegetation (Risser, 1984). One technique is the application of large-scale aerial photography.

1.2. PREVIOUS USES OF LARGE-SCALE AERIAL PHOTOGRAPHY

The use of large-scale (generally 1:600 to 1:2000) aerial photographs for a quantitative rangeland inventory and monitoring began in the late 1960s. Previously, its employment in resource management focused on forestry applications, but the demand for more comprehensive and less expensive rangeland management techniques has prompted its expanded usage (Tueller et al., 1988; Warren and Dunford, 1986; Carneggie et al., 1983; Tueller, 1977; Carneggie and Reppert, 1969). To date, the use of this method for arid and semi-arid rangeland vegetation sampling has been infrequent because of a lack of adequate information regarding the accuracy of vegetation measurements taken from the photographs, and because agencies have chosen not to use it. Few studies have evaluated the accuracy of vegetation measurements derived from large-scale photography (Warren and Dunford, 1986).

Remote sensing techniques were first used in range monitoring in the 1930s with the application of ground photography. Vertical and oblique photographs were taken along transect lines of plots to assess the vegetation qualitatively. Repeated over many years, photographic records of plant and ground conditions were assessed for historic comparisons. This technique had partial success in quantifying plant numbers, heights, cover and species composition, but was dependent upon the size, density, height and layering of plants in the community being analysed (Poulton, 1975).

In the mid-1940s, conventional panchromatic aerial photography became widely available and was particularly valuable for illustrating general range conditions and trends over long periods, i.e. 20 or more years (Poulton, 1975; Reid and Pickford, 1944). These photographs were useful because they offered a large amount of information for vegetation mapping, and provided the only record of past range conditions that could compared with similarly scaled photographs taken at later dates.

In the early 1970s, large-scale aerial photography came into general use and emphasized the following points to determine the extent to which (Poulton, 1975): (1) individual plants can be detected and identified; (2) plant parameters such as height, cover, density, number and frequency can be measured or estimated directly from photoanalysis; (3) large-scale aerial photographs taken at intervals of one year or more can be effective in monitoring changes within plant communities; (4) surface soil characteristics such as litter, rock erosion, bareground and soil type can be quantified and detected.

Equipment used for large-scale photographs includes a small low-flying aircraft, either a 35-mm or 70-mm aerial camera, and color or color infrared film. Success is based upon photographic resolution and the interpreter's ability to detect, recognize and evaluate changes present on the photography (Poulton, 1975).

1.3. FACTORS AFFECTING ACCURACY

Photographic resolution and scale are both affected by film type. Interpretations made from color film take advantage of the three-layer emulsion that is sensitive to blue, green and red wavelengths and when processed, the activated dyes in the film may portray actual objects accurately. True surface colors of terrain features are important because vegetation is often identified by correlation with terrain processes. Another benefit is that color photographs have greater exposure and processing latitudes than color infrared. Despite these advantages, either improper processing or exposure may diminish photo resolution power and image color of certain species may be below film spectral resolution capabilities, making interpretation difficult.

Color infrared film has a three-layer emulsion that is sensitive to blue green, red and infrared wavelengths, but the blue light is omitted using a Wratten 12 filter. When CIR film is processed, the resulting photographic colors are blue, green and red. The advantage to CIR film is that it captures the infrared reflectance from vegetation (which shows red on the photograph) and can characterize vegetation phenologic development, vegetation quantity, leaf moisture content and health (Mouat and Hutchinson, 1983; Carneggie and Reppert, 1969).

1.4. RELATED WORK

Driscoll and Coleman (1974) tested the ability of color and color infrared photographs to identify shrub species in different Great Basin plant communities. Their results showed that identification was done with 83% and 76% accuracy using color infrared photography and color photography respectively. The authors also found that color infrared photographs could be interpreted in two-thirds of the time it took for color photos. In a similar experiment in Sonoran desert shrub communities, multiseasonal color infrared photography (1:600) allowed the accurate identification of the major shrub and cacti species (Fish and Smith, 1973).

1.5. STUDY OBJECTIVES

The present study examined the utility of using large-scale color and color infrared aerial photography as a technique to make inventory of and monitor range conditions at Organ Pipe Cactus National Monument (OPCNM) in south-western Arizona. The objective was to determine the effectiveness of large-scale color and color infrared aerial photography for making accurate photographic estimates of total perennial vegetative, shrub, tree and cactus cover.

2. Study Sites

Test sites were chosen in Organ Pipe Cactus National Monument. The Monument, comprising an area of 1345 km^2, was established in April 1937 and is located in south-western Arizona along the international border. Grazing by domesticated livestock occurred from park inception to 1979.

2.1. STUDY PLOTS

This study was limited to nine test plots at three locations: Aguajita Springs, Senita Basin and Dos Lomitas. These plots were chosen because baseline vegetation data and large-scale color infrared aerial photography from late November 1975 were available and coincided with those of Steenbergh and Warren (1977) (Figure 1).

Four 0.1 ha (20 5< 50 m) sample plots were located at Aguajita Springs in the south-western section of the Monument. This section has minimal relief and an elevation of 335 m. The vegetation is classified as an *Atriplex*-desert seepweed community composed of *Atriplex polycarpa*, *Atriplex linearis* and *Suaeda torreyana*. Because of the palatability of the plants to livestock and the availability of water, this site was the most intensively grazed of the three areas.

Three physiographically uniform 0-1-ha plots were located at approximately 520 m in the south central area of the monument at Senita Basin. The flora is representative of the Sonoran Gulf Coast subdivision marked by high species diversity but dominated by *Ambrosia deltoidea* and *Larrea-divaricata*. Neither of these dominant species were palatable to livestock, and, with the exception of a few species such as *Fouquieria splendens*, little grazing forage was available. Nevertheless, because the presence of tinajas (small pools of water found in ephemeral streams) provided a water source, Senita Basin was subjected to moderate grazing pressure.

Two 1.4-ha plots were located in the flat south-western section of OPCNM along the international boundary at an elevation of 425 m. One plot was a control (DLC) while the other was an exclosure (DLX) which had been free from grazing pressure since 1963 (Steenbergh and Warren, 1977). Dos Lomitas' flora supports *Atriplex polycarpa* and *A. linearis*. The vegetation was subject to intense grazing pressure.

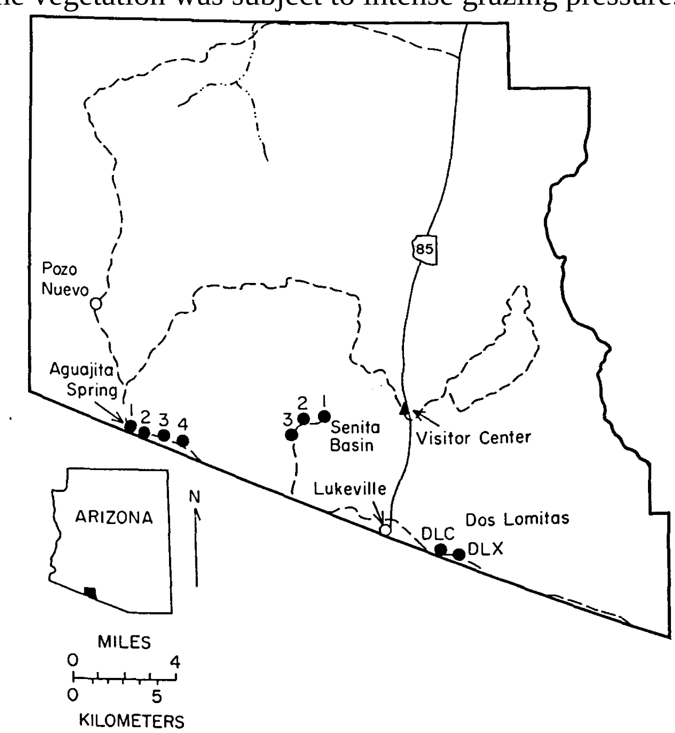

Figure 1. Location of study sites at Organ Pipe Cactus National Monument, Arizona, U.S.A. Roads, (—) paved, (---) gravel.

3. Methods

3.1. AERIAL PHOTOGRAPHY

Photo-interpretation was performed to measure vegetation cover change between 1975 and 1983 for nine study sites. Color infrared 9 × 9 in color transparencies taken in November 1975 and natural color 8 × 12 in prints from October 1983 were studied individually and the results compared. The camera used for the 1975 flight was a 9 in Wild RC 10 with a 6 in lens. The film used was Kodak aerochrome-infrared 2443 (ESTAR BASE), and the photographs were taken from an altitude of 460 m. The camera used for the 1983 aerial mission was a 35 mm Canon F-1 equipped with a motor drive and a 100 mm lens. Every plot was photographed from an altitude of approximately 600 m above mean datum using Ektachrome Professional film 5017 exposed at ASA 64. Both sets of photos were taken on clear days. The scale is approximately 1:1000 for the transparencies taken for plots at Aguajita Springs and Senita Basin and 1:1850 for the transparencies taken of the two Dos Lomitas plots. Each print produced from the 1983 flight had a scale of approximately 1:1200.

3.2. VEGETATION COVER MEASUREMENT ON AERIAL PHOTOGRAPHS

Vegetation cover for all species was measured on the photographs using the dot—grid method. A 100-point dot grid with the dots spaced 0.6 cm apart was used and covered at least one-half of the study area when overlaid on the photographs. The study areas outlined on the photographs were larger than the actual study plots for both Aguajita Springs and Senita Basin. These outlined areas on the photographs encompassed the actual study plots and, using a planimeter, were estimated to be approximately 0.9 ha. These enlarged areas were subjectively chosen to ensure that the homogeneity of the study areas was consistent with the ground study plots. This enlargement of the photographic study area gave a more accurate and representative dot—grid count and assisted with the use of the dot grid.

Each time a dot point coincided with a plant, the point was recorded as being either a tree, shrub, or cactus, so that cover values were apportioned by plant physiognomic type. Species type was not noted. For each site, a minimum of 200 points was recorded.

3.3. VEGETATION COVER MEASUREMENT ON GROUND

Each study plot was also sampled on the ground to determine vegetation cover using the line intercept method outlined by Lindsey (1955). Eleven 20-m line transects, spaced at 5-m intervals for the plots at Aguajita Springs and Senita Basin, and spaced at 17.3-m intervals at Dos Lomitas, were completed.

3.4. STATISTICAL ANALYSIS

Statistical analysis was conducted to evaluate photo accuracy using estimates of vegetation cover derived from dot—grid analysis as the dependent variable and average line transect cover measurements as the independent variable. Correlation and regression analyses were employed to measure the strength and quantitative character of the relationships.

Bivariate analysis was performed between the 1975 color infrared photograph estimates and 1975 ground measurements, and between 1983 color photograph estimates and 1984 ground measurements. Cover percentages (total cover, tree cover, shrub cover, cacti cover) for each of the nine study plots were compared to determine the strength of the relationship. Regression analysis was conducted to examine point scatter from the regression line. Also, because large changes in vegetative cover occurred after livestock removal, correlation and regression analyses were performed to determine the utility of large-scale photography for detecting these changes. Cover percentage for each of the color infrared transparencies and the color prints were separated into four categories: total cover, shrub cover, tree cover and cacti cover. These divisions then were compared with their respective classes from the data gathered from ground measurements.

4. Results and discussion

4.1. TOTAL COVER

A significant correlation exists ($P < 0.05$) between photographic estimates and ground measurements of total vegetation cover for both film types (Table 1). Both correlation coefficients (r) indicate exceptionally strong relationships.

TABLE 1. Comparison of aerial photographic estimates and ground cover measurements in 1975 and 1983/1984

Vegetation feature	Regression equation	r	P (H_o:r=0)
1975			
Total cover	$y=1{\cdot}393+0{\cdot}881x$	0·972	0·01
Shrub cover	$y=2{\cdot}820+0{\cdot}766x$	0·891	0·01
Tree cover	$y=1{\cdot}012+0{\cdot}647x$	0·685	0·05
Cactus cover	$y=0{\cdot}011+0{\cdot}453x$	0·812	0·01
1983/1984			
Total cover	$y=0{\cdot}049+0{\cdot}978x$	0·976	0·01
Shrub cover	$y=4{\cdot}690+0{\cdot}690x$	0·858	0·01
Tree cover	$y=3{\cdot}050+0{\cdot}771x$	0·501	>0·1
Cactus cover	$y=0{\cdot}103+0{\cdot}133x$	0·246	>0·1

For both sets of photographic/ground measurement comparisons, photo-interpretation underestimated vegetation cover for six of the nine study plots by 1-6%. Over-estimates were no greater than 5% and occurred only in three plots that had large stands of annual grasses and forbs. Over-estimation was a result of an inability to distinguish shorter vegetation features on the photographs. The separation between perennials and annuals is difficult when the annuals are closely interspersed with perennials. Coloration of the annuals gave them a photo tone similar to some of the perennials. The darkened photo tone of careless weed (*Amaranthus palmeri*) was not clearly distinguished at the Dos Lomitas plots from the two species of saltbush (*Atriplex linearis* and *A. polycarpa*). At plot 1 at Aguajita Springs, the numerous annual grasses such as six-weeks fescue (*Festuca octoflora*) created the appearance of dense vegetation cover. This caused perennial plants to appear to cover a larger area than they actually did because of the inadvertent inclusion of the fescue.

TABLE 2. Vegetation cover by groups in 1975 and 1984 based on ground measurements

Plot name	Percentage (%)							
	Total cover		Shrub cover		Tree cover		Cacti cover	
	1975	1984	1975	1984	1975	1984	1975	1984
AS1	3·43	18·85	3·43	18·85	0·00	0·00*	0·00	0·00*
AS2	10·51	23·11	10·51	23·11	0·00	0·00*	0·00	0·00*
AS3	16·64	21·98	12·91	19·70	4·18	1·80	0·27	0·48*
AS4	9·75	17·20	8·52	15·72	1·23	1·27*	0·00	0·21*
SB1	32·72	47·85	26·47	40·71	4·24	5·18*	2·01	1·96*
SB2	21·86	38·88	19·90	37·68	0·00	0·00*	1·96	1·20*
SB3	28·42	40·40	19·37	32·02	7·98	7·93*	0·89	0·45*
DLC	7·47	15·09	3·78	11·99	3·68	3·05*	0·01	0·05*
DLX	16·27	20·53	11·20	14·58	5·07	5·49*	0·00	0·36*

*Indicates insignificant differences ($P>0{\cdot}05$) in vegetation cover between 1975 and 1984.

Every plot has experienced a large increase in the vegetative cover during the last 9 years, primarily due to increased shrub cover (Table 2). Absolute increases in total vegetation cover were compared with photographic estimates and ground measurements to indicate how effective aerial photography is for determining trend. Again, the correlation coefficient for these matched values was high, indicating a strong relationship. (Table 3).

4.2. TREE COVER

The correlation coefficients between aerial photographic estimates and ground measurements of tree cover were moderate when using color infrared film, and insignificant when using color prints (Table 1). The large difference in accuracy may be attributed to several factors. Because color infrared aerial photographs were taken in late November 1975, most of the tree species common to this region, especially mesquite (*Prosopis juliflora*) and foothill paloverde (*Cercidium microphyllum*), had lost most of their leaves. Trees without their leaves are much easier to identify because their structural patterns were more recognizable, causing a greater distinction between tree shadow and actual tree cover. The color photographs were taken in October when most of the trees had a full-leaf canopy. This full canopy caused interpretation difficulties because no distinction between some of the smaller trees and larger shrubs, such as creosote and ocotillo, could be made. In addition, shadows cast by trees on the color photographs were not as well-defined as the shadows cast by the trees on the color infrared transparencies, creating a problem of interpreting between shadow and tree.

TABLE 3. Relationship between photographic estimates and ground measurements of vegetation change between 1975 and 1983/1984 at OPCNM

Vegetation feature	Regression equation	r	P (H_0: $r=0$)
Total cover	$y=1{\cdot}661+1{\cdot}151x$	0·936	0·01
Shrub cover	$y=0{\cdot}673+0{\cdot}717x$	0·774	0·02
Tree cover	$y=2{\cdot}452+0{\cdot}999x$	0·336	<0·1
Cactus cover	$y=0{\cdot}159+0{\cdot}255x$	0·203	<0·1

Another factor contributing to the apparent difference in accuracy between the two sets of photographs is the amount of vegetation cover. The 1975 transparencies were taken during a period of severe vegetation denudation. Most palatable plants had been severely overgrazed and could be found only as isolated vegetation components. By 1983, the area had recovered partially from grazing pressures and had a robust plant population. Cover had increased significantly and almost all plant species had fuller canopies than they did in 1975.

Cattle often graze intensively around the bases of trees, such as mesquite and foothill paloverde, because the shady conditions allow for an abundance of either grasses or, other soft and palatable shrubs and forbs. The cattle also seek the shade that trees provide and trample the area under the crown. Combined, these two conditions create a small, but intensively-used area around the tree that marks it from other areas. In 1975, this pattern was quite apparent and aided in the identification of trees. In 1983, no marked difference between tree cover and other cover could be found.

The correlation value generated for absolute tree cover percentage change between the 1975-1984 ground measurements and the 1975-1983 photo estimates was low, indicating little ability of the photographs to distinguish tree cover trends (Table 3).

4.3. SHRUB COVER

The correlation coefficient calculated between photographic and ground measurements of shrub cover were much higher than those observed for tree cover (Table 1). The high correlation values may be accounted for by several factors: the nine plots photographed in 1975 were generally void of all grass cover; with only a few exceptions, most plots had less than 1% grass cover in 1983; grass cover can make the detection of shrubs difficult, because the background contrast is greatly diminished; because there was little grass cover, this contrast was quite strong.

The fact that many of the shrubs are evergreen also contributed to the high correlation values. No difficulty was encountered distinguishing between cactus and shrub cover. Shrubs had strong structural characteristics which were consistent on both the 1975 and 1983 photos, even though the photographs were taken in different months.

At both the Aguajita springs and Dos Lomitas plots, a limited number of shrub species exist, primarily saltbush, ocotillo, desert seepweed and creosote. Because there were few species, and because these species were structurally and tonally distinct, identification was relatively simple. The plots at Senita basin had more shrub species and identification of shrubs became slightly more difficult.

The correlation coefficients of absolute shrub cover change observed among ground measurements between 1975 and 1984 and aerial photographic estimates between 1975 and 1983 expressed a strong relationship (Table 3). This indicates that large-scale aerial photography can be used to estimate short-term changes in shrub cover.

4.4. CACTUS COVER

The correlation coefficients calculated between photo estimates and ground measurements of cactus cover were different for the 2 years. The correlation coefficient for color infrared transparencies indicated a strong relationship, but the color prints had a weak relationship (Table 1). Several causes could be attributed to this difference. In 1975, many shrub species were severely overgrazed, resulting in smaller shrub size. The cactus species, on the other hand, were seldom touched and remained in their natural state. Since size is an excellent way to separate cactus from shrub species, this aspect was enhanced in 1975. In most instances, there was a clear distinction between cacti and shrubs. In 1983, the palatable shrub species had increased in size, which helped with distinguishing between the cacti and shrubs.

Cactus species, such as pencil cholla (*Opuntia leptocaulis*), buckhorn cholla (*Opuntia acanthocarpa*), jumping cholla (*Opuntia fulgida*) and saguaro (*Cereus giganteus*), are often found within the canopies of many of the shrub and tree species within OPCNM, because they provide more favorable growing conditions. Because of this, many of the cactus species were difficult to locate on the color prints. In contrast, shrubs were smaller in 1975, and the understory around trees was less, so that cactus species were more easily observed.

Color infrared photography was more sensitive to tonal differences among species than natural color, and was especially helpful where the cactus species were growing within the shrub species canopy. Whereas identification of cactus species was nearly impossible on the color prints, it was relatively simple with the color infrared transparencies. The correlation coefficient between photographic estimates and ground measurements of absolute cactus cover change from 1975 to 1983/1984 was low (Table 3).

5. Conclusions

Total vegetation cover derived from large-scale color and color infrared aerial photography provides accurate estimates of ground vegetation and no significant differences in accuracy were found between film types. Photographic estimates of tree cover were much lower than ground measurements. However, color infrared photographs measured tree cover more accurately than natural color prints, but the relationship between aerial photographic estimates and ground measurements of shrub cover were strong for both color infrared and natural color photographs. Photographic estimates did not accurately duplicate ground measurements of cactus cover. Color infrared transparencies were superior (r = 0.81) to color prints (r = 0.27) when used to identify cacti.

Absolute change in total vegetation cover and shrub cover between 1975 and 1983/ 1984 photography was accurately measured. The small changes in tree cover and cactus cover were not detected on the photographs.

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