and crude fibre of both grasses and legumes. Protein content decreased as the fibre content increased. Statistics related to these negative correlations existing between the content of crude protein and crude fibre are as follows, where Y = crude fibre and X = crude protein:

Species	Prediction Equation	Sy.x	r
Grasses	Y = 43.46 — 1.01 X	3.41	—0.716**
Legumes	Y = 48.01 — 1.24 X	2.38	—0.904**

It was previously reported by Hutton (1961), and Kamstra *et al.* (1966) that such a negative correlation was also found between the content of crude protein and crude fibre or lignin.

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(d) Aerial photography of native vegetation

Identification and measurement of herbland and shrubland vegetation from large scale aerial colour photographs

RICHARD S. DRISCOLL,[1] JACK N. REPPERT,[1] ROBERT C. HELLER,[2] and DAVID M. CARNEGGIE[3]

1 Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture, Fort Collins, Colorado, U.S.A.

2 Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture, Berkeley, California, U.S.A.

3 University of California, Berkeley, California, U.S.A.

Summary

Individual herbaceous and shrubby species can be identified most accurately on large scale (1 : 600–1 : 1,100) colour infra-red aerial photographs. There was no apparent advantage of this film type as compared with normal colour film for identifying non-vegetation characteristics in herbaceous and shrubby plant communities. Site delineation, as inferred by the plant community, can be equally well defined on either film type at a scale of 1 : 4,200. Species density and foliar cover can be estimated from this type of aerial photography within acceptable error limits. Colour infra-red photographs should be used for this purpose owing to the increased accuracy of individual species identification. A scanning microdensitometer can be used for automated interpretation to measure total vegetation cover and to discriminate between broad vegetation types. The microdensitometer does not yet seem suitable to identify individual species.

Introduction

Conventional black and white panchromatic aerial photographs (scale 1 : 20,000) have been used extensively for mapping general vegetation types. The available photographs were usually of average quality and may not have represented ground conditions by the time they were used, owing to changes in vegetation caused by use or seasonal growth. Identification and measurement of individual herbaceous and shrubby plants were difficult.

Recent improvements in aerial camera systems, coupled with new film types and photo-measurement devices, provide the opportunity to interpret more information about vegetation from large scale photographs than has previously been possible. These improvements also provide a possible monitoring device for surveillance of vegetation over time.

Aerial cameras and film types

Seventy mm format aerial camera systems have been developed with significant advantages over conventional camera systems. They have fast shutter speeds and rapid pulse rates, which produce high resolution stereo photography at scales as large as 1 : 600. They also provide: (1) small size and light weight, (2) rapidly interchangeable lenses, (3) narrow view angles, (4) small format for viewing uncut film with a lens stereoscope, and (5) easy film processing.

Colour aerial photographs provide three colour dimensions—hue, value, and chroma—for interpretative purposes. Hue, value, and chroma refer to the Munsell colour system, which is based on a three-dimensional colour solid corresponding to the physiological attributes of the dominant spectral colour (hue), brightness or lightness (value), and colour saturation (chroma) (Munsell, 1961). An additional feature is introduced when dealing with colour infra-red photography. Image signatures are obtained in false colour from reflected visible and near infra-red energy (0.5–0.9 micron wavelength band). It has been demonstrated that such photographs frequently register differences among objects not visible or difficult to see on conventional photographs (Heller, 1965; Colwell *et al.*, 1963).

The study

Research was initiated in 1967 on the use of large scale (1 : 600–1 : 4,200) 70 mm aerial photography, of the two film types flown at different times during the growing season for identifying plant species, communities, and other habitat features of herblands and shrublands. Additional investigation has involved photo measurement techniques for determining plant density and foliar cover.

Five test locations were selected:

1. A mountain bunch grass type in Colorado at an elevation of 3,000 m. *Festuca thurberi, F. idahoensis, Erigeron macranthus,* and *Geranium fremontii* were the most common herbaceous species.
2. A mixed shrub type in Colorado at an elevation of 2,450 m. *Artemisia tridentata, A. longiloba, Purshia tridentata, Symphoricarpos* sp., and *Gutierrezia sarothrae* were the most abundant shrubs.
3. An open woodland area in Colorado at an elevation of about 2,250 m. *Pinus edulis* and *Juniperus scopulorum* provided the general aspect. *Cercocarpus montanus* and *A. tridentata* were common understory shrubs.
4. A timber-grassland area in Colorado at an elevation of 2,350 m. *Bouteloua gracilis, Festuca arizonica, Artemisia frigida,* and *Antennaria* sp. were the most abundant species in park-like openings.
5. A timber-grass-shrub area in California at an elevation of 1,220 m. Grassland parks were typified by *F. idahoensis, Sitanion hystrix, Carex exerta,* and *Poa secunda.* The meadow areas supported mainly species of *Poa* and *Carex.* Different shrub stands were composed primarily of *A. tridentata, A. arbuscula, A. cana,* and *P. tridentata.*

Flight lines from 75 to 1,400 m long were established and marked on the test locations. Specific items were marked on the ground to provide positive identification, provided they were detectable in the aerial photographs. Plot areas 6 m square and line-transects 6 m long were marked on the ground to estimate foliar cover and plant density.

Dual mounted 70 mm aerial cameras were used to obtain imagery of the selected areas. Each camera was loaded with a different film type. They were pulsed simultaneously to assure synchronous coverage of the same area. Film types used were Anscochrome D-200 exposed with a Wratten 1-A skylight filter, and Ektachrome Infra-red Aero exposed with a Wratten 12 filter. The film was processed to positive transparencies.

Photo missions were flown four times during the plant growing season. Selection of these flight times was made on the basis that no single time period could be expected to provide optimal data for the test sites.

Results and conclusions

Species and site identification

Photographic image characteristics selected to evaluate the two film types for differentiation of species and community types were pattern, texture, shadow, shape, relative size, and colour. Results of selected examples of interpretation tests are given in Table 1.

Table 1. Percent correct identification of species on 70 mm Anscochrome D-200 and Ektachrome Infra-red Aero Film

Species	Film type	
	ANS-D-200	EIR
Herbaceous[1]		
Antennaria sp.	10	80
Bouteloua gracilis	10	10
Muhlenbergia montana	10	10
Festuca arizonica	80	80
Artemisia frigida	25	85
Erigeron flagellaris	85	60
Shrubs[2]		
Cercocarpus montanus	75	100
Purshia tridentata	80	90
Artemisia tridentata	95	95
Artemisia longiloba	25	75
Symphoricarpos sp.	25	75
Chrysothamnus sp.	25	75

[1] Based on 1 June 1968, photography, Colorado timber/grassland type, scale 1 : 600, one interpreter
[2] Based on 24 August 1967, and 3 August 1968, photography, Colorado mixed shrub and open woodland types, scale 1 : 1,100, average of two interpreters

Colour infra-red photographs appear best for herbaceous species identification. The low percentages for *B. gracilis* and *Muhlenbergia montana* occurred because they are late-developing species. The other species were early-developing, producing green plant material at the time of photography, which provided discriminate image differences. An exception to the "best" film type was *Erigeron flagellaris*. This small, mat-forming species had small green leaves at the time of photography and often was confused with bare soil in the colour infra-red photos. The colour-photo images of these two objects were sufficiently different to provide better discrimination. Generally, any plant less than 10 cm in diameter could not be resolved in either film type at the 1 : 600 scale.

Relative plant height and colour were the best discriminating characters for shrubs. With *A. tridentata,* these characters could be distinguished as easily on both film types. All other shrubs were more easily identified on colour infra-red photos.

No advantages of either film type to detect and identify non-vegetative characteristics, such as bare soil or soil disturbances, were apparent. When the plant community was used as a site indicator, there were no apparent advantages favouring either film type to differentiate sites on 1 : 4,200 scale photographs. However, colour infra-red photos offered possibilities for identifying individual large shrubs.

Generally, mid-summer (July and August) photography provided the best opportunity for discrimination among most plant species and communities. There were instances, however, when late spring (June) or early fall (October) photography gave needed information on early or late developing species.

Photo measurements

A scanning microdensitometer was used to measure the colour infra-red transparency densities of various species and plant communities to be related to ground measurements. This instrument senses density in the transparencies by means of a light beam passed through the film specimen onto a photocell. A strip-chart recorder is activated to produce a continuous density trace of a predetermined scan line marked in a transparency.

Although the mean densities of selected species appear to separate, the density ranges of the species indicate this method is not feasible for automatic image interpretation (Table 2). However, the differences between bare soil and cover of live vegetation indicate the system is capable of automatically separating these two categories.

To test the separation of plant communities, scan lines from grassland to deciduous forest to coniferous forest on 1 : 4,200 scale colour infra-red film exposed in August were generated by the instrument. The communities separated on the basis of film density readings and density frequency amplitudes of these images. Therefore this system, in line with direct input to a computer, would provide analytical interpretation for amount and kinds of plant communities. This is a new area of research in which new concepts must be developed and tested.

Table 2. Means, and ranges of transparency density values of colour infra-red images, of 5 shrubs and bare soil, scale 1 : 1,100, photo mission 3 August 1968

Species or object	Film density values Mean	Range
Cercocarpus montanus	3.676	3.15–4.42
Pinus edulis	3.655	3.26–4.12
Juniperus scopulorum	3.266	3.04–3.56
Purshia tridentata	3.169	2.97–3.53
Artemisia tridentata	2.805	2.56–3.00
Artemisia longiloba	2.768	2.62–2.72
Bare soil	2.497	2.44–2.58

Colour and colour infra-red photos exposed over the timber grass-shrub area in California in August at a scale of about 1 : 600 were used to compare photo measurements with ground measurements of shrub intercept. Shrub intercept was defined as the longest horizontal measure across a shrub crown. Forty-eight shrubs consisting of 3 species (*P. tridentata, A. tridentata,* and *Chrysothamnus* sp.) were used for the test. Highly significant correlation coefficients comparing measurements from both film types to ground measurements existed: 0.989 for colour infra-red and 0.991 for colour film. There was no significant difference ($t = 0.95$) of intercept measurements between film types. Therefore, both provide an acceptably accurate method of estimating shrub intercept if the shrub is resolved. Since film cost and cost of processing are similar, it would be feasible to use colour infra-red photos because they are better for identifying shrubs.

Density counts of 5 shrub or shrub-like species in a predefined 16 m × 32 m plot were compared on photographs with actual ground counts for the California area. The 5 species were *P. tridentata, A. tridentata, Eriogonum umbellatum, Leptodactylon pungens,* and *Chrysothamnus* sp. Colour infra-red photos procured in mid-July at an approximate scale of 1 : 600, were used. Based on the average of two interpreters, the percent correct counts were 98, 84, 87, 35, and 50, respectively, for the 5 species. The discrepancy between ground counts and photo counts, a persistent source of error, was due to:

1. Resolution constraints of the film and camera system;
2. Small size of young plants;
3. Lack of sharp contrast between certain shrubs and background;
4. Two or more shrubs growing close together being interpreted as a single shrub on the photograph;
5. Shrubs growing under or within the crowns of others being overlooked.

Significance of the results

Large scale colour infra-red aerial photographs, and to some extent normal colour aerial photographs, have a potential use to improve the definition of the vegetation characteristics of herbaceous and shrubby communities. The system provides for rapid data acquisition which, when coupled with potential automated interpretation, will produce much needed knowledge on the vegetation and ecology of herbland and shrubland areas. It is conceivable that the system would be less costly than ground survey methods, especially in remote areas. Ground truth, however, cannot be overlooked.

The 70 mm system must be considered a sampling tool. The small film format and narrow view angle of the lens do not provide the synoptic view of the landscape otherwise recorded by conventional aerial cameras. Sampling techniques need to be developed whereby 70 mm photography is used to sample strips of the landscape simultaneously photographed on conventional format film.

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