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MEASUREMENT OF SPATIAL AND TEMPORAL CHANGES IN VEGETATION FROM COLOR-IR FILM

by

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INTRODUCTION

When in operation, orbiting satellites, such as those planned for the ERTS Experiments, will have the capacity for following short-term changes in the appearance of the earth's surface. Weather conditions permitting, a large portion of the earth will be observed at intervals of only a few weeks. Most of the detectable variability on land will indicate either changes in snow cover, in soil moisture, or changes in the amount of green plant material. If measured, changes in vegetation that occur within periods of two or three weeks can be used to pinpoint likely areas for livestock grazing, to help identify crop types and wildland communities, and to estimate primary productivity and evapotranspiration in plant communities. Although measurements of the earth's variable plant cover are of importance to many resource management fields, the ability to estimate the amount of green plant material that covers the soil surface or that is supported by the branches of trees and shrubs remains one of the most elusive measures with which biologists and hydrologists must deal. Recent remote sensing research by the U.S. Geological Survey suggests an approach that may alleviate this data gap. We have been working with techniques which can be used whether the sensing vehicles are conventional aircraft or satellites. Data collection is in a form wholly compatible with current computer technology. Although all of our work has been in an arid area, these techniques should apply to any climatic region.

Most remote sensing studies of vegetation have emphasized measurement of spatial variability: for example, plant community mapping (Higer and others, 1970). A few investigators have used remote sensing techniques to measure plant vigor as it is affected by moisture supply, salinity, or disease (Hoffer and Johannsen, 1969). Measurements of spatial variability do not depend upon repetitive imagery. In contrast, evaluation of temporal variability of vegetation requires multiple observations. Aldrich and Heller (1969) observed vegetation changes over long periods of two and three years in diseased forests by rephotographing the same forested stands. They are probably among the first to apply remote sensing techniques to study changes with time in a vegetation canopy. So far, little attention has been given short-term changes occurring over periods of only a few weeks. The reason for this lies in the special problems that arise when attempting to quantitatively compare multiple photographic observations. Preliminary attempts to standardize repetitive color-infrared photographs will be reviewed in this paper. I wish to emphasize that, as hydrologists and plant scientists, we have been mainly concerned with ground-truth acquisition. We recognize a potentially important application for the tools of the photogrammetrist and photographic scientist and hope that specialists in these fields may soon apply existing control and calibration techniques to the solution of data needs similar to ours.

Three years ago the U.S. Geological Survey began observing with aerial photographs a 15-mile reach of the Gila River valley in southeastern Arizona (Fig.1). The purpose was to photogrammetrically evaluate short-term changes in the volume of transpiring plant material and to examine relationships between these fluctuations and variations in several hydrologic parameters being intensively studied in the valley. Ground-truth data collected in this intensive investigation of evapotranspiration include ground-water levels, streamflow, rainfall, soil moisture, temperature, humidity, evaporation, radiation, and plant volume (Culler and others, 1970).

The flood plain at the study site is covered by a growth of saltcedar (*Tamarix pentandra*) of varying density (Fig.2). The adjacent terraces support a short, open forest of mesquite (*Prosopis juliflora*). Nearby uplands are covered by plant communities comprising such xerophytes as creosotebush (*Larrea tridentata*), species of *Acacia*, and various cacti. Stands of each of these plant communities are being studied in our work.

SELECTION OF THE SENSOR

A readily and continuously available sensing system was needed because our program requires observations of plant changes at two- to three-week intervals. Accordingly, photography was selected as the best technique. Since photographic systems are restricted to wavelengths ranging from just below 0.4 μ up to 0.9 μ (Fig.3), this choice narrowed considerably the portion of the electromagnetic spectrum with which we would be dealing. We sought a film or combination of films that could uniquely sense green plant material by taking advantage of the characteristic reflectance of leaves between 0.4 and 0.9 μ. Within this range, typical leaf reflectance spectra reveal two bands (blue and red) that are greatly affected by chlorophyll absorption, plus a band of relatively high reflectivity in the near infrared region (Fig. 4).

A single black-and-white image could not be used, regardless of the filter employed, because a given grey density value produced by green leaves could be duplicated by many non-plant objects. A combination of two or more images, each recording the energy reflected from plants within different portions of the photographic spectral range was necessary. Black and white multispectral photography was considered but rejected because of the difficulty of exactly aligning the separate black and white images when obtaining densitometer readings from the film.

Another obvious possibility was color diapositive film, either as normal color film or as false-color infrared film. Because of their three-layer construction, these films produce, when exposed, three photo images in one--and the images are perfectly registered.

Without going into detail, note should be made of similarities and a basic difference between regular color film and Ektachrome-infrared (EKIR) film. Both take advantage of the fact that light can be broadly divided into three primary colors--blue, green, and red.(Fig.4). Furthermore, all colors can be produced by various combinations of these primary colors. Another feature these films have in common is their three-layer construction with the dye content of the superimposed layers selected to produce various combinations of blue, green, and red color in the image when it is viewed with transmitted light. The important difference between these films lies in the sensitivity of the dyes in the three layers: normal color film is sensitive to the same portion of the spectrum as is the human eye; EKIR film sensitivity is shifted toward longer wavelengths so that blues are excluded while invisible infrared is recorded (Fig.4).

Ektachrome-infrared film was finally selected instead of true color film. Compared to true color film, images of green plants on EKIR film are enhanced and subtle differences between plants are accentuated. This results from the characteristic leaf reflectance properties through the part of the spectral range to which the film is sensitive (Fig.4). As noted by Knipling (1969), the low reflectance of leaves through the visible region is integrated with the high reflectance in the near-IR. Leaf reflectance in these two bands is influenced by two distinct plant systems, one having to do with pigment chemistry, the other with mesophyll anatomy. Both of these systems are closely related to the volume of foliage. Thus, the real advantage of color-IR film over regular color film lies in the ability of the former to sense leaf reflectance in both the visible and near-infrared regions while integrating the effects of two distinct plant traits.

COLLECTION OF THE DATA

The photographs referred to in this discussion were taken from an elevation 8,500 feet above ground with a K-17 camera equipped with a 6-inch focal length Metragon lens. The film used during the portion of the study covered here was Kodak Ektachrome Aero Film (Type 8443) in 9-inch format. The lens was outfitted with a combination of three filters, Wratten numbers 12, CC20B, and CC30M. This combination was selected following a preliminary study in which 23 different filter combinations were tried according to a system suggested by Fritz (1967). The U.S. Geological Survey took the photographs and processed the film. Photographs were taken between 1000 hours and 1400 hours on 14 different dates between late March and late December 1968.

Optical density values were determined from the three film layers by use of a Macbeth digital read-out transmission densitometer, Model TD-402, outfitted with a 3-millimeter aperture. Readings were made with three filters: Wratten filters, numbers 92, 93, and 94, corresponding to the red, green, and blue spectral bands, respectively. Readings from a fourth filter, number 106 (visual band), were used for some analyses. Absorption characteristics of these filters are shown in figure 5.

As seen in figure 6, dyes in the three EKIR film layers possess overlapping regions of sensitivity and a given layer will be somewhat affected by wavelengths other than those in the range of its dominant sensitivity. By use on the camera lens of the three filters noted earlier (Wratten numbers, 12, CC20B, and CC30M), wavelengths below 500 mμ are excluded and the quantity of light reaching the film is slightly altered in the 500 to 700 mμ range to produce a color balance providing maximum detectability of the species with which we are dealing.

In the processed film, the energy received will be expressed as blue, green, or red depending on the layer affected. By using a densitometer, a value that is proportional to this energy can be obtained. Because the dyes in the three layers contribute small amounts of color to spectral regions outside the range of their dominant contributions, a density measurement at any point or band along the visible spectrum will be somewhat affected by all three dyes. In photographic parlance, density values of this sort are called integral densities. What is actually needed, though, is a separate density value for each layer with the effect of the other dyes in the tripack removed. This value is called analytical density. The only way to arrive at the analytical density for a tripack film is to derive the values by computation from integral densities. The analytical density values for the three film layers can be determined by matrix analysis if certain characteristics of the dyes are known and provided the green, red, and blue integral density values are read from the same points on the photograph (hence the critical need for exact registry of the images from which the measurements are made).

In practice, density values are obtained by positioning the densitometer aperture over the film by means of a template. The template serves to exactly locate the sample points within the project grid system. With the 8,500 foot photography (scale = 1/17,000) and with a densitometer aperture of 3-millimeter diameter, each sample point corresponds to an area of 0.20 hectares (0.50 acre). Optical density values using the blue, green, and red filters are read from each 0.20 hectare plot.

ANALYSIS OF DATA

Analysis of repetitive photography presents many problems that arise because of the inescapable changes in photographic conditions from one time to the next. A change in date will usually entail a change in sun angle. If the time of day that the photographs are taken varies, sun angle is again altered. Light intensities vary regularly with the season and randomly with unpredictable variations in atmospheric conditions. Not all the difficulties are related to celestial mechanics or to meteorology, however. Slight changes in film emulsions and in film processing may induce other unwanted effects. Also, variability across individual photographs occurs because of vignetting. As a result of these and still other factors, seasonal differences in color density, attributable solely to changes in plant volume and condition, are confounded with differences due to lack of photographic uniformity. Obviously methods for standardizing and calibrating the photography are essential.

As an illustration of the problems involved, figure 7 shows optical density values obtained from 1300 acres of saltcedar forest as recorded on photographs taken on 14 dates in 1968. Note that the values obtained with each of the filters vary similarly. The red values, which should portray changes in plant volume, are apparently affected by conditions unrelated to this parameter. Obviously an adjustment of the densitometer readings is essential.

To date we have employed few of the controls and calibrations necessary to precisely quantify our measurements and, at best, we are at the semi-quantitative stage. Some of our attempts to obtain standardized measures of plant volume changes will be discussed next.

CONCLUSIONS

An early attempt by the U.S. Geological Survey to normalize the densitometer readings was accomplished by expressing the color densities obtained with the blue, green, and red filters as percentages of the densities obtained with the visual (number 106) filter (Culler and Turner, 1970). Another standardizing procedure has also been examined. This entails calculating analytical densities from the densitometer readings, converting these adjusted values to transmittances and expressing transmittance for each of the red, green, and blue filters as a percentage of the total red, green, and blue transmittance. In figure 8, red transmittance values adjusted in this manner are shown for 14 dates in 1968. To determine how well this approach can discriminate between areas of different plant density, the densitometer readings for three different saltcedar volume classes are shown. Although detailed ground-truth measurements are lacking for this period, the transmittance values agree with general phenologic observations. The increase in red transmittance from March 22 to April 5 was in response to spring branchlet growth. The sharp reduction in values between April 19 and May 3 reflects a frost on April 20 which caused partial defoliation. New growth soon restored this loss and the transmittance values increased abruptly in response. The values slowly declined after the maximum of late August as the slow autumnal defoliation typical of the species took place.

As noted in an earlier section, EKIR film is sensitive to two spectral regions that are influenced directly by the amount and condition of green plant tissue. The standardized procedures explained above emphasize energy reflected in the near-IR range and give little stress to reflectance in the red band where plant pigments absorb heavily. Changes in a plant's physiologic condition often result in reduced chlorophyll content. When this occurs, the color balance on EKIR film changes and leaf images change in color from hues of red to yellow hues. There lies in this relationship additional possibilities for normalizing densitometric values obtained from EKIR film. We are currently investigating these possibilities.

Although only preliminary in nature, the results to date encourage us to continue looking for techniques to improve our data gathering capabilities. We feel that a quantitative, seasonal evaluation of the earth's plant covering is feasible and that the potential benefits are great. Solution of this problem is a dual challenge requiring the special skills of the photographic scientist and the resource manager.

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GLOSSARY OF TERMS

Analytic optical density. The optical density within the spectral range of dominant sensitivity of the individual film layers of a multi-dye layer film.

Ground-truth data. Information acquired independently of a remote sensing system but describing the object or phenomenon observed by the system.

Integral optical density. The total optical density of a multi-dye layer film.

Opacity. The ratio of the incident to the transmitted (or reflected) light.

Optical density. The logarithm to the base 10 of the optical opacity. Optical density in a multi-dye layer film can be described in two ways, analytic optical density and integral optical density.

Transmittance. The reciprocal of the opacity.

Vignetting. The effect of a lens system on a photographic image which produces a fading of the image from the center to the edge of the film.

GILA RIVER PHREATOPHYTE PROJECT
SAN CARLOS INDIAN
RESERVATION, ARIZONA

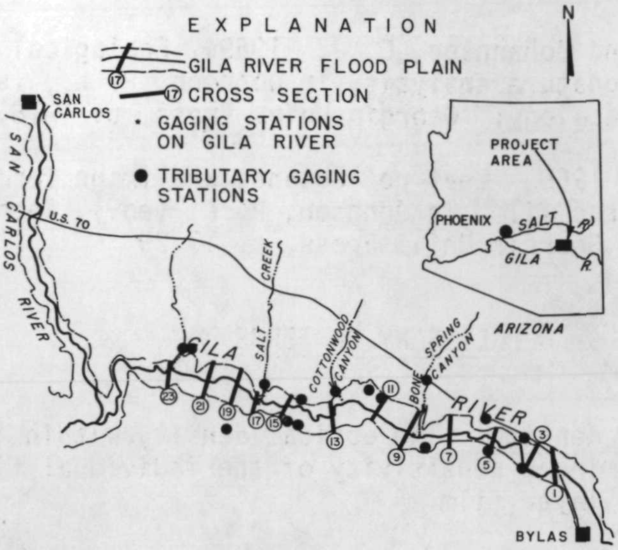

Figure 1.--Map showing location of the U.S. Geological Survey's remote sensing study of vegetation. The numbered cross sections show the location of cleared paths along which instruments for measuring hydrologic parameters are located.

Figure 2.--Unvegetated channel of the Gila River and adjacent flood plain with heavy saltcedar (<u>Tamarix pentandra</u>) growth. Low hills in right mid-ground are sparsely covered with creosote bush (<u>Larrea tridentata</u>) and other desert shrubs.

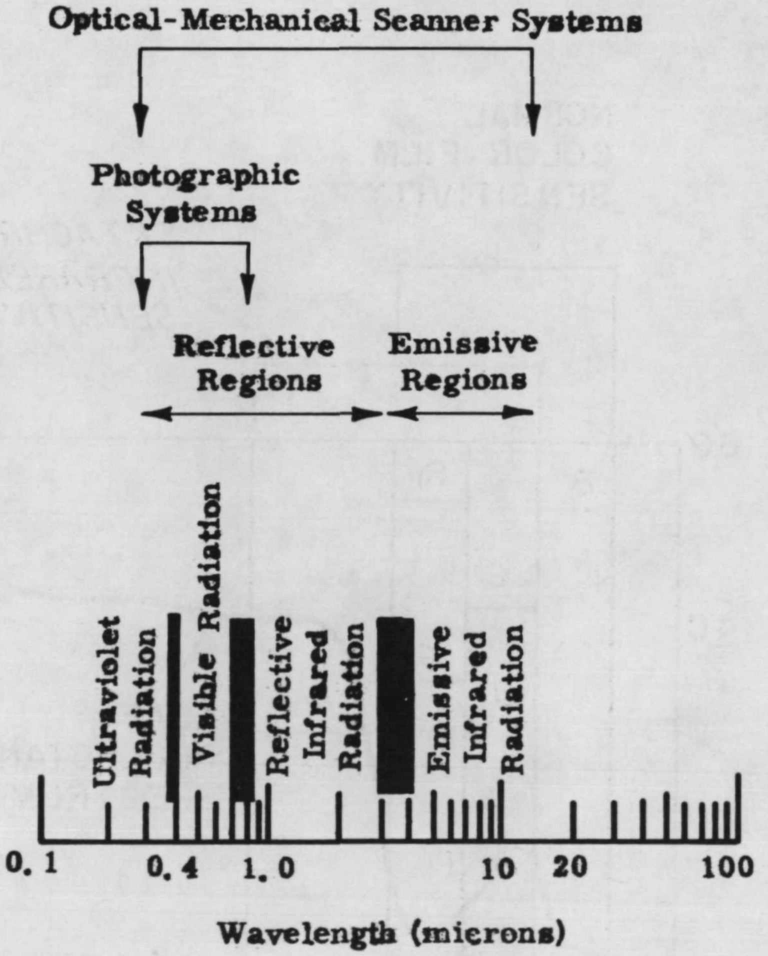

Figure 3.--Portion of electromagnetic spectrum illustrating spectral range of photographic systems.

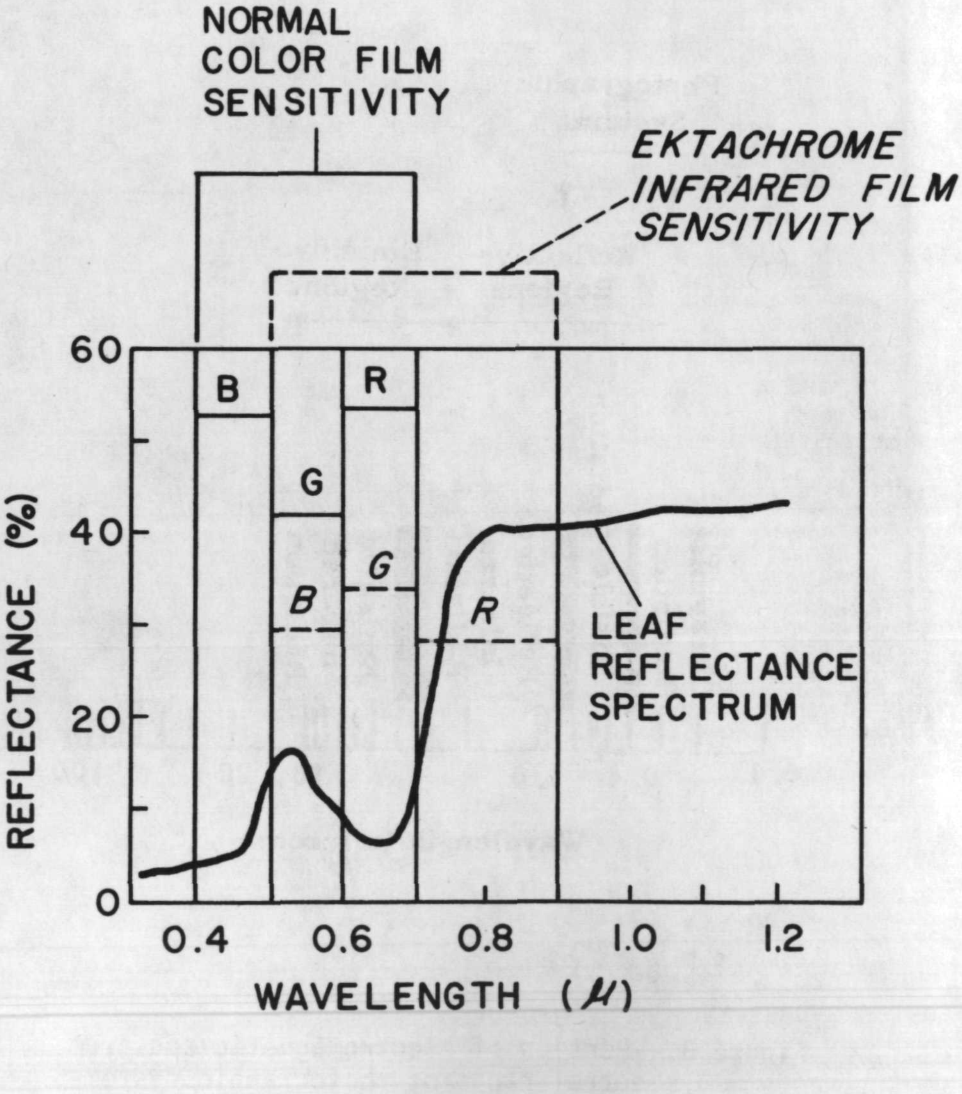

Figure 4.--Typical leaf reflectance curve. The letters indicate the portions of the spectrum which produce the colors blue (B), green (G), and red (R) on normal color film (letters underscored by solid lines) and on Ektachrome infrared film (letters underscored by broken lines).

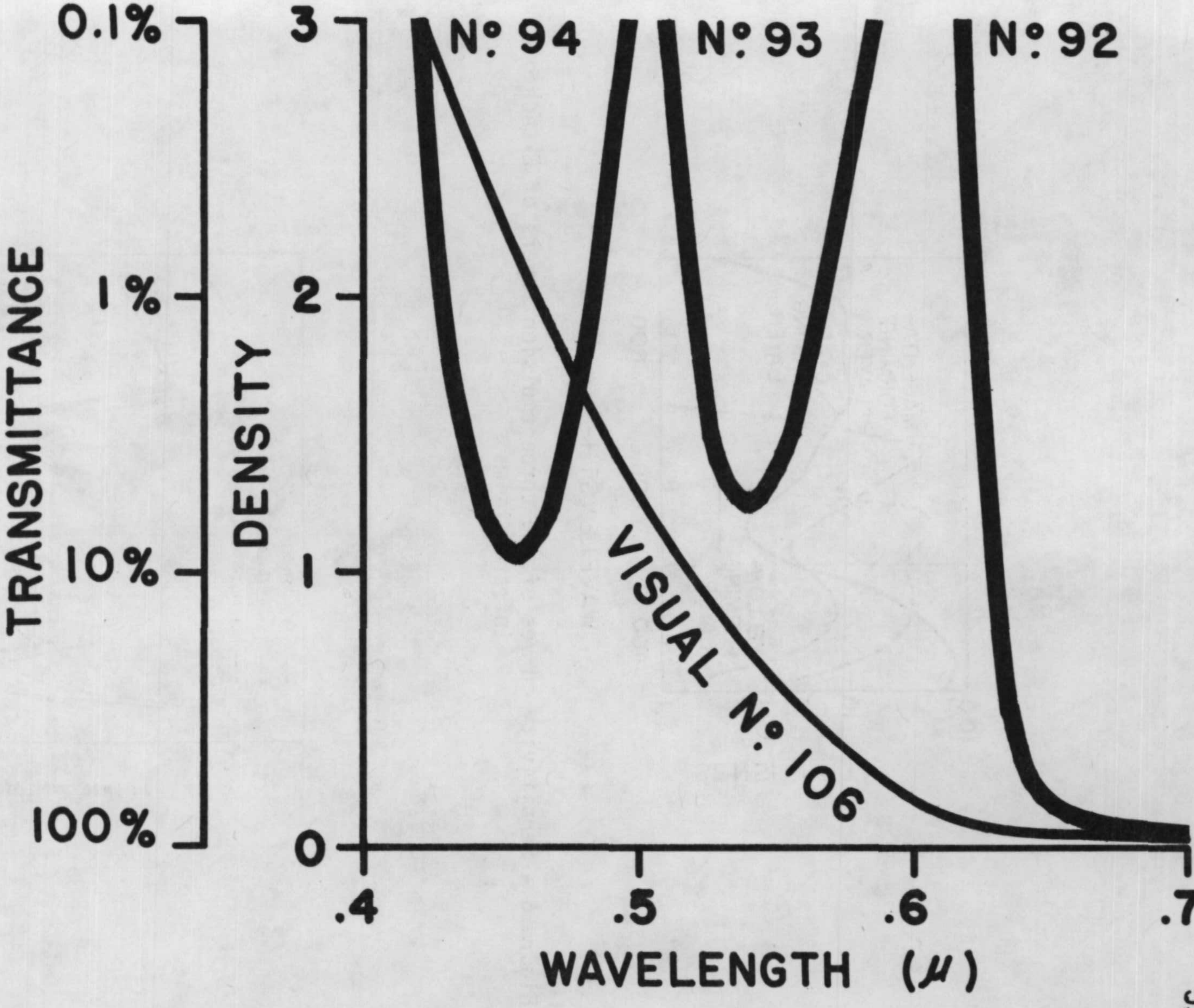

Figure 5.--Absorption characteristics of the densitometer filters used in the film analysis.

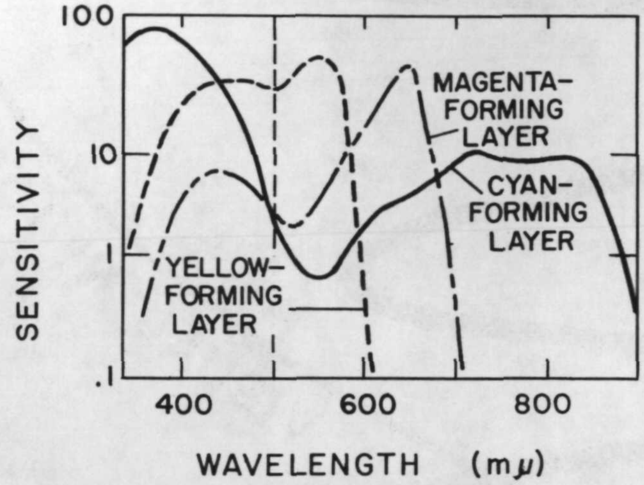

Figure 6.--Sensitivity curves of the three emulsion layers of Ektachrome infrared films.

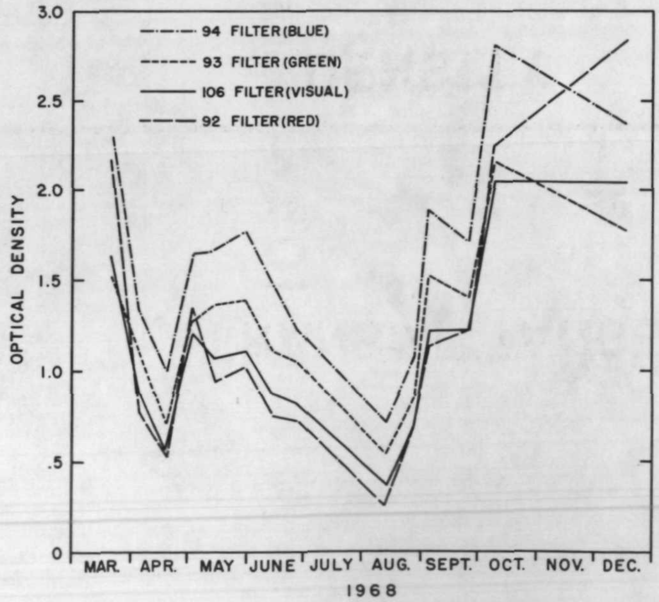

Figure 7.--Average optical densities obtained from Ektachrome infrared photographs of 1300 acres of saltcedar forest. Curves represent densities obtained with the four densitometer filters.

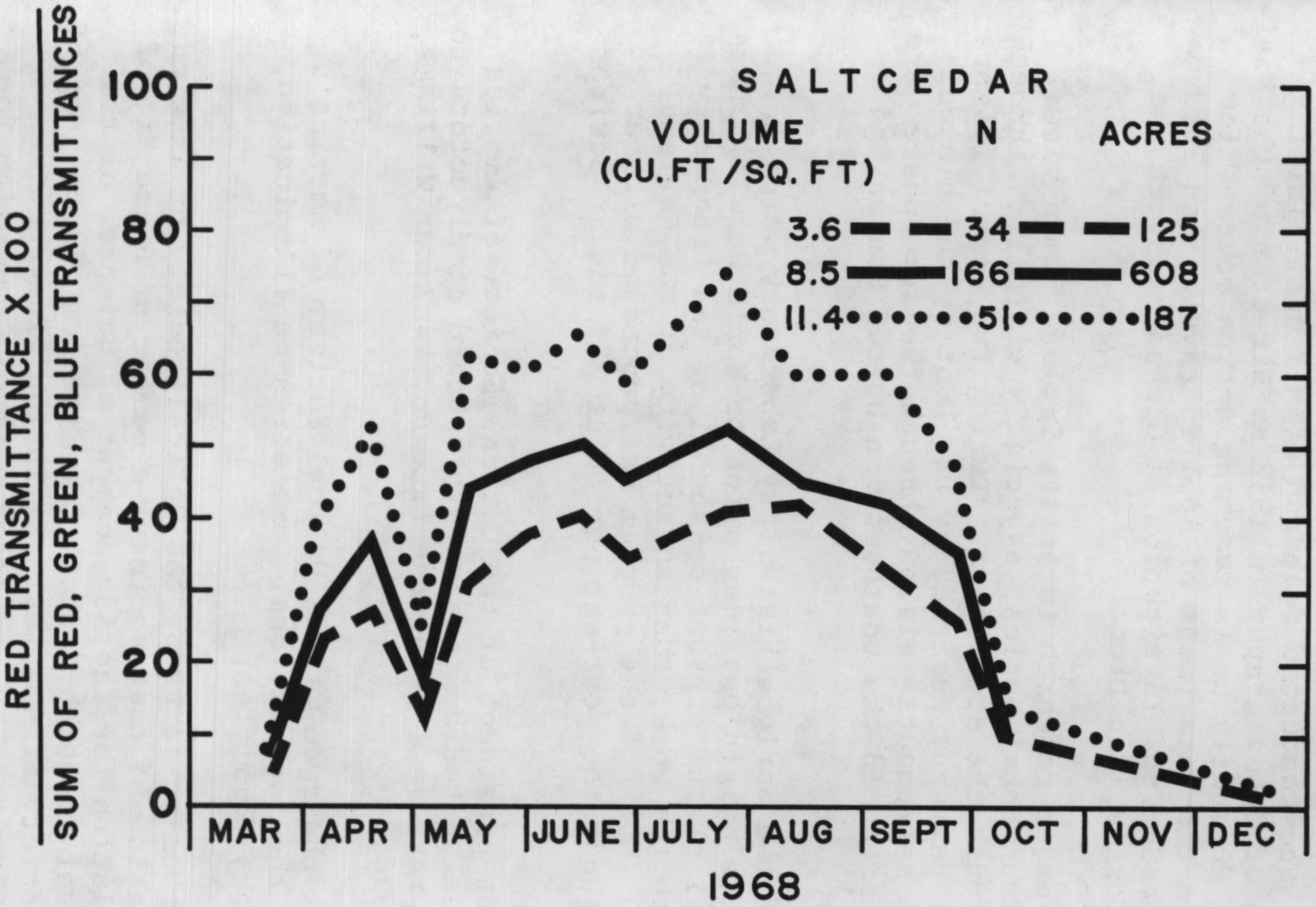

Figure 8.--Seasonal variation of adjusted red transmittances obtained from Ektachrome-IR images of a saltcedar forest, Gila River, Arizona. Data points are mean density values for forest plots representing three different foliage volume classes. N = sample size.