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"False-Color Film Fails in Practice"

The statement is refuted: the film actually offers wide possibilities in forestry studies.

Introduction

On the basis of Australian evidence, the Australian workers, Benson and Sims (1967), have stated that 'false-color film has proved of no practical advantage in the detection of insect or disease affected forest trees in Australia.' They further believe that 'true-color film can equally well portray forest condition without introducing an "interpretational" step' required with false-color film.

Evidence advanced by these workers of the unsuitability of color infrared, or false-color, or camouflage detection, or Ekta Aero Infrared, or Ektachrome Infrared Aero Film (Kodak Ektachrome Infrared Aero Film, Type 8443) for detection between healthy and damaged tissues actually refutes the second of their statements.

It is true that most color differences of vegetation seen on Ektachrome Infrared Aero photographs can also be observed on normal color photographs of the same vegetation. However, differences are much more striking on the former because of the false colors. Variations are usually observed first on the false-color film and many subtle color differences would possibly be overlooked if only the normal color photographs were used.

Color Infrared and Color Film

Benson and Sims show that diseased or damaged tissues, characterized by a deficiency of chlorophyll, show as yellowish—straw-colored, golden-brown, or silver grey—on false-color film. This is often more readily differentiated from the reds of green healthy tissues with chlorophyll on color infrared film than the contrast between browns of damaged leaves and the greens of healthy leaves on true-color film. In some plants the difference between olive-green healthy foliage and light brown damaged tissues is very difficult to observe with true-color film. whereas the differences are very obvious on false-color film.

In some applications false-color film has advantages over color film. Photographs of two adjacent tussocks of grass appeared identically brown on color film. On false-color film one showed greenish to straw-colored, the other faintly pinkish. Color film showed each tussock as dead: color infrared film showed one tussock dead (straw color) and one still living (pink).* The obvious advantage of using color infrared rather than color film for many range management studies does not need further elaboration.

Their argument that the use of color-infrared film involves an additional complication by introducing an "interpretational" step not present in true-color film cannot be considered seriously. All panchromatic film—which is still the most widely used film for aerial interpretation—involves a similar interpretational step. Information is recorded, and interpreted, by differences in grey scale values. Is not grey equally "false"? For small-scale photography particularly, false-color film, because it is always used with a minus-blue filter, reduces Rayleigh scattering. It cuts haze and gives better resolution than comparable true-color film. Haze and consequent poorer resolution is often a problem on color photography. Oblique panoramic color photographs, taken by the author, of

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* Also with the University of Auckland, New Zealand.

* N. L. Fritz, Eastman Kodak Research Laboratory, Rochester, New York, Personal Communication.

range land near the San Pablo Reserve in California recorded distant areas of scrub as a brownish green color. Color infrared photographs clearly differentiated three different types of scrub communities where only one was shown on color photographs. Field inspection showed that three different scrub communities were indeed present.

Benson and Sims' main concern appears to be that they want deficiency in chlorophyll in trees to show as *blue-green* rather than as *straw-colored.* Although this blue-green color has been shown to be the case in some studies in North America (Colwell 1960; Tarkington and Sorem 1963; Norman and Fritz 1965; and Meyer and French 1966) it is by no means universal (Meyer and French 1967). Recent studies by the author of damaged and healthy tissues of *Eucalyptus* spp. in California, of white fir (*Abies concolor*), Ponderosa pine (*Pinus ponderosa*), and of several sclerophyllous chaparral species, evergreen manzanita (*Arctostaphylos patula*), squaw carpet (*Ceanothus prostratus*) and snow bush (*C. velutinus*), in Oregon have shown a variety of results. This will be discussed later.

ABSTRACT: *The Australian Forestry workers, Benson and Sims, believe that "false-color film fails in practice". It is considered less suitable for disease and insect damage forest detection studies than true-color film. They assume that absence of chlorophyll should register as blue-green on false-color film. Evidence is advanced refuting their claim; published works and preliminary studies show that absence of chlorophyll does not necessarily infer green-blue color. Physical and physiological properties of leaves affect spectral reflectance particularly in the infrared region. Wide differences in leaf morphology between sclerophytic and mesophytic leaves probably explain some of the differences noted by Benson and Sims. Preliminary work on sclerophyll vegetation in North America supports this. The use of color-compensating filters to achieve a desired color shift is noted. Its adoption offers wide possibilities in forestry studies.*

INFRARED REFLECTANCE

Color infrared film is sensitive to reflectance in both the visible and the near infrared region. Thus imagery of vegetation is a *combination* of the green and red portions of the visible spectrum (the blue portion is filtered out) and of the near infrared. The largest contribution is in the infrared region. It is important to remember this. Benson and Sims are not strictly correct in their statement that false-color film was developed to detect the presence or absence of chlorophyll for military purposes (camouflage detection). Camouflage detection film was not developed specifically to detect the presence or absence of chlorophyll. Basically the film differentiated initially between (a) complex organic growing tissues containing chlorophyll and (b) non-living or non-organic objects; canvas, paint, rope nets, dead branches, and dead foliage used to camouflage military objects appeared a different color (often blue-green) to living higher vegetation (i.e. of complex morphology) which showed as red.

The characteristic red of living tissues in false-color film results jointly from high reflectance in the infrared, a secondary peak from the green and a smaller contribution from the red region of the electromagnetic spectrum. In the processing of the film absence of green light frequently results in blue-green rather than red showing on the photograph.

Paints have now been developed with spectral curves closely approximating those of living green tissues.† Some P. V. C. plastics have almost identical spectral curves to living complex chlorophyll bearing tissues. These plastics are difficult to differentiate from living "green" vegetation. Other plastics with low infrared reflectance are readily differentiated when photographed with color infrared film.*

Several workers have suggested that the high infrared reflectance from leaves is primarily a function of leaf tissue morphology (Clark 1946; Colwell 1956; Gates et al. 1965). Reflection is primarily internal but the whole problem of reflectance mechanism in leaves requires careful investigation. Knipling (1967) has shown that differential reflectance from healthy and diseased plants is very complex. It is not a simple function merely of presence or absence of chlorophyll-

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† N. L. Fritz, Personal Communication.
* N. L. Fritz, Personal Communication.

bearing tissue. Recent studies, by the author, of lichens—living organisms of simple morphology containing chlorophyll—show that these plants do not photograph as pink or reddish on color infrared film. Depending on exposure they were consistently recorded as blue-green to whitish.

LEAF MORPHOLOGY AND INFRARED REFLECTANCE

Physical and physiological factors affect both visible and infrared reflectance. For example, although epidermal cells are nearly transparent to reflection in both the visible and near infrared wavelength regions (Gates and Tantraporn 1952), the thick cuticle of some sclerophyllous species does contribute to leaf reflectivity, notably in the visible region (Schull 1929; Billings and Morris 1951; Colwell 1965; and Pearman 1966).

The plant species used by Benson and Sims in their most recent experiments, namely coniferous, eucalypt and citrus, all have relatively thick or waxy cuticles. These cuticles could all contribute some visible reflectance in the green wavelength band. This would partly counteract the chlorophyll deficiency and result in a straw color rather than the blue-green sought in the color infrared film for reduced chlorophyll content. Electron microscope studies of the wax structures (tubes, platelets, discs, etc.) on the surface of eucalypt leaves show that they differ very markedly. Also the wax cuticles are quite notably different between many species of eucalypt (T. C. Chambers, unpublished manuscript).

Several authors (Shull 1929; Krinov 1947; Olson and Good 1962; Gates and Keegan 1965; Thomas *et al.* 1966; and Knipling 1967) have observed that with maturing and aging of leaves the infrared reflectance increases and visible reflectance decreases. Thus the age of the leaves when they become diseased or damaged may also result in differences in the observed color on color infrared film. The upper, younger, and presumably relatively more mesic needles of a tall, dead, white fir (*Abies concolor*) tree in Oregon showed blue-green on color infrared film: the lower older needles were brownish. True-color photographs recorded all the tree foliage uniformly brown.

Preliminary investigations by the author in California and Oregon of sclerophyll tissues suggests that not only age of leaf at the time of damage but also total time that the leaf has been damaged may be important in the color registered on color infrared film. This is particularly true of *Pinus ponderosa* needles and of evergreen manzanita broadleaf foliage.

Little is known about the manner in which leaf morphology affects leaf reflectance. Many of the North American studies for detection of diseased or damaged foliage with color infrared film have been on mesophytic leaves. The presence of palisade cells plus a spongy mesophyll zone with many cell wall-air interfaces in mesophytic leaves differs markedly from the pattern present in eucalypts and conifers. In the latter the leaves or needles are characterized by tightly packed layers of palisade cells: spongy mesophyll is absent or greatly reduced. This may also affect reflectance, absorption, and transmittance patterns of both visible and infrared wavelengths. Conifers generally have a lower infrared reflectance than hardwood species. Visible reflectance is also lower because of compact leaf structure (Colwell 1956).

As *Eucalyptus* leaves age, the cuticles become thicker and the vacuoles of the palisade mesophyll cells become very densely occluded with an electron dense substance.† The effects of this on spectral reflectance after chlorophyll disappears from damage by disease or insect attack is not known, but could well contribute to the characteristic "straw-color" found by Benson and Sims, rather than the blue-green observed on mesophytic leaves.

These simple physical differences of internal leaf structure affect reflectance. Benson and Sims noted that frost damaged citrus leaves were recorded in pale magenta on false-color film not the straw-color of the sclerophyllous leaves and needles of eucalypts and pines. This difference could be attributed in part to the mesophytic leaves of the former and the sclerophyllous ones of the latter species. Preliminary evidence shows that juvenile foliage of *Eucalyptus viminalis* and of *E. globulus* in California have higher infrared reflectance than intermediate and adult foliage. This response is probably a function of the more mesic character of the juvenile leaves. Adult eucalypt leaves are markedly sclerophyllous. Visible reflectance may increase as eucalypt leaves mature. Current research being carried out on the spectral properties of *Eucalyptus* leaves at the School of Forestry, University of Melbourne may provide some of these answers.

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† Professor T. C. Chambers, School of Botany, University of Melbourne, Victoria, Personal Communication.

PHYSIOLOGICAL FACTORS

Equally important, but as yet little known, physiological factors, both separately or in combination with physical factors, may also significantly modify reflectance patterns in leaves. Professor Chambers (personal communication) believes that the chemical constitution of the surficial wax of eucalypt leaves has a major effect upon their spectral properties. He has used both infrared and ultra violet spectral analysis to obtain quick chemical analyses of the waxes of a large number of *Eucalyptus* species. Doubtless chemical differences within the internal leaf cells also contribute to the spectral properties of the leaf.

Physiological factors may well result in the varied color responses shown by diseased or damaged plants on color infrared film. Normally there is a reduction in infrared reflectance and an increase in visible reflectance in diseased or damaged plants. However, Keegan *et al.* (1956) have shown that infrared reflectance of diseased plants can vary considerably. Diseased plants of some hardwood and coniferous species show blue-green on color infrared film; other hardwoods show as straw-colored where infected (Meyer and French 1967). Elm with Dutch elm disease and black spruce with dwarf mistleloe are readily observed on infrared photography as blue-green areas (Meyer and French 1966, 1967). This largely results from an increased visible reflectance probably due to destruction of chlorophyll. The presence of the pathogens or some of their bi-products may affect reflectance causing higher infrared reflectance (McClellan *et al.* 1963).

Meyer and French (1967) also show that oak trees affected in the early stages of oak wilt show as straw-colored whereas killed trees show as blue-green. Wilt, caused by drought, in crowns of northern pine oak also show as straw-colored. The physiological change in drought-wilted leaves also appears to be similar to that associated with senescing leaves. Chlorophyll reduction occurs but it may not be so rapid as in disease infected plants. Also the yellow and brown carotenoid pigments do not break down as rapidly as chlorophyll. The resultant straw-color of these wilted leaves rather than the blue-green color on the false-color photographs may result from the reflectance contribution of these pigments. Field studies in Oregon show that the pigments giving the reddish-brown color to *Pinus ponderosa* and *Ceanothus patula* bark record as yellowish or straw-colored on color infrared film. Where green as well as yellow and brown (and possibly red) reflectance is totally lacking, as would be the case in the diseased rather than the wilted plants, the blue-green color would appear.

Insect damaged foliage of American elm also shows as brown or straw-colored not as blue-green (Meyer and French 1967). Healthy tissue shows as reddish. Thus, a universal pattern is not present in North America.

CONCLUSION

The 'familiar straw-color' of chlorophyll deficient tissues of eucalypts and conifers observed by Benson and Sims can possibly be explained by one or a combination of the physical or physiological factors outlined.

If it is so important to these workers to have the 'chlorophyll-deficient' tissue shown as 'blue-green' rather than for it to be clearly differentiated—albeit a straw-color—both Fritz in his studies at Rochester, and Pease and Bowden in their studies at California and elsewhere, have demonstrated that considerable color shift (Fritz 1967), or color shift and enhancement (Pease and Bowden 1968), can be achieved with the use of color-compensating filters. This technique offers many exciting possibilities for the use of false-color film in vegetation studies.

Improved results may not come easily but one should not condemn the value of false-color film merely because we do not fully understand all the complexities present. The characteristics and properties of the Kodak Ektachrome Infrared Aero Film, Type 8443 are generally known but much experimentation is still required. The complex physical and physiological properties of plants and their influences on reflection, absorption, and transmission of spectral wavelengths is not well known.

Should one expect the same color response from leaves affected by insect damage, fungal infection, chemical and physical change, turgidity fluctuations, wilting, and so on? If the contrasts between straw-color for sclerophyllous tissues is a persistent one—which may be possible—in contrast to blue-green for more mesic tissues, is this not a recommendation rather than a condemnation of the usefulness of color infrared film? Perhaps the straw-color of damaged eucalypt foliage and the blue-green color of many chlorophyll deficient mesic leaves can be related to presence and absence of tannins respectively. The answer may be this simple:

it is probably more complex. Only experimentation will provide the answers.

False-color film portrays forest condition as well and often better than true-color film (Anson 1966). Color infrared film does have definite practical advantages in the detection of insect and disease affected forest trees. Much has still to be learned in the control of color balance for optimum results to be achieved. Notable recent advances in the use of color compensating filters to achieve a particular desired color balance promise well for the wider and more varied use of false-color film in forestry.

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Articles for Next Month

J. T. Parry, *W. R. Cowan* and *J. A. Heginbottom*, Soils studies using color photos.
Steven L. Wert and *Bruce Roettgering*, Douglas-fir beetle survey with color photos.
Leonard A. Le Schack, Polaroid color film for P.I.
Simha Weissman, Auxiliary data in strip adjustment.
George H. Rosenfield, Automatic data verification.
Duane C. Brown, A unified Lunar control network.