COLOUR AND FALSE-COLOUR AERIAL PHOTOGRAPHY FOR MAPPING BUSHFIRES AND FOREST VEGETATION

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SUMMARY: Bushfires are common in Australia. They cause much damage and considerable loss annually. However, some use could be made of these wildfires for forest mapping if developments in colour and false-colour (colour infrared) aerial photography were more fully exploited. The advantages that colour and false-colour aerial photography have over panchromatic minus-blue aerial photography are analyzed for the Australian forest environment.

A technique is described, using colour or colour infrared aerial film, either separately or together for multispectral analysis, that could improve the accurate mapping of Australian sclerophyll *Eucalyptus* forests (after fire) and provide valuable information on the effect of fire on forest ecology. This technique involves sequential aerial photography to record the very distinctive regeneration patterns that follow bushfires. This technique should have wide application for forest studies and for much forest mapping, both within and beyond Australia.

INTRODUCTION

Periodic wildfires (bushfires) have long been part of the natural environment of the sclerophyll forests of Australia. Their frequency has increased greatly over recent decades in south-western, south-eastern and eastern Australia. Accepting the inevitability of bushfires and recognising that great gaps are still present in detailed systematic forest mapping within Australia, current systematic mapping could be augmented from aerial photographic studies of bushfire areas. At present, inadequate use is being made of advances in aerial photography.

Bushfires, instead of being regarded primarily as state or national disasters, could be used for greatly improving knowledge of distributions of sclerophyll forest trees by using colour and false-colour aerial photography. This information is urgently needed if better fire prevention, fire control and prescribed burning practices are to be adopted (Hodgson 1967). The use of colour film would yield much more information than can be interpreted from the traditional panchromatic minus-blue (black-and-white) film currently used. The Forest Research Institute at Canberra first used aerial colour photography in 1959 and Sims and Benson (1966) have demonstrated the value of the negative-positive system of aerial colour photography for photo-interpretation of unburnt forest in Australia.

False-colour or colour infrared photography (also called Infrared Ektachrome, Ektachrome Infrared Aero and Ekta Aero Infrared), which combines the visible (400 to 700 nanometre) and near infrared (700 to 950 nanometre) regions of the electromagnetic spectrum, is more useful than panchromatic, black-and-white near infrared or colour photography for mapping and identifying many plant communities. Striking contrasts between burned and living vegetation suggest that false-colour film, such as Ekta Aero Infrared, may prove much the most suitable film for mapping bushfire areas. Despite Benson and Sims' (1967) condemnation that "false colour film has proved of no practical advantage in the detection of insect or disease affected forests in Australia", they reluctantly concede "that fire effects on snow gum (*Eucalyptus niphophilia*) 12 months prior to photography were more readily seen on infrared than on Ektachrome". (Sims and Benson 1960, p. 46). These authors noted that dramatic colour differences in infrared film between healthy and fire-damaged snow gum trees appeared as similar tones on Ektachrome, and that recovery from fire, detectable in infrared cannot be detected on Ektachrome.

Although the cost of positive reproduction of colour film is four times that of panchromatic film, the cost of an aerial survey in colour to the stage of a processed negative is little more than that of a black and white panchromatic coverage. The increase in costs using colour or false-colour film would be more than offset by the greater ease of interpretation and the additional information so obtained. The use of colour or false-colour films rather than panchromatic film would be feasible even within the tight budgetary restrictions that may apply in Australia. Aerial colour photography was used in Tasmania following the 1967 bushfires about Hobart.

Although in no way belittling the contributions made by systematic mapping by Forestry departments within available map units and State forests or the use of aerial colour photography over the last four years by the Australian Forest Research School, much Australian forest remains virtually unmapped and little is known of the ecology of many areas. In bushfire areas the use of sequential aerial colour or aerial false-colour photography, or both — even in forests of very mixed species or mixed age stands — could substantially augment knowledge of forest species' distribution and composition. I am fully aware that fire intensity, which varies with a multitude of factors including season, slopes, aspect, fuel accumulation, wind, fire history, age and composition of forests, affects regeneration patterns (Cochrane 1963, 1966, 1968a, 1968c, 1969, Cochrane *et al*. 1968). However, detailed ecological studies of a complex burned area for four years after a fire indicate that distinctive patterns of species regeneration are often more dominant than variations resulting from differences in fire intensity. Evidence to date, therefore, is sufficiently encouraging to warrant a thorough testing programme of the use of both colour and false-colour aerial photoraphy for: (a) accurately delimiting burned from unburned areas, (b) mapping the distribution of different *Eucalyptus* associations following bushfires, (c) planning catchment control, firebreak construction and maintenance, logging, controlled burning and silvicultural practices, and (d) studies of fire ecology. Aerographic (black-and-white) infrared film also shows differences between burned and unburned areas more readily than panchromatic film. This preliminary evidence forms the basis of the present paper.

LIMITATIONS OF PANCHROMATIC FILM IN BUSHFIRE MAPPING

The relative limitations of panchromatic film and the respective advantages of other film, especially colour and false-colour aerial film, can be demonstrated with reference to the severe Dandenong Range bushfire of 14–17 January 1962 and the subsequent regeneration of the forest. Immediately following this summer fire, aerial photographs, using panchromatic film, were taken. These were intended to serve as an accurate and rapid record of the extent and damage caused by the bushfire. Panchromatic film records all wavelengths of reflected radiation within the visible spectrum. The film emulsion is sensitive to radiation in the 400 to 700 nm. range. Aerial panchromatic film is always used with a minus-blue filter, such as a Kodak Wratten 12, which cuts out wavelengths from 400 to 500 nm. This reduces Rayleigh scattering and eliminates 'noise' without significantly reducing background information. Thus, panchromatic minus-blue photography records all visible wavelengths from 500 to 700 nm. Consequently, many features that may differ significantly from each other in their spectrazonal signatures — for example, the wavelengths of the peak reflections — may have almost identical tones on panchromatic minus-blue films because the integrated response over the entire spectral region is the same or very similar. Such was, in fact, so with the bushfire areas in the Dandenong Range. The panchromatic minus-blue aerial photographs did not consistently show clearly the difference between burned and unburned areas. It was difficult to assess the bushfire perimeter and the amount of fire damage; it was impossible to identify species (Fig. 1). Ground surveys were required to map boundaries. In steep terrain of difficult access, errors in the accuracy of these boundaries could be substantial.

The general results from bushfires in sclerophyll forests in Australia are twofold: (a) the scrub understorey is completely razed by fire leaving the ground bare and (b) the forest tree dominants — almost exclusively of the genus *Eucalyptus* — are not killed. However, the foliage is killed by the radiant heat from the ground fire, turns brown and remains on the tree for several weeks. About one month after the fire many trees are largely defoliated and the ground carpeted with the dead leaves. An important exception is the 'ash group' of *Eucalyptus* (e.g. *Eucalyptus regnans*, *E. gigantea*) which includes some of the most important commercial species of south-east Australia. These are easily killed by fire (Cunningham 1960, Cochrane 1969).

The photographs were taken one week after the fire, when most leaves were present on both burned and unburned areas. There were no marked structural differences in the canopy. Similarly, the differences between spectral reflection

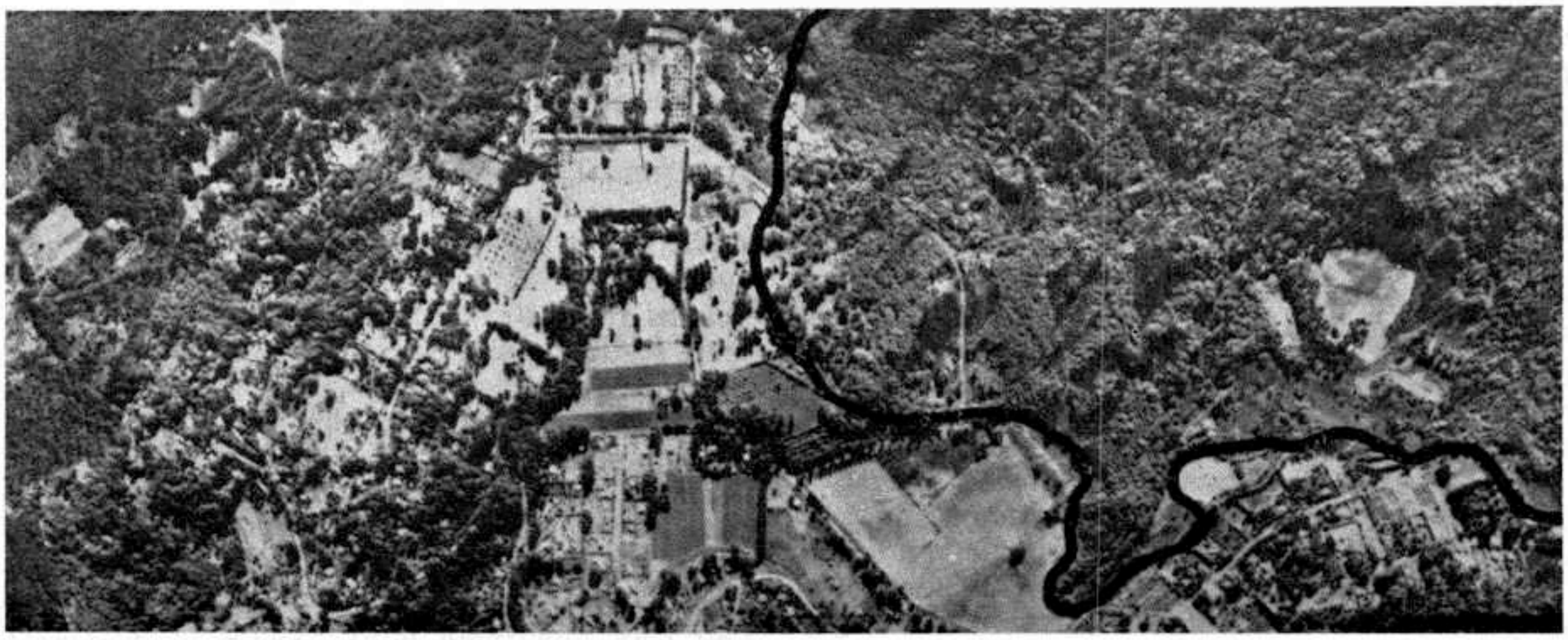

FIGURE 1. *Panchromatic minus-blue aerial photo taken immediately after the Dandenong bushfire of January 1962. Differences between unburned (left) and burned (right) are difficult to detect. Boundary between these areas is shown by black line.*

[Photo State Aerial Survey, Victoria, 1962]

of dead brown leaves of the burnt areas and the dull dark-green of living *Eucalyptus* leaves, although obvious on colour photographs, were not distinguishable on panchromatic minus-blue photographs.

It is doubtful if any better results would have been achieved than that shown in Figure 1 if the photography had been done about three or four weeks after the fire, when many of the burned trees would have been completely defoliated. The dense carpet of brown leaves covering the ground would probably still have spectral reflection values, similar to those of green foliage. The resolution of the 1:10,000 photographs would not have enabled one to identify individual trunks, although large dead trees (stags) can be separated from trees in full leaf.

Panchromatic minus-blue aerial photographs, if taken several months after the fire, could probably be used by a skilled interpreter to distinguish between burned and unburned areas on the basis of the reproduction of their textural differences. Thus the unburned areas with forest canopy would be different from the bare soil and regenerating scrub understorey. However, I have shown (Cochrane 1966, 1968c) that simple clear-cut differences are often not present because of very different and distinctive regeneration patterns between tree species and their associated undergrowth. In some areas regeneration of trees would result in textural characteristics not greatly different from forest. Some areas of bare soil and leafless trees could probably be detected on tonal and textural variations. Thus, differentiation between burned and unburned areas would still be difficult.

If spectrophotometric curves of burned and unburned bush could be measured, differences in spectral reflection could be used. Burned and unburned areas then could be detected photographically on panchromatic film, by using suitable filters to emphasise the spectral regions of greatest difference and to eliminate the regions of no difference. Such a procedure would have to be tested to determine its practical validity for bushfire studies.

Is such experimentation warranted, however, when these results may be achieved so readily from colour and false-colour photography? Meyer and Trantow (1961), in examining tonal differences in conifers and deciduous trees in northern Minnesoa, found variable-filter photography was inferior to colour infrared photography with a minus-blue filter. Recently, Carneggie and Lauer

(1966) and Lauer (1969) have successfully used spectrazonal aerial photography to identify trees. Recent tests I have made with panchromatic film and minus-blue, minus-green, and minus-red filters on both living and dead, but not burned, foliage of blue gum (*Eucalyptus globulus*) and manna gum (*E. viminalis*) gave rather unsatisfactory results. Colour and false-colour photographs taken at the same time showed the differences more effectively.

BLACK-AND-WHITE INFRARED FILM

Black-and-white infrared or Aerographic infrared film records wavelengths from 400 to 900 nm. With the exception of a noticeable dip at 500 nm. it can record both visible (400–700 nm.) and near infrared (700–900 nm.) reflection. When used with a Wratten 89B filter it records only infrared. Within this spectrum of electromagnetic energy the different reflection between dead and living tissue of the burned and unburned forest is substantial. This film could be used for mapping burned and unburned vegetation in Australian forests, but would show less total detail than panchromatic film because of poorer resolution. Thus, although Carneggie, Draeger and Lauer (1966) and other workers have clearly demonstrated the superiority of black-and-white infrared film over panchromatic minus-blue film for distinguishing between burned and unburned coniferous vegetation it is not widely used.

COLOUR FILM

No aerial colour photographs were taken in the Dandenong Ranges but ground photographs using colour film demonstrate the high potential of colour photography for studies of forest fires. Kodachrome and Ektachrome film showed clearly the difference between the dun-brown of burned forest and the greens of unburned forest. On aerial colour photographs supplied by Carneggie, the brown of a burned area near Russian River, California contrasting clearly with the green of unburned vegetation, indicates the potential value of aerial colour photography.

Previously, true colour has been difficult to achieve with Aerial Ektachrome colour film because of haze, filter and exposure problems. However, the many subtle differences of hue, value and chroma recorded enable many more features to be interpreted than is possible on either panchromatic minus-blue or black-and-white infrared film alone. Small-scale aerial colour photography can yield more accurate information than comparable pan minus-blue photography (Tarkington and Sorem 1963, Sorem 1967). Anson (1966) demonstrated that, not only does colour photography enable one to interpret more categories or classes than on comparable pan minus-blue photography, but much more detail can be deciphered and more positive identification of features made. Lauer (1966) found that identification of tree communities made from aerial colour transparencies were significantly more accurate than those made from aerial black-and-white prints. Although these interpretations were chiefly of different genera and thus more simple than identification between different *Eucalyptus* forest communities, some of his divisions were between species of one genus.

The problem of haze with colour film taken at altitudes above 10,000 ft. may well be solved with the introduction of a negative-positive system. In this process, developed in Australia in 1966–67, haze is filtered out at the time of processing, not at the time when the photographs are taken. Results with the introduction of this system showed good colour balance in a special trial at altitudes ranging from 5,000 ft.–25,000 ft. Blue haze was effectively eliminated (Sims and Benson 1967). These authors recognise colour negative systems, such as MS Ektachrome 2448, as being superior to conventional Aerial Ektachrome for identification of Australian forest species.

Because tonal and textural differences are usually enhanced by colour variations, Aerial Ektachrome clearly differentiates between tree and scrub cover. Subtle differences aid in interpreting tree species, tree density, tree and scrub densities, tree heights and classes of forest. At large scales, this film is useful for distinguishing between healthy and diseased or damaged trees (Carneggie, *et al.* 1966). Benson and Sims (1967) recognised its value for such purposes in Australian forestry. Colour infrared (false-colour) film is more widely used for this purpose (Norman and Fritz 1965; Meyer and French 1966, 1967; Knipling 1967; Weber and Olson 1967), although Benson and Sims refute its value for studies of Australian vegetation. Their refutation may result from incomplete understanding of certain problems inherent in the use of such film (Cochrane, 1968b).

Aerial photography using Aerial Ektachrome colour film would have recorded sharply and accurately the boundaries of the Dandenong bushfire. Even small areas of green trees that escaped burning may be expected to be readily identified because of sharp colour contrast. Experimental photography in the Plumas National Forest in the Sierra Nevada Mountains of California, has demonstrated the potential value of high altitude, small scale, aerial, colour photography for mapping wildfire boundaries (Carneggie *et al.* 1966).

Similarly, colour film would also record differences between intensities of bushfires. A large bushfire rarely burns evenly over a large area. This was particularly true in the Dandenong fire, and the same has been observed in many bushfire areas I have investigated over the last 10 years. Intensity of burning varies with many factors (Cochrane 1963) and ranges from severe burning, to light burning and defoliation from radiant heat (Cochrane 1966, 1968c, 1969). In Australian *Eucalyptus* forests, such as in the Dandenong Range, leaves are burned in areas of most severe fires. On true colour photographs such areas show as black rather than the brown of areas where fire results in death of leaves from radiant heat. These differences could not be detected on the aerial panchromatic minus-blue photographs (Fig. 1), but showed readily on ground colour photographs. Panchromatic photographs, taken on the ground immediately following the Dandenong fire, did not show these differences in panoramic views. Differences were difficult to observe even in ground panchromatic photographs taken at close range.

Colour film such as Aerial Ektachrome is better than either black-and-white infrared or panchromatic minus-blue film for identification of trees with foliage of similar density or scrub with similar texture (Anson 1966). If infrared reflection is similar these cannot be distinguished on black-and-white infrared photography. Subtle colour differences between species can often be used in colour film to identify and map plant communities or species.

Aerial colour photographs would be most valuable taken directly after a fire when contrasts in colour between burned and unburned vegetation would be most marked. Its great superiority over panchromatic minus-blue photography for distinguishing between burned and unburned areas warrant its testing and, if satisfactory, its wide use in Australia. Accurate delimitation of burned areas would be valuable for assessing extent of damage and for planning prescribed burning to reduce dangerous accumulations of ground fuel where such silvicultural control methods are considered practical or economic (Hodgson 1967). No published results of the use of true colour aerial photography taken after the 1967 Tasmanian bushfire are available. However, the use of true colour aerial photography rather than panchromatic suggests that wider use of colour photography techniques is imminent.

AERIAL COLOUR PHOTOGRAPHY AND THE MAPPING OF FOREST VEGETATION

I have drawn attention to the grave deficiencies in the fundamental description of vegetation within Australia (Cochrane 1967). Only a small percentage of the continent's plant communities have been fully described ecologically. This applies especially to much of the sclerophyll forest. Detailed species distributions are virtually unknown, particularly where such forests are found on rough dissected country. Accurate maps of distributions are not likely to be produced by conventional field mapping methods in such difficult country.

Colour aerial photography, if used at key times following bushfires can contribute information on (1) forest composition and (2) the ecology of forest dominants and of understorey species following fires.

The *Eucalyptus* dominants of the sclerophyll forests exhibit remarkably distinct regeneration patterns following bushfires. Species differ in the time of appearance, rate, vigour, form, density and colour of the regenerating foliage (Cochrane 1968c). Although it is true that regeneration patterns are affected by the severity of fires, seasonal conditions and geographical locations, the distinctive regeneration patterns of the species were not masked by these factors in the Dandenong Range study area. Thus, if aerial colour photographs were taken after the fires at successive times corresponding to the known times of significant stages in the regeneration of the *Eucalyptus* species, it may well prove that accurate detailed maps could be made of distributions. Detailed ground surveys I have made indicate that in the Dandenong Range, aerial colour photographs taken between one and two months after the fire would have shown very distinctive and vigorous regeneration from dormant epicormic shoots present on three species — the long-leaved box (*E. elaeophora*), mountain grey gum (*E. goniocalyx*), and narrow-leaved peppermint (*E. radiata*).

The former two, with blue-green (glaucous) juvenile leaves, can be easily distinguished from the latter with its light green foliage. Waxes present on the juvenile foliage of long-leaf box and mountain grey gum increase the peaks of reflection in the visible spectrum (e.g. 5% to 10% at 537 nm.). Although certain eucalypts frequently present a different appearance on vertical colour aerial photographs from that expected from knowledge of the species on the ground, this separation could be made readily on the basis of colour alone, even if the hues in the aerial photographs differed from the distinctive ground colours. Distinguishing between the two former species, would not be difficult as they both have strongly contrasted tree forms and habitat requirements. Areas of these species would show clearly against the stringybarks which do not regenerate so soon. These differences could not be detected on panchromatic (black-and-white) film.

Another series of photographs, using colour film, and taken seven months after the fire, would show dark, greenish-red, relatively sparse regeneration of the messmate stringybark (*E. obliqua*). The different colour, the less dense foliage, the different tree form and the concentration of regeneration along upper surfaces of main branches would allow easy identification of this species. The other stringybarks of the area — brown stringybarks (*E. baxteri*) and red stringybarks (E. *macrorrhyncha*) — would show clearly as dark areas with no green growth. It would be difficult to distinguish these two species from one another by leaf regeneration patterns on colour photography taken when regeneration had begun.

Regeneration of undergrowth is largely absent under these stringybarks for the first six months but is present later. It is difficult to distinguish sparse tree regeneration from understorey vegetation in aerial photographs. However, by applying ecological principles in interpretation — these two species exhibit very distinct habitat preferences — boundaries could probably be drawn fairly accurately.

Thus, two sets of aerial colour photographs of the burned area taken two months and seven months after the fire give real promise of providing sufficient information to map the vegetation distribution rapidly and more accurately than previously. To achieve a similar map by ground surveys would involve much time and staff. In addition, the finished ground survey map would probably lack the accuracy and exact detail of the aerial photographs.

The limitations of such procedures would not result from technical problems of photography but from the lack of information concerning patterns of regeneration after fire. More information is required on the ecology of many species of the sclerophyll forests after fire so that information on aerial colour photographs may be correctly interpreted. Variable epicormic emergence within a species because of altered site or altitude, or both, latitudinal location, fire intensity and numerous other factors would have to be considered in selecting optimal times for aerial photography in other places. For the Dandenong Range, which is an area of mixed species, mixed age stands and varied habitats (Cochrane 1968a, 1969), the times suggested would provide maximum information.

COLOUR INFRARED FILM

Colour infrared photography (also called false-colour, Ektachrome Infrared Aero, and Infrared Ektachrome photography and formerly known as camouflage detection photography) often yields a wider variety of multi-spectral information than colour film. This has been demonstrated in several studies, particularly those by Anson (1966), Carneggie *et al.* (1966), Carneggie and Lauer (1966), Meyer and French (1966, 1967), Fritz (1967), Lauer (1968) and Carneggie (1968). It is one of the most useful single remote sensing devices and is useful for detailed field research and for medium and high altitude studies. Recent investigations by Pease and Bowden (1968, 1969) indicate that it may be exceedingly useful for mapping programmes from space.

The film is sensitive to radiation in the blue, green and red portions of the visible spectrum as well as in the near-infrared region. A minus-blue filter is always used to exclude wavelengths shorter than 500 nm. Thus, images on colour infrared photographs result from reflection from both the near-infrared (700 to 950 nm.) and the green and red (500–700nm.) portions of the solar spectrum. Actively growing vegetation has a plateau of maximum reflection in the near infrared at 700–950 nm. This activates the infrared sensitive dye which produces red in the processed film (Fritz 1967). Infrared colour photography, particularly when enhanced by the use of appropriate filters, records the most subtle differences between growing vegetation (Pease and Bowden 1969). This can frequently be used to identify different species very accurately. In addition, the technique is often useful for distinguishing between species that look similar in colour but which have very different infrared spectra. Thus, one species may appear as a lighter 'blush' than the other on false-colour film.

Angle of sun, light intensity, plant geometry, leaf incidence and plant vigour all affect infrared reflection. In addition, ground infrared photographs of vegetation may show a different pattern from aerial photographs of the same. Despite these problems, I have used false-colour film successfully for vegetation studies in a wide range of environments, including Australian and North American deserts, forests of California, Oregon, New York and Florida, South-eastern Australian sclerophyll forests, New Zealand mixed podocarp-broadleaf forests and Canadian tundra.

Infrared colour film gives sharper images than other films when haze is present. This is an important advantage. It is therefore much clearer than colour photography for distant views, although some of the haze and resolution limitations of colour film have been rectified by the recent development of the negative colour system mentioned earlier. This distinction applies particularly to small-scale colour infrared photography, i.e. filming from high altitudes. There is negligible (or very little) Rayleigh scattering of the longer wavelengths to which this infrared film is sensitive; and, in any event, it is less than that of the short wavelengths to which colour film and most other films are sensitive.

Infrared colour photography using Kodak Ektachrome Infrared Aero Film, Type 8443 (Ektachrome Infrared Aero, false-colour Infrared Ektachrome or Ekta-Aero Infrared film) would be excellent for mapping bushfire boundaries. The colours — red for unburned bush and blue to charcoal grey for the burned area — enhance boundary differences because of their unusual (false) character. The contrast is greater than that between brown and green on true colour film. Living vegetation has a high infrared reflectivity and shows red. The dead leaves absorb infrared and thus have a low reflection; they show bluish-black.

In a series of air photo studies of the vegetation at San Pablo Reservoir and at the Meadow Valley–Buck Lake Area, California, at scales from 1:2,500 to 1:30,000, Lauer (1966) found colour infrared more useful than colour film for the consistent identification of species. Both were vastly superior to black-and-white infrared and panchromatic minus-blue film. Tarkington and Sorem (1963) earlier emphasised some of the uses of false-colour film for aerial photography. Fritz (1967), who made brief reference to the technique of optimising for the wavelength required with panchromatic film and filters, pointed out that better results can be achieved more readily with the use of aerial infrared colour film. Sims and Benson (1966), while emphasising the potential of true colour aerial photography for identification of Australian forest trees, recorded the marked superiority of false-colour film for studies of burnt vegetation.

Anson's (1966) comprehensive and detailed comparison of aerial panchromatic minus-blue, colour, and infrared colour photographs also demonstrated the advantages of the latter for maximum detail and greatest range of categories for mapping. Recently, I was able to consistently distinguish between individuals of two species of *Eucalyptus*—*E. globulus* and *E. viminalis*—in California, on colour infrared film at scales of 1:10,000. This was more difficult on similar scale Aero Ektachrome colour photographs. Within the limits of the resolution cell, identification, with almost the same degree of accuracy, was possible on 1:30,000 infrared photographs. Identifications made on photographs were all verified in the field. Additional variations in infrared reflection in eucalypt communities shown on the 1:10,000 colour infrared photographs, when checked in the field, corresponded with differences between age and composition. Mature, even-age stands, irregular mixed stands and regeneration variations with different ratios of seedlings, saplings and poles of eucalypts, all had specific recognisable signals. Thus it appears that infrared colour film would be very useful in studies of Australian bushfire ecology.

The regeneration patterns discussed earlier that followed the 1962 bushfire would show up on infrared colour photography at least as clearly as on colour photography. Most studies of vegetation on infrared colour photographs have been made in the northern hemisphere. Little has been published on infrared colour studies of evergreen, sclerophyllous, isobilateral leaves of the Australian forests or, indeed, of southern hemisphere and tropical vegetation. Exact parallels with northern hemisphere evergreen conifers and broadleaf deciduous plants cannot be made. Howard (1966) has shown that four species of *Eucalyptus*, all found in the Dandenong Range, namely, *E. goniocalyx*, *E. elaeophora*, mountain ash (*E. regnans*) and the stringybark (*E. obliqua*) all have high but not identical infrared reflection. Thus differences on infrared colour film between these species would result largely from a combination of the high infrared reflection and from differences in reflection of green and red visible light. The darkish glaucous regenerating leaves of *E. goniocalyx* and of *E. elaeophora* shows as a darker red — similar to evergreen conifers on infrared colour film — than those of the willow-like, paler green leaves of *E. radiata*. The latter show as a bright red similar to that recorded by broadleaf deciduous foliage. Juvenile leaves of stringybarks, which have a lower absorption of visible red than the other leaves, show as orange-red on colour infrared film.

Discriminating between tree and understorey layers is often easier with infrared colour photography than with colour photography. The former also provides a greater contrast between vegetation and soil than does colour film, although it is less valuable than the latter for distinguishing soil types (Anson 1966). The use of infrared colour photography would have been equally, or even more, useful than colour photography for recording regeneration stages and mapping species distribution following the Dandenong bushfire. Infrared colour aerial photographs taken immediately after the fire would record sharply and clearly differences between burned and unburned vegetation. The former would show as blue to blue grey; the latter as red. Intensity of burning could be analysed by the amount of bare ground shown and by the variations between bluish-green or, perhaps, shades of yellow (Benson and Sims 1967; Cochrane 1968b) shown by lightly burned areas and the bluish-blacks of severely burned areas with much charcoal, dead leaves and fire ash. Boundaries between burned communities and smooth-barked trees such as *E. goniocalyx* and *E. regnans* and between the fire-blackened and charred, fibrous-barked stringybarks and blackened, charred, rugose-barked long-leaved box and narrow-leaved peppermint could possibly also be made on colour infrared imagery taken at this time.

These features and the regeneration patterns discussed under colour photography would all be detectable on colour infrared photography taken between one and two months after the fire. The vigorously regenerating juvenile leaves clothing the trunks of *E. goniocalyx*, *E. elaeophora* and *E. radiata* would show distinctly as various reds contrasting with those of the adjacent burned ground or non-regenerating stringybarks. The pattern and the colour of regenerating leaves would show as a different red from the living unburned foliage, as juvenile and adult *Eucalyptus* foliage have different spectral responses. Some of the reasons for this are discussed more fully elsewhere (Cochrane 1968b). See also Knipling (1967).

Photographs taken about seven months after the bushfire would have been valuable for identifying burned stringybark communities from adjacent communities in the Dandenong area. At this stage much bare ground would be present in the stringybark communities because of their sparse regeneration and the lack of undergrowth. Other communities would have most ground covered by regenerating understorey. Infrared colour aerial photographs have not been taken of bushfire areas but accumulating evidence suggests that such films could probably record the many subtle regeneration patterns — varying from bare ground, grass, fern and xeric and mesic shrubs — which are not obvious on panchromatic minus-blue aerial photographs. Such infrared colour photography would save many hours of field investigations, allowing time to be devoted to detailed studies rather than to reconnaissance mapping and sampling later.

Discrimination between species with similar appearance could probably be achieved from subtle colour variations by using colour compensation filters. Fritz (1967) and Pease and Bowden (1968, 1969) have demonstrated that much additional information can be recorded by slight, moderate or great enhancement of infrared imagery by using such filters. The techniques developed are particularly useful for small-scale aerial photography. These workers believe that such film has potential for universal use.

Truly accurate mapping of the distribution of Australian sclerophyll species from photo-interpretation, however, is dependent upon a sound knowledge of the ecology of such forests after fire. Furthermore, this knowledge is vital if the annual destruction and loss of resources from bushfires is to be arrested or at least better controlled. To date there have been insufficient investigations of this topic. Studies of mountain ash (Cunningham 1960, Cochrane 1969), make a notable exception. Other useful contributions have been made by Lawrence (1939), Gardner (1956), Gilbert (1959), McArthur (1962), King (1963), Hodgson (1967) and Cochrane (1963, 1968c), but much remains to be done.

Sclerophyll forests are made up of many different associations which reflect the many differences in rocks, soils, climatic and biotic factors. Very varied patterns are present in broken, dissected country where many such forests are found. Studies of the ecology of sclerophyll forests show that fires do follow a broadly predictable pattern. Differences in structure (Cochrane 1968a), in understorey composition, in pattern of burning, and in degree of fire tolerance, all exert important influences upon bushfire patterns. Both the form and rate of vegetation regeneration after bushfires (Cochrane, 1966, 1968c), when known, contribute to a better understanding of vegetation-fire relationships and possibly, if wisely used, to better bushfire control in the future. Many of these vegetation-fire relationships could be obtained from aerial colour infrared photography.

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