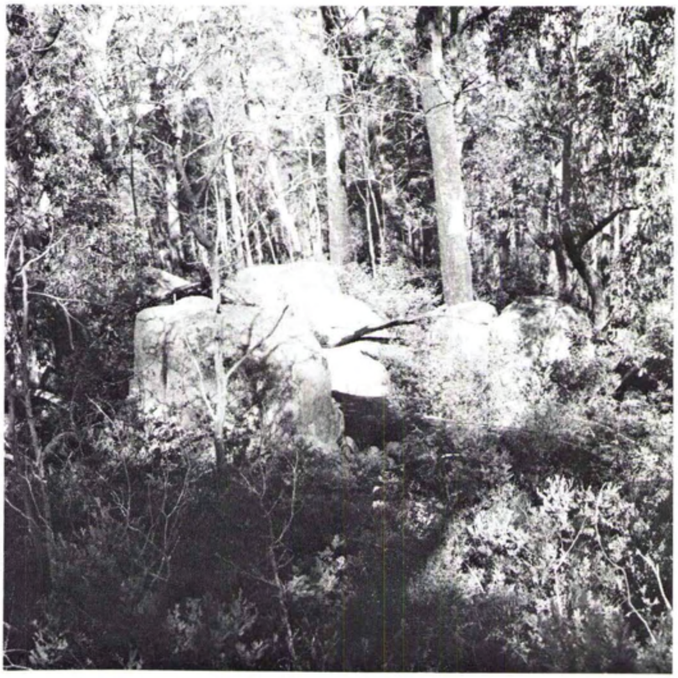

FIG. 1. Heavy rock cover was often difficult to detect due to the dense canopy, understorey, and shadows.

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Rock Outcrops Beneath Trees

Airphoto interpretation under a eucalypt canopy was most successful using color photographs, large scale, and under a complete altostratus cloud cover.

(Abstract on next page)

INTRODUCTION

IN RECENT years many forestry applications of large-scale 70-mm color aerial photographs have been developed. These include the determination of timber losses due to insects, diseases and fire; and the inventory of the quantity, quality, species, size and location of forest resources (Aldrich, 1966). These uses have been concerned mainly with interpretation of the forest canopy, but in some instances interpretation of the understorey, ground vegetation or the forest floor is necessary.

Lund *et al.* (1967), in a preliminary study of color and color-infrared aerial photos for evaluating understorey vegetation as a forest-fire fuel found color at 1:3500-scale better than other film-scale combinations. Crown closure, shadow and radial displacement on large scale 9 × 9-inch photos were limiting factors.

Bradshaw (1974), faced with detection of dying understorey species as prime indicators of the presence of "jarrah dieback" (a disease of Western Australian eucalypt forests caused by a root rotting pathogen

Phytophthora cinnamomi Rands), tested 70-mm color and color-infrared aerial photographs at various scales on paper print and transparent media. He found that color, 1:3000 transparencies exposed under cloud were superior to other combinations.

During the Australian program of conversion of areas of native eucalypt forest into exotic pine plantations, occasional patches of heavy rock occurrence are severely limiting to mechanical plantation establishment. Faced with the task of stand conversion in an area where rocky patches were known to exist, the problem was to determine an effective and rapid technique for mapping the precise area and location of the rock using the equipment which was readily available to the State Forestry Commissions (i.e., 70-mm or 35-mm equipment). In this trial eight combinations of film, illumination and scale were studied to determine the ability of an interpreter using each combination to interpret ground detail beneath a moderate to dense eucalypt canopy.

To evaluate the relative usefulness of each combination, an area of eucalypt forest under which rock outcrops occurred was photographed and an attempt was made to map the rock from the photographs. The rock was then mapped by an intensive ground survey and the percentage of the rock detected on each set of photographs was determined.

The study block, 420 acres in extent, was located on the Glenbog State Forest in south-eastern New South Wales (latitude 37° S). The exposed rock was weathered granite boulders occurring in low ridges with deeper soil in the intervening depressions. The rocky ridges (areas of greater than 40 percent rock cover) comprised 28 percent of the study block; the rock-free area (less than 10 percent rock cover) comprised 66 percent of the block; and the transitional zone between the two formed 6 percent of the area.

The tree cover that occurred on the study block was mainly wet sclerophyll forest 75 to 150 feet in height with a luxuriant understorey of mesophytic shrubs, ferns and mosses (see Figure 1). In the wetter gullies a very dense layer of rainforest shrub and vine species was encountered, whereas patches of dry sclerophyll forest occurred on some of the higher ridges. Large sections had been selectively logged 15 years previously, reducing the canopy density to an average of approximately 40 percent although some 15 percent of the stands still retained almost complete closure (See Plate 1).

The forest types encountered were primarily in the Messmate-Brown Barrel League as described by the Forestry Commission of New South Wales, (1965) and included the species *Eucalyptus obliqua, E. fastigata, E. robertsonii, E. viminalis, E. dalrympleana and E. fraxinoides.*

ABSTRACT: *Large-scale 70-mm color aerial photographs were used to detect and map the occurrence of weathered granite under a moderately dense eucalypt canopy. Eight combinations of film, illumination and scale were studied. The best results were obtained on color film under cloud at 1:4000 scale. The main limiting factors were dense vegetation and shadow.*

METHODS

PHOTOGRAPHY

Aerial photographs were exposed using a Vinten 70-mm aerial camera mounted in a Cessna 337 aircraft. Two films, two scales and two illumination conditions were combined to produce eight different sets of photographs in a 2 × 2 × 2 factorial design. The two films were KODAK AEROCOLOR Negative Film Type 2445 (ESTAR Base) and KODAK AEROCHROME Infrared Film Type 2443 (ESTAR Base). The two scales were 1:4000 and 1:8000. The two illumination conditions were full sunlight and diffused light produced by a complete altostratus cloud cover. The under-cloud photography was repeated with several exposure settings in anticipation of exposure problems due to the unusual lighting conditions. The run with exposure setting that appeared to reveal the most ground detail was selected for interpretation.

In order to obtain a sufficiently large area of coverage on each photo to enable typing and mapping, both films were exposed at scales of 1:24,000 and 1:12,000 and processed to negative. Three-diameter linear enlargement color diapositives were printed from the negatives of all runs, producing 7 × 7-inch transparencies at the desired scales of 1:8000 and 1:4000. Diapositives were used rather than paper prints in order to minimize the

PLATE 1. A print enlarged 2× from a 70-mm negative exposed over the study area. The photograph is from the best combination of film, illumination and scale: color, under cloud, 1:4000. The rock outcrops show up quite clearly on this combination in one of the areas of lowest crown density (approximately 25 percent).

TABLE 1. FILM, ILLUMINATION, SCALE COMBINATIONS.

Film	*Illumination*	*Scale*	*Code*
Color	Cloud	1:4000	CC4
		1:8000	CC8
	No Cloud	1:4000	CN4
		1:8000	CN8
Infrared	Cloud	1:4000	IC4
		1:8000	IC8
	No Cloud	1:4000	IN4
		1:8000	IN8

loss in definition incurred through photographic enlargement (Sims, 1966; Welch, 1968).

The missions were conducted in early summer with a sun angle of approximately 73 degrees. The combinations of film, illumination and scale studied and the codes used to identify them are shown in Table 1.

MAPPING

A theodolite survey was conducted on the roads and tracks in the study area to provide the information for the compilation of a base map. Various ground control points which were visible on all eight sets of photographs were tied-in to this survey. Using these ground control points and additional photo control points, eight transparent base maps were produced by stereo compilation. The base maps for both scales of photography were made at a scale of 1:4000.

TYPING

The photos were interpreted for rock by a single interpreter using a simple lens stereoscope at 2× magnification. The classes to be recognized were: areas containing less than 10-percent rock cover, and areas with greater than 10-percent rock cover. These classes were based on the degree of hindrance posed by the weathered granite boulders to mechanical plantation establishment, — over 10-percent rock cover was considered a possible hindrance to workability by machines. The interpreted rock areas were subsequently transferred to the eight base maps using an Aero-Sketchmaster.

A systematic line survey with a random start was conducted in the field to record the locations of the two classes. The survey lines were one chain wide and five chains apart giving a 20-percent sample of the study block. They were tied-in to the stations of the theodolite survey, plotted on the base map and the rock areas were mapped.

The maps were evaluated by superimposing each one in turn on the ground map and measuring the length of survey line on which the rock classes had been correctly identified.

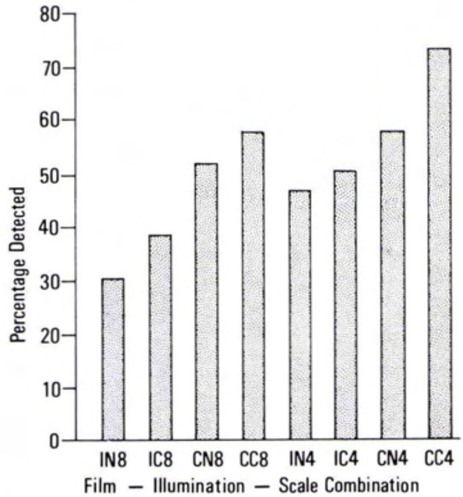

FIG. 2. Rock areas detected on various film-illumination-scale combinations.

RESULTS AND DISCUSSION

Figure 2 shows the percentage of the rock-covered area which was detected on the various sets of photography. The best result was obtained on color film under cloud at 1:4000 scale on which 74 percent of the rock was detected. The other combinations ranged from 30 to 58 percent rock detected.

The classical analysis of variance could not be used for the numerical interpretation of data as the nature of the experiment did not permit meaningful provision for two or more replications of the treatments. It was also impossible to account for the interpreter variable as no additional suitably trained staff was available. Under these circumstances, statistical analysis using the t-test for paired observations was employed. It showed that color photography was significantly better than color-infrared at the 99-percent level of probability, the 1:4000 scale was significantly better than 1:8000 at the 95-percent level of probability and diffused illumination was significantly better than direct sunlight at the 90-percent level of probability. The values of t in these tests are given in Table 2.

Table 3 shows both the relationships between the two levels of each factor and the interaction effects between the factors, whereas Figure 2 shows only the former without regard to the interaction effects. The factor showing the largest difference between levels was film, followed by scale and illumination in that order.

TABLE 2. STUDENT *T*-TEST FOR PAIRED OBSERVATIONS.

Color/CIR	*1:4000/1:8000*	*Cloud/No Cloud*
	$t_{.05,\ 3\ d.f.} = 3.18$	
6.47_{**}	4.65_{*}	2.67
	$t_{.10,\ 3\ d.f.} = 2.35$	

TABLE 3. PERCENTAGE INCREASE IN ACCURACY

A. *Color/Color Infrared Film*

	Illumination	
Scale	Cloud	No Cloud
1:4000	48	23
1:8000	46	73

B. *1:4000/1:8000 Scale*

	Illumination	
Film	Cloud	No Cloud
Color	30	12
CIR	28	56

C. *Cloud/No Cloud*

	Scale	
Film	1:4000	1:8000
Color	28	10
CIR	6	30

A large amount of rock was not detected on any film-illumination-scale combination due mainly to the overtopping vegetation. Much of the rock, even where not overtopped by dense eucalypt canopy or rainforest species, was still concealed from view by a dense layer of scrub, bracken ferns or moss. It is considered that the accuracy was reduced by the loss in definition incurred through photographic enlargement, although this hypothesis was not verified. Results could possibly be improved, at the expense of area coverage, by obtaining the photographs at contact scale rather than as enlargements.

As well as these factors, which were common to all sets of photographs, other factors caused the difference in the results for each film-illumination-scale combination. As the subject being interpreted was beneath a forest cover, shadow played a very important part in the interpreter's ability to detect rock areas. Due to the narrower exposure latitude of color-infrared (2443) as compared to color (2445) film (Eastman, 1972) the shadow areas on the former were underexposed whereas the crowns were correctly exposed. The underexposure of shadowed areas resulted in less ground detail being visible on color-infrared than on color. An exposure which tended to overexpose the crowns and correctly expose the understorey would pre-

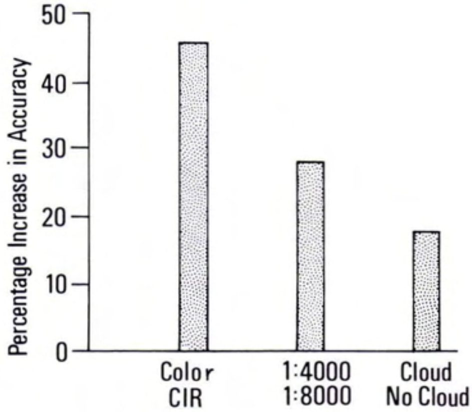

FIG. 3. Relative increase in accuracy of color over color-infrared, 1:4000 over 1:8000, and cloud over no clouds.

sumably increase the accuracy of understorey interpretation.

On the under-cloud photography the diffused light reduced the reflectance contrast between crowns and shadowed understorey. Although this resulted in a more evenly exposed image on the color-infrared and the colors had reasonable saturation and density, the color contrast between the rocks and the surrounding vegetation was greater on color than on color-infrared.

The third factor studied was scale. The percentage rock detected was greater on each set of 1:4000-scale photos than on the corresponding 1:8000-scale sets due to the greater amount of detail visible and the greater precision possible in delineating type boundaries on the large scale. Also, the 1:4000-scale photos were exposed using a longer focal-length lens than the 1:8000. The resultant lower degree of radial displacement of the crowns enabled a better view of the ground.

Although this study was concerned with the detection of rocks that contrasted sharply with surrounding vegetation in quality and quantity of reflected light, the same photographic techniques would presumably be useful in other applications such as the identification of understorey species or of various degrees of fuel accumulation or in ecological studies. In a detailed aerial photographic study of a layer in the forest structure that is shaded by the dominant canopy, color film should give better results than color-infrared film, a contact scale of 1:4000 or greater is indicated and if possible the photographic mission should be flown under complete altostratus cloud cover or any other cloud formation which diffuses the sunlight without seriously reducing the total illumination.

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