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Shadowless or Sunlit Photos for Forest Disease Detection?

An Australian study compares shadowless and sunlit aerial photographs on color and color infrared film for detecting crown dieback in a eucalypt forest.

Abstract: *Color and color infrared aerial photographs, exposed over diseased eucalypt forest in Tasmania, Australia under sunlit and shadowless conditions, were compared for precision and efficiency of rating stand damage levels. The criteria used in interpreting damage levels were crown texture, structure, size, shape, color, proportion of epicormic foliage, and the number and size of dead branches. All combinations of film and illumination provided accurate estimates of disease severity. No combination enabled more precise evaluation than any other. However, interpretation was easier and more rapid on color film exposed under shadowless conditions. Limited frequency and duration of suitable cloud cover in the region was recognized as a possible impediment for large-area shadowless surveys. All four interpreters overestimated damage severity in healthy stands and underestimated it in severely affected stands.*

Introduction

Forest managers in Southern Tasmania, Australia require an estimate of the extent and severity of a disease which has severely damaged eucalypt forests in the region. This disease known as 'regrowth dieback' affects *Eucalyptus obliqua* and *E. regnans*, the predominant species in tall wet forests of regrowth resulting from logging and burning of virgin forests, which in places exceeded 90 m in height. The disease, which was first observed in 1964 (Bowling and McCleod, 1968) and is believed to have originated about 1959 (West, 1979), now affects about 60,000 ha and has caused substantial loss of volume and value (West and Podger, 1980). A recent account of the disease, its symptoms, and the various theories about its cause has been presented (Podger *et al.*, 1980). It is believed that drought and *Armillaria* root rot are important factors in the etiology of the disease (West, 1979; Kile, 1980; Podger *et al.*, 1980).

Healthy regrowth eucalypts support dense clumps of uniformly distributed foliage at the branch tips. Trees affected by regrowth dieback usually progress through the following visible symptoms as they decline: the appearance of epicormic foliage which develops from dormant buds on the main branches and upper trunk; thinning of the foliage of the primary crown and dieback of the fine twigs; dieback of larger branches; increasing production of a secondary or epicormic crown, usually much smaller than the primary crown; and death of the epicormic crown (see Figure 1).

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(a) (b) (c) (d)

FIG. 1. (a) A healthy *E. obliqua* with foliage uniformly distributed in clumps at the branch tips. (b) An affected *E. obliqua* with thinning foliage in the primary crown and well developed epicormic foliage on the trunk and main branches. (c) Advanced dieback with most of the crown composed of epicormic foliage and many dead branches. (d) Final stages of dieback with no primary crown remaining and the secondary epicormic crown is dying.

Difficulty of access in the dense undergrowth and mountainous terrain of the region together with other economic considerations have led to a search for techniques of aerial survey which are suited to the problem. The particular symptoms and characteristics of a disease determine the most appropriate techniques of survey for assessing the extent and severity of the disorder. The most important characteristics of the disease for choice of survey technique are

- It affects only the eucalypt overstory and not the dense understory,
- The disease is a slow decline which results in a gradual thinning of foliage and dieback of branches over periods of 5 to 10 years or more,
- The distribution of diseased individuals within the stand is random, and
- The size and color of living leaves on diseased trees are not different from those of healthy trees in the same stand.

Because of these characteristics, regrowth dieback is not amenable to sketch mapping or to small scale aerial photography, which was useful for the mapping of *Phytophthora cinnamomi* infected jarrah forest in Western Australia (Bradshaw, 1974). Thus, Myers and Bird (1978) found 1:8000 scale aerial photography taken in full sunlight suitable only for the separation of dead from living trees. They found scales of 1:3000 or 1:4000 allowed recognition of the four classes of degree of dieback in individual trees, considered necessary for photo determination of a stand dieback rating.

A number of recent reports have indicated that the use of shadowless photographs (taken under a thin cloud cover) gave improved results in forest damage survey (Bradshaw and Chandler, 1978; Gregg *et al.*, 1978; Myers, 1982; Schultz, 1978; Wear and Wheeler, 1977; Willett and Ward, 1978). The purpose of this study was to compare the usefulness for dieback detection of color and color infrared photographs exposed under full sunlight and under shadowless conditions.

Methods

Twenty-four established yield plots were selected near Dover, Tasmania (43° 30′S, 147°E) and photographed vertically from the air in February 1980. The plots were then visited, and a crown dieback rating was assigned to each dominant and codominant tree. Four interpreters classified each dominant and codominant tree on the photo plots into four classes of dieback.

In a separate exercise each interpreter classified 246 trees of known dieback rating. By this procedure, four sets of standardized and four sets of unstandardized estimates were prepared for each combination of film and illumination. Relationships were examined by regression analysis.

The experimental design encompassed 768 observations in total, 24 plots by two films by two illumination conditions by four interpreters by two estimation methods (unstandardized and standardized). In fact, it was not possible to photograph all the plots with every film/illumination combination, and 13 plots were missed on some combination, with the result that 104 of the 768 observations were missing.

Selection of Plots

Detailed records are available on the severity of dieback in individual tree crowns on some 88 permanent yield plots which were established in the late 1940s and early 1950s. The severity of dieback in individual crowns has been periodically recorded on these plots since 1966, and in some instances annually since 1971. Twenty-four plots were selected for study to establish the correlation between photo-interpreted and ground-assessed dieback severity. The plots were chosen to represent the full range of dieback severity which occurs with the following constraints: they were unthinned and had suffered no fire severe enough to cause crown scorch during their measurement history.

Aerial Photography

The plots were photographed vertically at 1:3000 scale using a 230-mm format, KA-2 Fairchild camera with a 305-mm focal-length lens. Stereoscopic overlap of 80 percent was used to assist stereo viewing, which can be difficult at large scales when using survey format cameras. The photographs were exposed under full sun and under a thin cloud cover in February 1980 on color film (Kodak Aerochrome MS Film 2448 Estar Base) and on color infrared film (Kodak Aerochrome Infrared film 2443 Estar Base). Both films were processed to positive transparencies (see Plate 1).

Ground Classification of Dieback Rating

Disease severity in all 24 plots was assessed in the field close to the time of photography by determining the 'crown dieback rating' of each dominant and codominant tree in each plot. *Crown dieback rating* is defined as the proportion of primary branches in the actively growing part of the crown on which the leaves have died at the branch tip (Podger *et al.*, 1980). The rating of each tree was determined in the field by inspection of the tree with binoculars. It was determined in the range 0 to 100 percent of primary crown affected in steps of 10 percent. *Stand dieback rating*, defined as the mean crown dieback rating of all dominant and codominant trees in the plot, was calculated for each plot as a single measure of stand health for the purpose of evaluating photointerpretation results and was based on an average of 53 trees per plot.

Photointerpretation of Dieback Rating

Four interpreters with varying degrees of experience interpreted photographs of each plot. The

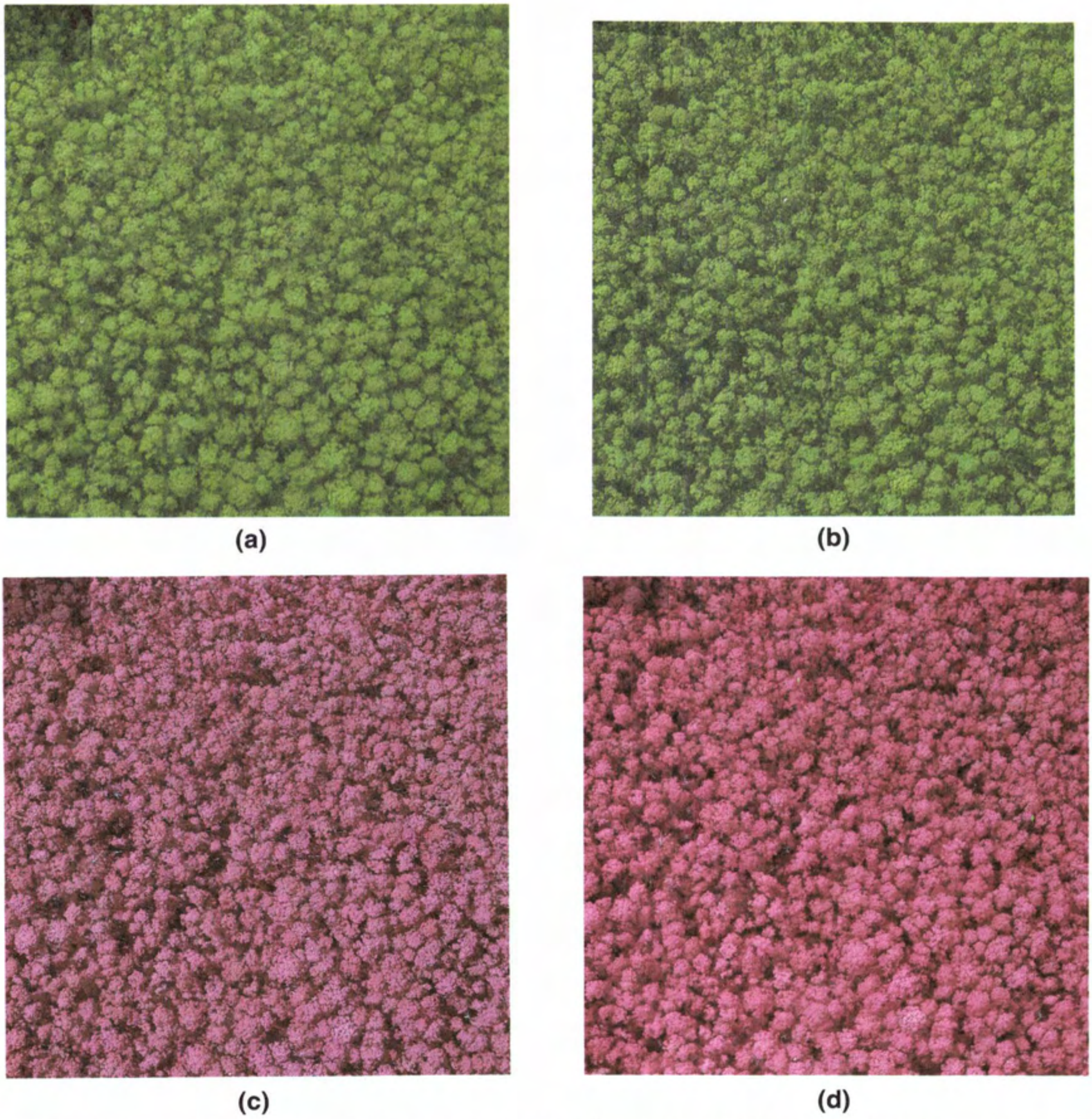

PLATE 1. An example of the four combinations of film and illumination at 1:3000 scale. (a) color sunlit. (b) color shadowless. (c) color infrared sunlit. (d) color infrared shadowless.

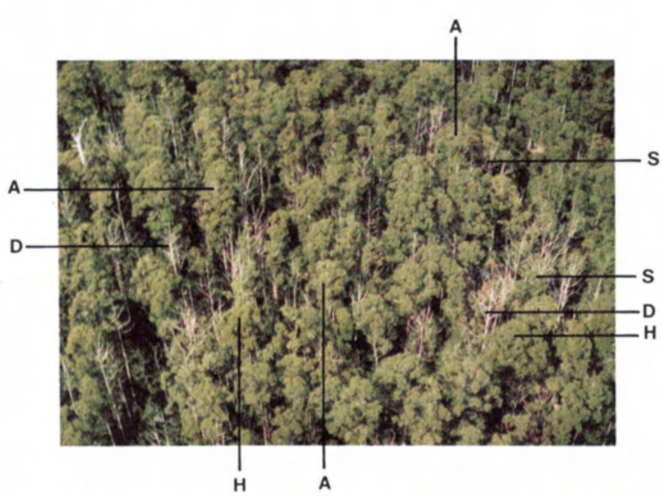

PLATE 2. A low oblique aerial photograph taken over a severely affected *E. obliqua* stand showing the four photointerpretable classes of crown dieback. H—Healthy, A—Affected, S—Severe, D—Dead.

order in which the four different types of photographs were considered was random as was the order of interpretation of the plots on each medium. Prior to interpretation, extensive training was conducted on five study sites to familiarize the interpreters with the photo-appearance of the various stages of crown dieback. Three of the four interpreters had also had experience with assessing the level of dieback in the field. The interpreters classified each dominant and codominant tree on the photo-plots into one of four classes of apparent crown dieback:

- Healthy—up to 20 percent primary crown dieback
- Affected—30 to 40 percent primary crown dieback
- Severe—greater than 40 percent primary crown dieback
- Dead—leafless

These four classes were successfully identified with about 80 percent accuracy in earlier trials on 70-mm color diapositives exposed under full sun at scales between 1:2000 and 1:4000 (Myers and Bird, 1978). As well as being recognizable classes on the large scale photographs, these class limits closely correspond to meaningful dieback levels observed in the field. Podger *et al.* (1980) considered that dominant and codominant trees with dieback ratings less than 20 percent should be regarded as healthy because occasional branch dieback and production of epicormic foliage can occur in any healthy eucalypt as a result of action by a number of agents. They considered that 'affected' stands are those with a dieback rating of 20 percent or greater and that 'severely affected' sites have a rating of 40 percent or greater.

More than 22,700 assessments of the health of tree crowns were made by the four interpreters on the four photographic media. The criteria used in interpreting the crown dieback ratings were crown texture, structure, size, shape, color, proportion of epicormic foliage, and the number and size of dead branches (see Plate 2 and Table 1). The time required for interpretation of each plot on all media was recorded as a measure of ease of interpretation.

STANDARDIZATION AND ANALYSIS

In addition to the plot trees, another 246 trees were classified on each photographic combination by each interpreter. Subsequently, the trees were located in the field and the crown dieback ratings were assessed. By comparing an interpreter's photo-interpreted dieback classifications with the ground-assessed dieback ratings for these sample trees, it was possible to calculate a bias factor for each interpreter and each photographic combination. The bias factor was then used to standardize his interpreted classifications on the 24 yield plots.

Regression equations were established to remove the bias in estimating stand dieback ratings for a large scale survey of the regrowth forest. The equations related actual stand dieback ratings to interpreter's estimates and were based on the pooled, standardized data of two of the interpreters. The equations were tested by applying them to the data of the other two interpreters. They were found to be unbiased in estimating actual stand dieback rating from interpreters' estimates, and there were no significant differences in precision of estimates between interpreters.

RESULTS AND DISCUSSION

Initial inspection of the data showed that all the interpreters underestimated dieback ratings of stands with high ratings and overestimated dieback ratings of stands with low ratings. This occurred with both films and under both illumination conditions regardless of whether interpreters had been standardized or not. Figure 2 demonstrates the effect for one interpreter. It shows, for the various photographic combinations with and without interpreter standardization, scatter plots of the interpreter's estimates of stand dieback rating for the various plots against their actual ratings. In all cases, the relationship between estimated and actual stand dieback rating appeared to be linear. Straight-line, least-squares fits to the data of the various photographic media are shown on the figure. Similar patterns were obtained from the other three interpreters.

The bias in interpreters' estimates was most likely because the interpretation of the crown dieback rating of an individual tree was influenced to some degree by the condition of the neighboring trees in the stand. That is, each interpretation was somewhat relative, not absolute. If most of the trees on a plot were 'severe,' then ones which were only 'affected' would look relatively much healthier and were more likely to be misclassified as 'healthy,' resulting in an underestimate of the stand dieback rating. Similarly, in very healthy plots, 'healthy' trees, which showed some abnormality and which in an average plot would be correctly classified as 'healthy,' had a higher probability of being misclassified as 'affected,' resulting in an overestimate of stand dieback rating.

The interpreters estimates of stand dieback rating were analyzed to determine whether there were significant differences between interpreters, films, illumination conditions, or estimation methods. The precision of the estimates was examined by considering the residual variances of the regression relationships relating estimated to actual stand dieback ratings (Table 2). The variance of these data was analysed as a 4×2^3 factorial design. There was a significant difference ($P < 0.05$) between the estimation methods and between interpreters but not between films or illumination conditions. The significant means are shown in Table 3. The standardized estimates of stand dieback rating were signifi-

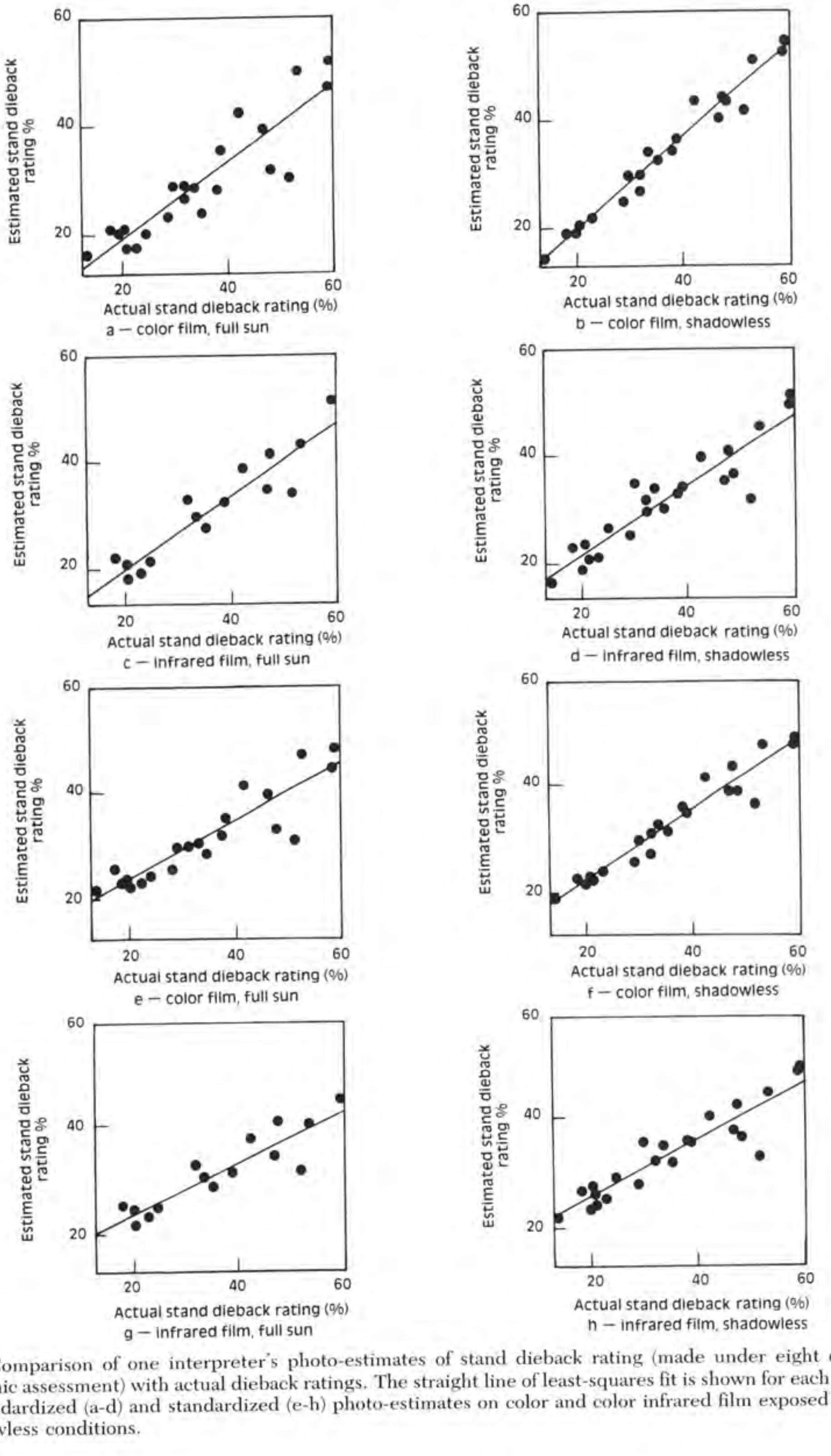

FIG. 2. Comparison of one interpreter's photo-estimates of stand dieback rating (made under eight conditions of photographic assessment) with actual dieback ratings. The straight line of least-squares fit is shown for each combination of non-standardized (a-d) and standardized (e-h) photo-estimates on color and color infrared film exposed under sunlit and shadowless conditions.

Table 1. Interpretation Criteria for Crown Dieback Ratings on 1:3000 Scale Color and Color Infrared Aerial Photos of Regrowth Eucalypts in Tasmania

Interpretation criteria	Crown dieback classification			
	Healthy	Affected	Severe	Dead
Crown texture and structure	Solid clumps Crisp sharp edges accentuated by shadows on sunlit photos. No epicormic foliage visible.	Fuzzy texture No distinct lobes No sharp outline	Not fully occupying available space Very coarse irregular texture Fuzzy, semi-transparent clumps irregularly distributed. Epicormic foliage visible on trunk and main branches	No foliage or sparse dead foliage
Crown color*	Partially dependent on amount and stage of foliage flush. Col. Sun—moderate to strong yellow green. Col. shad.—moderate yellowish green CIR sun and shad.—deep to strong yellowish pink	Less vivid on all photos. Col. sun and shad.—grayish yellow green or grayish greenish yellow CIR sun and shad.—grayish yellowish pink	Highly variable depending on position in crown and whether primary or epicormic foliage. Dull colors	When dead foliage remained Col. sun and shad.—moderate orange yellow CIR sun and shad.—pale yellowish pink
Branch visibility	No dead branches visible	Very fine dead branch tips may be visible on crown surface on col. and CIR shadowless only	Many large branches visible Few fine branches remaining	Few bare large branches and bare trunk

* Color names are after ISCC-NBS centroid color system (Kelly and Judd, 1955)

TABLE 2. RESIDUAL VARIANCES OF STRAIGHT-LINE REGRESSION RELATIONSHIPS OF ESTIMATED ON ACTUAL STAND DIEBACK RATINGS

Estimation Method	Interpreter	Film: Color, Illumination: Sunlight	Film: Color, Illumination: Shadowless	Film: Color infrared, Illumination: Sunlight	Film: Color infrared, Illumination: Shadowless
Unstandardized	1	15.0	10.5	17.4	10.1
	2	22.3	4.8	12.9	12.7
	3	12.5	11.9	8.9	6.6
	4	39.6	23.3	24.7	37.0
Standardized	1	7.1	6.5	7.5	5.4
	2	12.5	6.2	9.7	9.7
	3	8.4	8.5	7.1	5.1
	4	9.4	11.0	12.1	14.3

cantly more precise than the non-standardized estimates because of the use of the bias factor for each interpreter. The analysis showed that interpreter 4 was appreciably less precise in his estimates than were the other interpreters. Interpreter 4 was not the one without field experience nor was he the least experienced. However, it was subsequently found that he needed corrective lenses, which would account for his lower precision in interpreting crown health.

Each combination of film and illumination provided accurate estimates of actual stand dieback rating, and there were no significant differences either in the degree of bias or in the precision of the estimates from the various combinations. As mentioned previously, in regrowth dieback the size and color of living leaves are normal, even in severely affected trees. The change in color on the photographs which was associated with decline was due to the loss of leaves, resulting in thinner foliage clumps with more included shadows, which affected the spectual reflectance. At a scale of 1:3000, the morphological symptoms of thinning foliage, dead branches, and epicormic foliage were sufficiently visible to enable equally precise estimates of actual

TABLE 3. MEANS OF INTERPRETERS AND ESTIMATION METHOD FROM VARIANCE ANALYSIS OF DATA IN TABLE 2

Interpreter 1	Interpreter 2	Interpreter 3	Interpreter 4
9.9[a]	11.4[a]	8.6[a]	21.4

Estimation Method: Unstandardized	Estimation Method: Standardized
16.9	8.8

[a] Means with similar superscripts do not differ significantly (as assessed by a least significant difference test with p = 0.05).

stand dieback rating to be made on color or color infrared film and on sunlit or shadowless photographs. There appeared to be no change in infrared reflectance with advancing disease which would favor color infrared film, and the visible color changes which did occur appeared to be more easily distinguished and more consistent on color film than on color infrared.

Bradshaw (1974) found that color differentiation between healthy and diseased foliage was improved on shadowless photographs by the elimination of the bright reflection from shiny flat leaves typical of many Australian indigenous plant species. Similar comments have been made about shadowless photographs of a number of eucalypt crown diebacks in Victoria (Willett and Ward, 1978). In this study the reduction of specular reflection and elimination of shadows within the crowns did not reveal sufficiently increased details of the key morphological symptoms to enable a more precise estimate of actual stand dieback ratings to be made. It is possible that at a smaller scale, if the specular reflectance from sunlit foliage clumps obliterated details of dead branches, shadowless photography may enable increased precision.

Because none of the combinations of film and illumination studied was superior in terms of precision or bias, the decision with respect to photographic medium for conducting the sample survey of the entire forest must be based on other considerations. In the Australian forest environment, where the atmosphere is generally very clear and favorable for aerial photography, the superior haze penetrating characteristic of color infrared film is not an important consideration. In addition, the use of color infrared film poses greater technical problems of storage and processing than color film. Interpretation of the stand dieback ratings on color film was about 25 percent faster than on color infrared film, reflecting the greater ease of interpretation. Interpreter preference was also for the color film because of the greater range of crown colors and their more natural appearance. Therefore, the use of color film is more appropriate in this situation.

The choice between shadowless and sunlit photographs is not as clear cut. Total interpretation time was about 20 percent longer for sunlit than for shadowless photographs, and interpreter preference was for the shadowless photographs. The more uniform illumination across the scene and the absence of dark shadows enabled better depth penetration into the crowns. However, the frequency and limited duration of cloud cover suitable for shadowless photography of extensive areas may prove to be a limitation. Shadowless aerial photography tables (Myers and Watts, 1981) for the region indicate a probability of ideal cloud conditions occurring in any month of 2 to 10 percent. Less than ideal but still suitable conditions for shadowless photography occur for 14 to 39 percent of the time, depending on location. In view of these consideratons, color shadowless photography at 1:3000 scale should be used for assessing Tasmanian regrowth dieback. It may be necessary from practical considerations to conduct part of a survey under sunlit conditions, but this should not affect the precision of the estimate of stand dieback ratings. The techniques, limitations, and special precautions for obtaining shadowless photography have been reviewed by Myers (1982).

Conclusion

Large-scale color and color infrared aerial photographs exposed under sun and under a high cloud cover have been shown to be a successful and useful tool for assessing eucalypt regrowth dieback in Tasmania. In this study, interpreters accurately assessed the damage levels of affected stands on all four combinations of film and illumination conditions, and there were no significant differences in the precision of estimates from the various combinations. Standardizing an interpreter's assessment of individual tree health, by using his calculated bias factor, significantly improved the precision of his estimate of stand dieback rating. The bias factor was based on the interpreter's assessment of a number of trees for which the actual crown health had been assessed in the field. All interpreters tended to overestimate stand health in severely affected plots and underestimate it in healthy plots. Regression equations were established to remove this bias in estimating stand dieback ratings. The recommended film/illumination combination is color film exposed under a high cloud cover based on practical considerations and interpreter preference, but the results showed that accurate interpretation can be achieved on a variety of photo products obtained under varying weather conditions.

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