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FILMS AND FILTERS FOR FOREST AERIAL PHOTOGRAPHY[1]

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SINCE the publication of the author's previous paper on this subject in 1946,[2] and the discussion in his book published in early 1948,[3] much has been learned concerning the uses of various films and filters for aerial photography to be used for forestry purposes. Such photography is now of major importance as many tens of thousands of square miles have been photographed since 1943 primarily for forestry purposes, and to specifications prepared in part by forest photogrammetrists.

The present paper summarizes briefly the author's impressions of recent commercial experience with various film and filter combinations; reviews the work on film and filter combinations in California by Jensen and Colwell; and presents recent experimental data obtained during the period of normal summer coloration of the foliage in the northeastern United States.

RECENT EXPERIENCE

Since 1945, some thirty-seven thousand square miles of modified infrared photography (infrared film exposed through minus blue or similar filter) have been undertaken for the United States Forest Service,[4] while another large amount has been undertaken for other public and for private agencies interested in forest land. In addition, considerable panchromatic photography has also been taken for forestry purposes. All in all, probably from fifty to one hundred thousand square miles of forest aerial photography has been taken less than four years. Most of this photography has been made in the Northeast, the northern Lake States, the Southern Pine Region, and the Pacific Northwest.

The writer has had the opportunity of examining samples of much of this photography and has visited a number of the photographed areas on the ground. His impressions may be summarized as follows:

1. East of the Great Plains, infrared photography seems to have been more successful than panchromatic in practically every instance, and will continue to be the more widely used type for forestry purposes. In only one instance was pronounced dissatisfaction expressed concerning infrared photography, and this was because the photography, although excellent, was too similar to panchromatic, and was not enough better (although it was better) as the purchaser had expected.

2. There exists, however, many special sets of circumstances where panchromatic photography is to be preferred, such as (a) fall photography after the foliage of the deciduous trees has changed color but before the leaves have fallen, a time when better tonal contrasts between species and types are obtained on panchromatic film; (b) photography when deciduous trees are leafless; and (c)

[1] The experimental work described in this paper was financed by a grant from the Research Corporation of New York City.

[2] Spurr, Stephen H. and Brown, C. T. Jr. 1946. Specifications for aerial photographs used in forest management. PHOTOGRAMMETRIC ENGINEERING 12: 131–141.

[3] Spurr, Stephen H. 1948. *Aerial Photographs in Forestry.* New York, The Ronald Press Co. 340 pp.

[4] International Photogrammetry Congress. 1948. Report of Commission I—Photography. PHOTOGRAMMETRIC ENGINEERING 14: 229–279.

photography where broadleaf trees are of very limited areal importance, as in many parts of the west.

3. Tonal contrast in infrared photographs seems to decrease from north to south. In the southern pine region, it is difficult to obtain more than minor contrasts between species and types, although these minor contrasts can be used to great advantage by the qualified photo-interpreter. It has been suggested that the low contrast is due to the similarity in tone between the new foliage of the southern pines and the associated hardwoods, especially early in the season of normal green coloration (late spring and early summer). The author thinks it more likely associated with the different spectral qualities of solar radiation in the south, where, because of the high angle of the sun, more radiation of the shorter wave-lengths (blue and green) reaches the ground. In these shorter wavelengths, the absolute difference in reflectance between the various tree species is not great. The observed lack of pronounced differences in tone may also be related to the absorption of infrared radiation by atmospheric moisture which is apt to occur in large amounts because of the high summer temperatures.

4. Tonal contrast in infrared photography seems to be greater in the late summer than in the spring or early summer, a phenomenon due in part to the changes in reflecting properties of the foliage as the season progresses, but probably due to a greater extent to the angle of elevation of the sun and to atmospheric moisture conditions mentioned in the above section.

5. Several areas have been photographed with red or green filters and infrared film. In general, the results have confirmed early experimental findings. Excessive tonal contrasts are apt to be obtained, broad-leaved types being much overexposed and narrow-leaved types underexposed. Such photographs provide a ready means of recognizing contrasting forest types, but are generally inferior to modified infrared photographs in general pictorial quality. In other words, normal infrared photographs are apt to be better than modified infrared for type mapping purposes, but are generally inferior for all-round use.

6. Scale is an important factor in determining what film should be used. Other factors being equal, infrared is better suited to the smaller scales and panchromatic to the larger scales. Infrared is useful where it is primarily desired to locate stand boundaries, while panchromatic is better at large scales (above 1:12,000) because it provides the clearer detail and shadows of lesser density, thus facilitating the study of individual trees.

7. There is some evidence that hardwood tones on infrared are darker in the autumn, when the leaves have their autumn coloration, than in the summer, and that tonal contrasts during the fall period are better on panchromatic.

8. In an intensive study of aerial timber cruising carried out by the Harvard Forest, a large number of different aerial photographic coverages were used. Panchromatic photography proved unusable because of the impossibility of distinguishing hardwoods from softwoods accurately, and the large error in volume estimation that was due to this factor as softwood stands characteristically have a far greater volume per acre than hardwoods of the same height and density class. In these tests, quality of photography was found far more important than the specific filter used with the infrared film or the scale of photography.[5] The best volume estimates were obtained from 1:18,700 photographs of excellent quality, and the poorest from 1:5,300 photographs, also modified infrared but marred by underexposure and long black shadows.

[5] Pope, Robert B., Cameron, Robert C. Hill, Miles R. and Spurr, Stephen H. 1949. Aerial Photo-cruise Tests in Central New England. Unpublished manuscript.

THE CALIFORNIA TESTS

The final answer to the question of which film and filter combination should be used in a given region for a given purpose, however, can only be obtained by specific tests carried on objectively and under controlled conditions. In many cases, test strips of various film and filter combinations have been made preparatory to commercial coverage, but in too few instances has adequate study been made of the resulting photographs.

The tests carried on by Jensen and Colwell[6] constitute an excellent example of what is needed to supply information for a given set of conditions. The tests were detailed and well-executed, and the findings logical. Only a few minor points seem to merit further discussion in reviewing their paper.

The chief criticism of the California paper is that the conclusion that panchromatic photography yielded "much more information than is obtainable from infrared minus-blue photography" is not fully borne out by the detailed analyses presented. This reviewer is inclined to concur with Jensen and Colwell that panchromatic photography is preferable for the purposes of the California vegetation survey, but feels, after a careful study of the results and of a few of the photographs (but not of the ground itself) that for the ponderosa pine region at least, infrared photography has much to offer and for some purposes may be superior.

We should clearly bear in mind that the California survey is a broad vegetational and land-use survey. In this respect, the term "forest survey" is a misnomer. Indeed, the chief difficulty experienced with infrared seems to lie in distinguishing between various non-forest vegetation types (chaparral, bushy herbs, grass, bare ground, and rock). In the pine region, the infrared seems to be actually better for distinguishing between the various commercial forest types.

This in no way contradicts the findings of the investigators, but merely serves to point out with them that the film and filter combination must be tailored to the purpose of the survey. We may add that it should be further tailored to the way the survey will be conducted. For instance, the amount of field work planned and the way in which it will be undertaken might well influence the decision as to film and filter. In most cases, infrared will give more information concerning areal distribution of forest types and the location of the boundaries between them, while panchromatic will yield more concerning the individual tree or shrub. For most efficient use of either, the subsequent field work should be carefully planned to take into consideration the information furnished or not furnished by the photographs. It may well turn out that, to pick an example, infrared should be chosen for the ponderosa pine region if field work must be limited to one man-day per square mile, but that panchromatic is indicated if the amount of field work can be doubled.

It follows that a different field procedure may well be evolved for each type of photography. If we carry the logic a step farther, a different classification system may well be also evolved.

In other words, the most efficient use of aerial photographs of any type demands a technique predicated not only upon the needs of the client, but also upon the contribution of the photographs themselves. Only when the classification system, the field procedure, and the photographic analysis procedure have been evolved with both factors in mind can a truly objective decision be made and the best survey obtained.

[6] Jensen, H. A. and Colwell. R. N. 1949. Panchromatic vs. Infrared Minus-blue Aerial Photography for Forestry Purposes in California. PHOTOGRAMMETRIC ENGINEERING. Vol. XV, 2:201–223.

Returning to the Jensen and Colwell paper, their third figure provides much necessary information. In addition, however, it might be well to consider also the spectrum of the sunlight reaching the ground. This is a factor which varies with the angle of elevation of the sun and with atmospheric conditions, and as stated in the preceding section dealing with recent experience, may well be of major importance in affecting tonal contrasts on infrared film.

This reviewer does not accept the statement that "orange-red light theoretically should be excluded because of glare in this part of the spectrum." Wholly aside from theoretical arguments, we should remember that panchromatic film registers a very great deal more orange and red light than does infrared and, photographs taken with it exhibit no harmful effects of the glare. Also, although theoretically green "seems to be more useful than other wave-lengths," it should be pointed out that in the California tests, the green filter with panchromatic gave somewhat poorer results than the minus-blue. The subsequent section on tests in New Englandwill deal in part with these points.

Finally, this writer tends to agree that infrared ordinarily does not record quite the fineness of detail that panchromatic does, although several experienced workers maintain that there is no noticeable difference. On the other hand, the loss of detail is ordinarily not great. The California infrared photographs seem to be somewhat poorer than most infrared photographs in this respect. As to the focus of the lens, empirical tests with several standard aerial camera lenses have apparently demonstrated that both infrared radiation and visible light with wave-lengths greater than 500 millimicrons (that portion of the visible spectrum admitted by the minus blue filter) can both be focused on the photographic plate well within the tolerance of the optical system. Such loss of detail as does occur in infrared, therefore, seems ordinarily more due to the greater tonal contrasts and to the very slightly poorer resolving power of the film than to camera focus.

Everything considered, the Jensen and Colwell paper is a real contribution to forest photogrammetry, and should serve as a model for future studies of a similar nature, studies which are much needed today.

THE NEW ENGLAND TESTS

During the summer of 1948, the writer carried out tests of a somewhat different type in an effort to learn more about the use of various films, filters and exposures for forestry purposes. In order to permit a large number of tests under controlled conditions, photographs were taken obliquely from high ground elevations. A Kodak Medalist II camera equipped with a 100 mm. Ektar lens was used, mounted on a tripod. Fresh roll film and conventional Series VI filters mounted in glass were used. Both the films and filters closely approximated those used and usable with aerial cameras, but were not in all cases identical.

Four series of photographs were taken. Test 1 was made from Choate Ledge on the Slab City Block of the Harvard Forest in Petersham, Massachusetts. The elevation of the ledge is 996 feet above sea level, and that of the Swift River in the valley below about 730 feet, giving a maximum difference of elevation of 266 feet. The scale at the center of the view is about 1:6,000, this point being about three-eighths of a mile from the camera. The camera was pointed to the southeast, or into the sun, and the photographs taken between 10:00 and 11:00 A.M. Eastern Standard Time on July 28, 1948.

Test 2 was made from Cathedral Ledge in North Conway, New Hampshire. The elevation of the camera station was 1,140 feet and that of the valley below 500 feet, a difference of 640 feet. The distance to the near edge of Echo Lake in

the center of the view was one-half mile, giving a picture scale of about 1:8,000 at this point. The mountain spur in the upper left hand corner of the picture (Figure 3) was 4 miles distant, and the mountains in the center background about twice this distance or more. The camera was pointed to the southeast or into the sun, and the photographs taken between 8:30 and 10:00 A.M. Eastern Standard Time on August 11.

Test 3 was made from Cannon Mountain in Franconia, New Hampshire, looking across Franconia Notch. The elevation of the camera station was 4,300 feet, and that of the valley below 1,800 feet, a difference of 2,500 feet. The distance to the valley in the middle of the view was $1\frac{1}{4}$ miles, and the scale at this point approximately 1:20,000. Mt. Liberty in the center background was 4 miles distant and 4,460 feet high. The camera was pointed at approximately right angles to the sun, and the photographs taken between 12:30 and 2:30 Eastern Standard Time on August 11, 1948.

Test 4 was made from Prospect Hill Fire Tower on the Prospect Hill Block of the Harvard Forest in Petersham, Massachusetts. The elevation of the camera station was 1,440 feet, and that of the view from about 1,100 to 1,300 feet. The scale in the center of the photograph is approximately 1:6,000, but both near and distant areas are included. The camera was pointed to the northeast away from the sun, and the photographs taken between 3:00 and 4:30 P.M. Eastern Standard Time on August 31.

The films tested were Kodak Verichrome representing the orthochromatic emulsions, Kodak Super-XX panchromatic, Kodak infrared, and Ansco Color. The filters included the K-2 (light yellow), G (dark yellow), X-1 (light green), B (dark green), A (red), Kodak Polar Screen (polaroid), and Ansco UV-17 (cutting out ultraviolet radiation). Many film and filter combinations were tried in the various tests, but not all in every test. As many as seventy exposures were made from a single camera station.

Exposures were determined by photo-electric cell light meter. In most cases, four exposures were made with each film and filter combination—the exposure indicated by the light meter, one-half this determined exposure, twice the determined exposure, and four times the amount of the exposure. The desired exposures were obtained by varying either or both the time and the lens opening. In some cases, only two exposures of each film and filter combination were made, the exposure indicated by the light meter and twice this.

All developing and printing was done by the writer. Fresh fine-grain developer was used under careful temperature and timing control to insure equal development for all film. Five by seven enlargements were made of each $2\frac{1}{4}$ by $3\frac{1}{4}$ negative. In many cases, several such enlargements were made to test the effect of printing time and paper. That is, film development was not treated as a variable in these tests, but printing was.

The study of the negatives and prints brought forth the following observations and conclusions:

1. Oblique ground photography from elevated points proved to be an adequate substitute for aerial photography in the testing of film and filter combinations. Any given film and filter combination resulted in pictures closely comparable to those previously obtained from aircraft with the same combination.

2. In order to draw adequate conclusions concerning the film and filter combination, it was necessary to study both the negatives and the prints. If only one or the other were used, highly doubtful conclusions could easily be drawn.

3. Of the variables in the experiment, the type of film used had the greatest effect on the resulting picture. Infrared produced by far the best pictures for

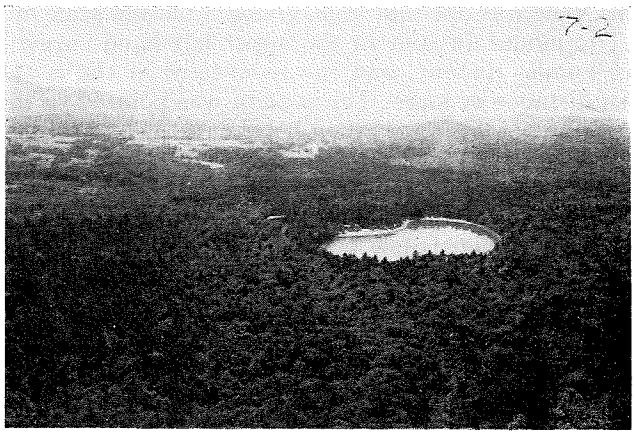

FIG. 1, Test No. 2
Panchromatic Film—Yellow (K-2) Filter

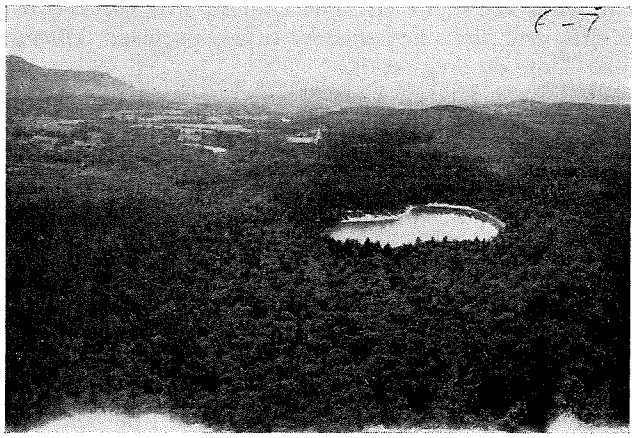

FIG. 2, Test No. 2
Panchromatic Film—Red (A) Filter

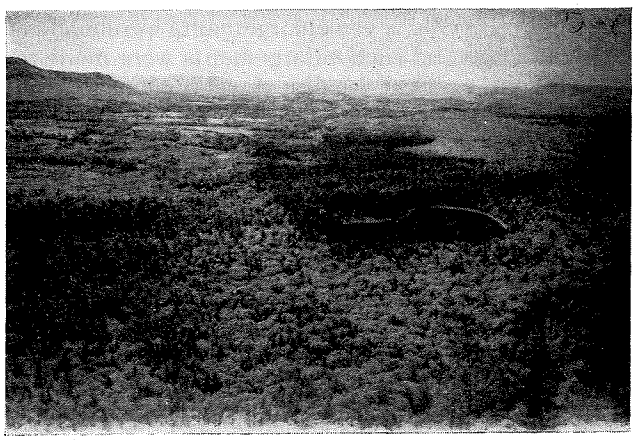

FIG. 3, Test No. 2
Infrared Film—Green (X-1) Filter

forestry purposes followed by panchromatic, orthochromatic, and color in that order. The infrared pictures were of high pictorial quality and clearly differentiated between most of the forest types, being especially good for hardwood-softwood distinctions. The haze-penetrating qualities of infrared film, even when used with a yellow filter, proved to be excellent and superior to that of panchromatic, even when the latter was used with a red filter. The panchromatic photographs were also of high quality, but failed under practically all conditions to provide enough pictorial contrast to distinguish hardwoods and softwoods. The orthochromatic pictures were similar to the panchromatic, but were somewhat poorer in over-all quality in three out of the four tests. The color pictures were technically good, but provided little tonal contrast between tree species, and none that could not be picked up on all the black and white films.

4. The filter used with a given film had little effect (except in color photography) on the resulting photography, provided that exposure, development, and printing were carefully controlled. It was very apparent that much of the variation that has previously been attributed to various filters in forest aerial photography has been in fact due to slight differences in exposure, development, and printing of the particular strips in question.

5. In no case (except with color) were adequate pictures obtained without the use of a filter, or with the use of the polaroid filter. Atmospheric haze in all instances was sufficient under such circumstances to detract from the quality of the photograph. Photographs taken with the polaroid filter were usually very flat and apt to be underexposed under the light conditions of the test photography.

6. With panchromatic film, the various color filters produced little variability in the pictures. Provided that exposure, development and printing were controlled, it proved impossible in most instances to distinguish between pictures taken with yellow, green, or red filters. Studying the whole series, however, it did seem that the best photographs were obtained with the yellow filters, the next best with the red filter, and the poorest with the green filters. The dark yellow G filter was possibly somewhat better than the light yellow K-2 filter. Good pictures, however, were obtained in most instances from all filters.

7. In the two tests where the camera was pointed in the direction of the sun (the sun was sufficiently elevated so as not to interfere with the photography), the use of the red A filter with panchromatic film resulted in photographs in which the hardwoods and softwoods were clearly distinguished. In fact, these photographs somewhat resembled modified infrared photographs, and were noticeably different from all the other panchromatic photography.

8. Various filters used with orthochromatic film yielded similar results to their use with panchromatic. The yellow filters seemed to give somewhat better results than the green filters, although the difference was not clear-cut.

9. With the infrared, excellent pictures were obtained using yellow, green, and red filters, and poor pictures using the polaroid filter. The two yellow filters seemed to produce pictures with slightly less contrast and better detail than the two green and the red filters, thus confirming the general usefulness of the modified infrared technique.

10. The polaroid, ultraviolet, light green and light yellow filters were tried with color film. All produced good pictures of contrasting types. The polaroid filter resulted in excellent photographs and in a farther extension of green coloration into the background than was obtained when no filter was used. The ultraviolet produced perhaps the best all-round photographs. The reduction of the blue light by the K-2 filter and of both ends of the spectrum by the X-1 filter reduced tonal contrasts between forest types as well as producing unnaturally tinted photographs.

11. The time of exposure had more effect on the final picture than did the filter used, but less than did the film emulsion used. Despite the fact that the longest (or widest-open) exposure allowed eight times as much light to reach the film as the shortest exposure, usable pictures were produced in most cases, thus illustrating the wide latitude of the films employed. Tonal contrast between species, however, generally increased with the amount of overexposure, provided that such overexposure was not excessive. Underexposed negatives produced very flat prints, while slightly overexposed negatives produced the best contrast of the series. This indicates that photographs to be used for forestry purposes should be overexposed by about one stop in order to accentuate species differences. The print should be correspondingly underexposed so as to produce a normal final tone.

12. With infrared, overexposure resulted in too much contrast in that the hardwood images were overexposed to the point of exhibiting a loss of detail. Normal exposure appeared to be best for infrared. The same applied to color photography.

13. The photographs taken away from the sun were much flatter in tone than those taken into the sun. The latter were preferable for forestry purposes. Translated into aerial photographic conditions, this would indicate that pictorial contrast is accentuated by a low angle of elevation of the sun, and would help to explain the low contrasts obtained with infrared photography in the south in mid-summer. Further research, however, is needed on this point.

Figures 1 to 3 illustrate the variation in the black and white photographs obtained in the tests. All are from Test 2, taken from Cathedral ledge, and portray a red pine stand around Echo Lake which grades off into softwood-hardwood mixtures and pure hardwoods in several directions. Figure 1 (photograph 7–2) was taken on panchromatic film with a K-2 filter at 1/100 second and f 11. It is of good quality, but is affected by atmospheric haze, and does not distinguish clearly between the forest types although it is better in this respect than most of the panchromatic exposures obtained. Figure 2 (photograph 6–7) is taken with panchromatic and an A filter at 1/50 second and f 4. It illustrates the almost infrared-like quality obtained by a slight overexposure of the negative and compensating underexposure of the print when the camera is pointed into the sun. The picture is well-suited for forestry purposes. Figure 3 (photograph 5–6) is taken on infrared with the X-1 filter at 1/50 second and f 4. It is excellent in all respects.

These tests were undertaken in the hope of evolving a panchromatic or orthochromatic film and filter combination that would produce the tonal contrasts between species, without also being characterized by the black shadows and the small loss of detail found on infrared photographs. No such combination was found. The infrared photographs turned out to be superior to any other film used with any filter.

Actually, the filter used had surprisingly little effect on the final picture. Exposure time was more important. Although there was little to choose between as to exact film, filter, and exposure time for visible light photography (as opposed to infrared), one combination did appear to be promising and merits further investigation. This was the use of a red filter when the film was slightly overexposed and the sun so positioned that both high-lights and shadows could be photographed on the tree images.

SUMMARY

From a discussion of recent experience in the use of films and filters for aerial photography for forestry purposes, a review of the California tests by Jensen

and Colwell, and the presentation of original results of recent film and filter tests in New England, it is apparent that much remains to be done before a specific film and filter combination can be recommended for any given forestry purpose and any given forest region.

Both infrared and panchromatic photography have a very real place at the present time. Each type of film has qualities that dictate its use in certain places and times, and for certain purposes, and limitations that detract from its value under other conditions. It is hoped that the present paper will prove a step towards the eventual solution of this problem, and, at the same time, point out which film should be used under a given set of conditions at the present stage of our knowledge.