J. T. PARRY*
W. R. COWAN
J. A. HEGINBOTTOM
McGill University
Montreal, Canada

Color for Coniferous Forest Species

Not only is the total amount of information greater on the color photo, but it is also better differentiated and therefore more easily interpreted.

PHOTO INTERPRETERS have only recently realised the distinct advantages of having a colored as opposed to an achromatic image when attempting the identification of forest tree species on aerial photography. The color reproduction has a greater resemblance to the original scene than a panchromatic, and so the stimuli in interpretation are more varied and identification is usually more immediate. R. Evans[1] has recorded that at best, the human eye can distinguish approximately 200 gradations on a neutral or gray scale, whereas it is capable of differentiating more than 20,000 different hues and chromas. In air photo interpretation, information about the vegetation cover is derived from the photographic image, and so it is apparent that the more information available from the image, the more complete and positive will be the interpretation.

ABSTRACT: *Considerable interest has been aroused in aerial color photography in recent years, and in this study panchromatic and color photos at a scale of 1:5,000 were compared with regard to their relative value in the identification of coniferous tree species. It was concluded that in using color photos the interpreter can benefit from more varied stimuli in the interpretation process, a natural color appearance which can provide specific color signatures for many species, a greater amount of information on the canopy texture in general, and the morphological characteristics of the tree crown in particular. Not only is the total amount of information greater on the color photo, it is also better differentiated and therefore more easily interpreted.*

Few studies have actually attempted to assess the specific advantages of color aerial photography in distinguishing between tree species, but the investigations that have reached publication stage give clear evidence of the more positive information available from the color photographs compared with black and white.[2] The study presented in the next few pages confirms this view point with regard to the main coniferous species found in eastern Canada.

PURPOSE OF THE STUDY

This research was undertaken to examine the information content of aerial color photography compared with panchromatic in differentiating between the coniferous tree species of eastern Canada.† The Lac Bevin basin in the Laurentides north of Montreal was selected as a convenient study area‡ because, although the basin is only 11 square miles in extent, a variety of site types occur, all of which are readily accessible for ground checking. The area lies in section L4a of Hal-

* Submitted under the title "Aerial color photos in the identification of coniferous forest species."

† This study is part of a wider investigation of surface conditions and their interpretation from air photos which is being undertaken at McGill University. The research has been supported by the Defence Research Board of Canada, Contract 2GR. 7-38 GR. 700005.

‡ Lac Bevin test area—45° 56′ N to 46° 00′ N; 73° 34′ W to 74° 37′ W. Canada N.T.S. map sheet 31 G 15 E (1:50,000).

liday's revised classification of the forest regions of Canada.[3] This section forms part of the Great Lakes—St. Lawrence mixed forest region, and is included within the range limits of ten of the eastern coniferous species. Of these, the larch (*Larix laricina*) was not included because of its deciduous character, which meant that foliage was absent at the time of photography, and the two other species, jack pine (*Pinus banksiana*), and black spruce (*Picea mariana*), were not found within the confines of the basin. Thus, a total of seven species was included in the study: red and white pine (*Pinus resinosa* & *Pinus strobus*), eastern hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea*), eastern white cedar (*Thuja occidentalis*), and white and red spruce (*Picea glauca* and *Picea rubens*).

Initially the use of twin cameras was planned in order to obtain simultaneous panchromatic and color photography at a scale of approximately 1:5,000. However, this was not possible for various reasons, and so each film was flown separately. The panchromatic photography was taken with a six-inch lens in early November using Super XX Aerographic film type 5425-Eastman Kodak, and the color photography (Aerial Ektachrome type 8442-Eastman Kodak) was obtained in the second week of May. A Williamson F 52 reconnaissance camera with a 12-inch focal length was used for the color film using a Wratten HF 3 filter at an exposure of 1/300 second at $f/8$.

The lack of synchronism in the exposure of the two films meant that the conditions were not identical; the appearance of coniferous trees does not change to any appreciable extent from the end of the growing season until the flush of the new needles, which does not begin in the Lac Bevin area until late May. In studies of red pine (*Pinus resinosa*) at Ann Arbor, Michigan, C. E. Olson[4] recorded a fairly large increase in spectral reflectance between May and July continuing at a lesser rate until late in the growing season, and then a rapid decline in October and November, with a relative stillstand until the following May when the reflectance was at its lowest (Figure 1). The total percentage reflectance was found to be approximately five percent lower in May than in late August to September when it reached a maximum, and the shift in peak reflectance amounted to 10 mμ, which meant that the foligage in May was appreciably darker and considerably yellower than later in the season. Spectral reflectance data from other sources[5] suggests that the phenological effect is similar for other coniferous species. It follows that the general reflectance levels for all the coniferous species treated in this study are at a minimum, and the peaks in the reflectance curves occur at somewhat longer wavelengths than is the case with the summer foliage.

In assessing the amount of information available from each film type, all of the characteristics normally considered by the photo interpreter were taken into account—crown morphology (including shape, branching habit, apex and margin), crown texture, and the dominant neutral value (gray tone) and color. Considerable attention was given to this last factor in view of the greater discrimination which may be expected on theoretical grounds from the colored image. The main reason for this is physiological: in normal photoptic vision the receptors which line the retina of the human eye are sensitive to very small differences in wavelength, which means that any objects which differ only slightly in hue will be distinguishable, and any boundary or discontinuity which incorporates an edge gradient of only a few millimicrons will be perceptible. It has been shown that the human eye is most sensitive in the region of 550 mμ,[6] which corresponds to hues of yellow and yellow green, and so it may be expected that even slight differences between the foliage of one species and another can provide a basis for their differentiation on aerial color photography.

Field Procedures

In order to avoid anomalies due to disease, or differences in age and vigour resulting from site factors or genetic variations within the species, a sample consisting of 10 mature trees of each species occurring in different parts of the study area was selected giving a

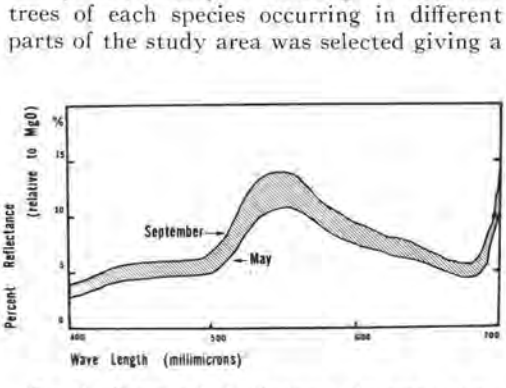

FIG. 1. Phenological effects on the spectral reflectance of red pine (*Pinus resinosa*) adapted from C. E. Olson (1962).

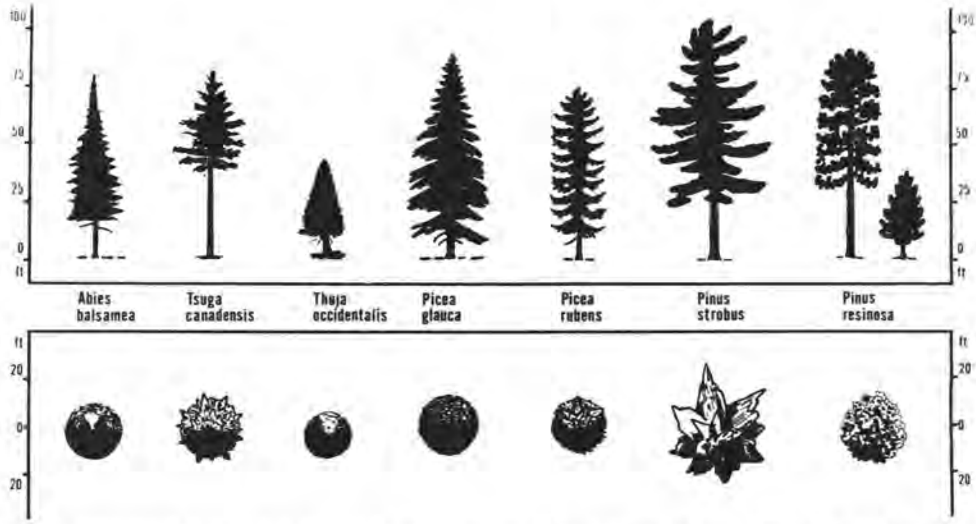

FIG. 2. Crown morphology in plan (air photo view) and elevation (field view and air photo shadow) for some eastern Canadian conifers.

total of 63 trees.* Each of these was identified on the air photos, and it was established that the crown was clearly visible and not obscured by the foliage of adjacent trees.

In most cases the trees were open grown and the crown morphology was typical of the species. In general, coniferous species have a characteristic shape and branching habit, which is useful in their identification both on the ground and on the air photo. Size was also considered; however, it is less valuable as a diagnostic factor since it depends on a variety of controls including age, site conditions, competition and so on. An attempt has been made to show the distinctive features of crown morphology for each species in a somewhat idealised manner in Figure 2. The silhouette elevation views are adopted from the *Key to the Native Trees of Canada*[7] and a recent study by L. Sayn-Wittgenstein.[8] Some of the plan views are from the latter source, whereas others have been composed *ab initio* from all photos and ground views. In all instances, the scale is that of the open grown mature tree.

Foliage colors were assessed in the field, thus providing a basis for the evaluation of the aerial color photography. The assessment was made while the foliage was still on the tree or immediately after removal.† The colors were established using the Munsell system.[9] The procedure consisted in matching the foliage samples with the color chips in the Munsell charts, which provide an orderly arrangement of colors in approximately equal visual steps according to the three attributes of *hue*, *value* and *chroma*. In the Munsell notation, the *hue*, or dominant spectral color, is assessed in terms of five primary divisions including green and yellow, subdivided to give a total of 12 separate *hues* in the color segment green/yellow. The relative lightness or darkness of the color is indicated by its *value*, which is established in relation to a neutral gray scale extending from black symbolised as *value* 0/ to white symbolised as 10/. Thus, bright colors have *values* greater than five, and darker colors have lower *values*. The *chroma*, which appears as the final digit in the notation, indicates the color saturation or degree of departure of a particular *hue* from a neutral gray of the same *value*. The chroma scale extends from /0 for a neutral gray (achromatic) to /10, or farther, depending on the intensity of the color. Thus, 10GY 4/5 indicates a fairly light greenish yellow with moderate color saturation.

Strictly speaking it is not possible to assign a specific color to a particular species since

* In the case of red spruce (*Picea rubens*) only three trees were found in the study area, and so the sample is not sufficiently large to be representative. The red pines (*Pinus resinosa*) were all immature trees, and so this sample is not strictly comparable with the others.

† Unfortunately pruning equipment was not available and so foliage samples were obtained from different portions of the crown periphery up to heights of 15 feet.

the color attributes *hue*, *value* and *chroma* are affected by a variety of factors many of which are phenological, but others are peculiar to a particular site, or even to an individual tree. Pigmentation is the major influence on color since it controls the predominant wavelength of the reflected light. Although the green pigments, chlorophyll *A* and *B* are the same for all plants, their absolute concentration in a plant, and their concentration ratio relative to the other chlorophylls, the xanthophylls and the carotenes is determined by local factors such as temperature, humidity, sunlight, moisture stress and the availability of plant nutrients.[10]

In spite of these influences it was found that the colors were very constant within any given species sample. The predominantly recurring colors are listed by species in Table 1 and, in addition, the differences between the upper and lower surfaces of the foliage and the variations between needle face and keel or midrib were recorded, because the total reflectance from the crown as imaged on the air photo is a function of all the reflecting surfaces.

Contrary to what might have been expected, the colors recorded were not green but green yellow with a limited range of *hue*, 2.5GY to 10GY. The range of *value* was found to be even more restricted. White spruce (*Picea glauca*) has the brightest foliage (*values* of 5–6), while balsam fir (*Abies balsamea*), eastern hemlock (*Tsuga canadensis*), and red pine (*Pinus resinosa*) are equally dark (*values* of 4), and the remaining three species have intermediate values. For the two species, balsam fir (*Abies balsamea*) and eastern white cedar (*Thuja occidentalis*), an appreciable difference amounting to two steps of the *value* existed between the upper and lower surface of the foliage, with the latter being the lighter. This is due to the concentration of stomata on the lower surface of the leaf, and this same factor accounts for the weak *chroma* in the case of the balsam (*Abies balsamea*). The only other species exhibiting weak chroma is the white spruce (*Picea glauca*), hence its name, and in this case, stomata cover most of the leaf surface between the lateral ribs and the upper and lower keels. *Chroma* for all the other species is moderate.

Office Procedure for Photo Analysis

The aerial Ektachrome color film, that had been processed as a direct positive transparency, gave almost perfect rendition with a correct color balance. It was examined on a Zeiss L2 viewing desk illuminated with five daylight-type fluorescent tubes. Each of the trees selected during the field survey was identified, and the colors were carefully assessed. The procedure consisted of matching the average or overall colors of the tree crowns as represented on the color film with the chips in the Munsell system. The cards were the same as those used in the field, with holes punched beside each color chip to facilitate matching. A Bausch and Lomb Zoom 95 stereoscope was used for viewing the film; however, even with the 20× magnification provided by this instrument, it was only possible to obtain the average or overall color for each crown.*

Because of the photo overlap, each of the trees selected during the field survey appeared on three successive frames, and it was found that the brightness or illumination of the crown varied because of the different amounts of reflected light received at each camera position. This variation is due simply to the relation between the angle of incident sunlight and the position of the object within the field of view at successive exposures. It was found that the color *values* for the same crown could change by as much as two or three steps on the Munsell scale due to this factor. The other two attributes of color remained essentially unaffected. However, in order to obtain comparable results, it was decided to make the color measurements on the frame where the individual tree occupied the middle of the field of view. This was usually the middle frame of any sequence, and the color values obtained were generally the average of the range experienced over the three exposures. By using the middle of the field of view in this way, the two factors that result in progressive darkening of images towards the edges of the field of view (the vignetting effect of the lens mount and the decrease in illumination away from the optical axis) were minimised.

Some initial difficulties were encountered in the assessment of colors on the film because of the fact that the Munsell charts require front or top lighting, whereas the film is illuminated from below. However, by experimenting with the position and amount of top lighting, which was daylight fluorescent type, it was found that consistent results could be obtained.

The same office procedures were followed with the panchromatic air photos, which were in 9×9-inch print format, and so only front illumination was needed. As with the color

* Even with maximum magnification the images of the tree crowns were only 10–15 mm in diameter.

TABLE 1. COLORS AND NEUTRAL VALUES FOR SOME EASTERN CANADIAN CONIFERS

	Species	Balsam Fir (*Abies balsamea*)	Eastern Hemlock (*Tsuga canadensis*)	Eastern White Cedar (*Thuja occidentalis*)	White Spruce (*Picea glauca*)	Red Spruce† (*Picea rubens*)	White Pine (Pinus *strobus*)	Red Pine (*Pinus resinosa*)
Foliage Color in the Field	Upper surface of leaf	5GY4/4–6	5GY4/4–6	2.5GY4/4–6/6 5GY5/6	10GY5/2–6/2	7.5GY4/4–6	10GY5/4	5GY4/6
	Lower surface of leaf	5GY6–7/2	5GY5/4–7/4	2.5GY5/4–6/6	10GY4/2–5/2	2.5GY4/4 5GY4/4–6	10GY5/4	5GY4/6
	Keel or midrib upper	—	—	—	10GY5/4–6	7.5GY4/4	10GY5/4	5GY4/6
	Keel or midrib lower	5GY7/4	5GY5/4	—	10GY5/4–6	5GY4/4	—	—
Foliage Tone and Color on Air Photos	Panchromatic	N4	N4	N5	N5	N4.5	N5	N4
	Color	5GY4–6/4–6	5GY5–7/4	10YG5–6/4–5 2.5GY5–6/4–5	2.5G5–6/2–4	7.5GY7/4–6†	10GY3–6/3–4 2.5G5–6/3–4	*

* Color could not be established because of small size of crowns.
† Limited sample.

film, each tree selected during the field survey was identified, and the gray tone values were determined using the nine-step Munsell neutral value scale.

Air Photo Interpretation of Size, Crown Morphology and Texture

If viewed from above, objects are not so familiar as if seen from the ground; however, their shape may be just as characteristic from either viewpoint. Although coniferous tree species are more easily identified in elevation or side view than in plan view, the crown shape of a particular species which results from its branching habit, foliage density, and leaf arrangement is distinctive, even if viewed from above, especially under stereoscopic examination.

The basic differences between the species are illustrated in Figure 2 and may be summarised as follows:

BALSAM FIR (*Abies balsamea*)

The crown is acuminate and symmetrical with a spire-like apex, which appears as very light toned, and is especially distinctive when the crown is obliquely illuminated. The crown displays no major structural features since it consists of large numbers of slender whorled branches, with the result that the outline is regular, and the crown surface appears dense and finely layered.

EASTERN HEMLOCK (*Tsuga canadensis*)

The crown is coniform, but the apex is more obtuse than either the balsam fir or the spruces. Where open-grown, often a somewhat irregular grouping of branches develops, which gives rise to a stellate or wheel-spoke structure with a serrate or spiked crown margin. However, where in dense stands, the crown is narrower, more regular, and acuminate so that it closely resembles the balsam fir. Usually more light and shade contrast is present within the crown than in the case of the balsam fir; as this is a relative matter it does not provide a particularly valuable air photo characteristic.

EASTERN WHITE CEDAR (*Thuja occidentalis*)

The cedar is usually a small tree with a symmetrical, conical crown that has the trim appearance of a topiary garden species. The apex is rounded, the margin is regular, and the crown is smooth and finely layered without any apparent structure. Because of the arrangement of branchlets and twigs in flat drooping sprays, there is a speckled light and shade pattern within the crown.

WHITE SPRUCE (*Picea glauca*)

The crown is conical, but the apex appears blunt, even rounded, and lacks the spire-like character of the balsam fir. Branching is fairly coarse, so that although the crown is dense, it has a coarse layered or stepped appearance somewhat like an opened cone. For this reason there is considerable light and shade contrast within the crown.

RED SPRUCE (*Picea rubens*)

The branching habit of the red spruce is quite different from that of the white spruce. The middle and upper branches grow out more or less horizontally, and then curve up at the ends, with the result that the crown is ovally conical and fairly broad. In plan, the crown appears stellate with a serrate margin. It differs from the white pine in that the branches are more numerous and less massive, and so the crown margin is not so indented.

WHITE PINE (*Pinus strobus*)

This species is usually readily identified because of its distinctive morphological features. It is the tallest of the eastern conifers and has the largest crown. The branching is fairly coarse, and the upper branches sweep upward giving a bowl or saucer shape which is responsible for the irregular, stellate pattern seen in the plan view. The apex appears obtuse and almost flat as the result of the upper branches approaching and even overtopping the tip of the bole.

RED PINE (*Pinus resinosa*)

The crown is fairly large and symmetrical with a circular outline in the plan view. The foliage is not particularly dense, and for this reason there is less contrast between the illuminated and shaded portions of the crown than is the case with most other conifers. The crown consists of whorled, upturned branches with tufts of needles producing a candelabra appearance in profile. This gives rise to a stippled texture in the air photo view, which is readily apparent under high magnification.

The plan views in Figure 2 were built up from photo and field analysis, and they show considerably greater detail than could be discerned on the air photos used in this study. The main control in using the morphological characteristics of the crown in species identification is photo scale, and even with the high magnification provided by the Bausch and Lomb Zoom 95 stereoscope, the image size was too small at the 1:5,000 scale to permit detection of the more minute morphological features. However, a relatively small increase in scale to 1:3,000 would probably provide all the detail necessary to make accurate identifications using the morphological information summarised above.

Photo scale is not the only factor influencing the amount of detail discernible in an image. It is often assumed that a relationship exists between the resolving power of a film and the amount of detail that is recorded: however, this is not the case, and as R. M. Evans has emphasized, there is no way of exgressing how a given emulsion will record fine detail.[11] Both the panchromatic and the color film used in this study had the same nominal scale, and according to the Kodak data, the resolution of the panchromatic film

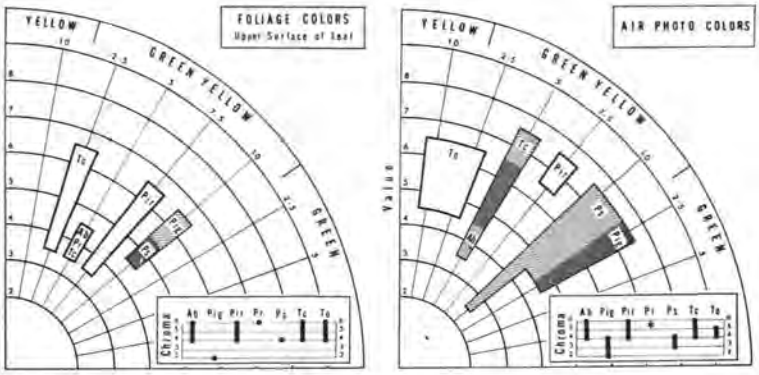

FIG. 3. Field and photo colors for some eastern Canadian conifers.

Ab–*Abies balsamea* Pr–*Pinus resinosa* Pig–*Picea glauca* Ps–*Pinus strobus* Pir–*Picea rubens* Tc–*Tsuga canadensis* To–*Thuja occidentalis*

* Color could not be established because of small size of crowns.

is superior to the color. (For a test object contrast of 1,000:1, the resolving power of the color film is only 56 lines per mm. compared with 75 lines per mm. for the panchromatic[12].) However, the amount of detail that could be discerned was appreciably greater on the color film. This may result from the smaller dye grain sizes of the color emulsion or from differences in emulsion turbidity. Whatever the cause, finer textures, were recorded with color film, and so in dealing with foliage characteristics, it is apparent that the colored image has a distinct advantage over the panchromatic.

Air Photo Interpretation of Neutral Values and Colors

The neutral *values* obtained in the interpretation of the panchromatic air photos are given in Table 1. The range of *values* for the seven tree species was found to be very small (N4-N5), and the overlap between one species and another was considerable. Comparable results were cited by R. C. Heller[13]; although the neutral *values* for individual species are not identical to those given here (presumably because of differences in illumination and processing), the same relative standing is obtained. In neither instance do the neutral *values* provide a means of differentiating any single species from the others.

The prospects for species differentiation are considerably improved when foliage colors are taken into consideration. Exact color rendition cannot be expected in the sense of matching the spectral characteristics of the original material because of the absorption of unwanted light in the dye layers of the film; however, a visually satisfactory color reproduction can be achieved. The colors obtained from the photo interpretation are listed in Table 1, and the polar diagrams in Figure 3 illustrate the relationship between the field and photo colors. The predominant colors of the upper surface of the foliage as obtained on the ground are given in the left diagram, and the dominant photo colors for each species are shown to the right. The correspondence between field and photo colors is fairly good, although some variation is encountered from one species to another:

BALSAM FIR (*Abies balsamea*)

Foliage and photo colors correspond in *hue* and *chroma* (5GY 4–6); however, the range of *value* is somewhat different. The photos give a range of *value* from 4–6, while the actual foliage *value* is 4. The extended *value* range on the photos is very probably a result of the oblique lighting effects produced by the low solar altitude, which give rise to a high reflectance from the dense foliage and shiny needles on the illuminated side of the crown, particularly the apex, and a relatively low return from the shaded side.

EASTERN HEMLOCK (*Tsuga canadensis*)

The foliage colors of the hemlock and balsam fir correspond exactly, and there is overlap in the photo colors as far as *hue* and *chroma* are concerned (5GY 4–6). The photo *values* are similar; however, the hemlock includes somewhat higher *values* in its range. It is probably a better reflector than the balsam fir, because the leaf is broader and more shiny, and although the leaf arrangement is decussate in both species, the hemlock tends to have a larger proportion of leaves in the horizontal plane[14]. The large branches which project beyond the general margin of the crown produce strong highlights on the photos and obviously have a high reflectance, particularly on the illuminated side of the crown.

EASTERN WHITE CEDAR (*Thuja occidentalis*)

Because of its yellow-yellow green *hue* the cedar is distinctive among the conifers. The dominant *hue* encountered in the field was 2.5GY; however, 5GY was also recorded, and it was found that the tips of the leaf were often considerably yellower than the central part. This difference may account for the tendency toward yellow *hues* revealed in the photo analysis (2.5GY–10Y). The foliage of the cedar is more responsive to wind effects than other conifers, and with upturning of the leaves, the yellow tips and edges become more prominent and make a greater contribution to the total reflectance of the crown. *Value* and *chroma* are not affected and a good correspondance exists between field and photo measurements.

WHITE SPRUCE (*Picea glauca*)

In many texts the white spruce is described as bright green [15], and this corresponds to the visual impression. However, field measurements on individual needles show that the actual foliage color is green yellow with moderate *value* and weak *chroma* (10GY 4–6/2). It should be noted that the spruce leaf is tetragonal in cross section, and the colors given in Table 1 and Figure 3 are those of the lateral margins and upper and lower keels. Stomata are concentrated along the intervening faces, and in these sections the leaf is essentially achromatic. The growth form of spruce leaves is falcate, which means that the keels, lateral margins and intervening faces contribute to the reflectance. The contribution of the intervening faces may have the effect of modifying the visual appearance of the foliage when viewed at a distance. This would explain why the white spruce appears green rather than yellow green, and in addition it suggests the reason for discrepancy between the field and photo colors. The difference in *hue*, which is only one step (2.5G as opposed to 10GY), represents a shift towards shorter wavelengths on the air photo, which would be expected with an achromatic image or one with weak chroma, because the diffraction effects of atmospheric haze would introduce predominantly short wavelength energy into the return from the tree crown.

RED SPRUCE (*Picea rubens*)

Unfortunately it was only possible to locate three red spruces in the study area, and since these showed signs of disease their colors must be treated with some caution. In all three instances, the actual foliage color was found to be 7.5GY, which corresponds to the bright yellow green of the textbook description. Even if viewed at a distance the foliage of the red spruce can be readily distinguished from that of the white spruce on the basis of its *hue*, and this distinction is maintained in the air photos. The photo color for the red spruce (7.5GY7/4–6) corresponds in *hue* and *chroma* to the field measurement; however, the *value* is considerably greater. The most likely explanation is that the effects of the disease are more pronounced in the upper part of the crown, and the green pigmentation is reduced, thus giving higher reflectance values.

WHITE PINE (*Pinus strobus*)

The foliage of the white pine is dark, and although it has the same *hue* as white spruce, the *chroma* is stronger, which makes it appear greener than any of the other species considered in this study. The photo colors show general correspondence with the foliage colors; however, there is a spread in the former to include *hues* of 2.5G which may result from the diffraction effect discussed above. A greater range of value also occurs in the photo colors, which comes about because of the marked difference of illumination between the prominent upper branches and the shaded lower ones.

RED PINE (*Pinus resinosa*)

The foliage colors obtained in the field were the same as for balsam fir and eastern hemlock. Reliable measurements could not be made on the air photos, because of the fact that the red pines had been planted quite recently and were immature, thus the crown area was too small to provide an identifiable color.

Conclusion

Although this study was restricted to a small area, and did not include all the coniferous species of eastern Canada, it is possible to arrive at conclusions which are significant at a more general level.

- Color is fundamental to our perception, and there is a definite advantage in having a colored as opposed to an achromatic image. The color photo provides a better representation of the original scene, and introduces more varied stimuli in the interpretation process, thus increasing the likelihood of correct identification.
- Absolute color fidelity is impossible to attain in the film image, and even homogeneous color rendition is unlikely because of the variability of illuminance over the photo area; however, it is possible to obtain visual equivalence between the color photo and the original scene. It follows that when actual color differences exist, it is possible to establish color signatures for objects such as tree crowns, as illustrated in Table 1 and Figure 3. This is important because a forester or botanist often associates a particular color with a particular tree, and the possibility of recognising the color on the air photo adds a new step in the identification process.
- The amount of detail discernible in the color photo is considerably greater than that available in the panchromatic. For example, the tree crowns can be readily distinguished from the shadows, and the detail within the crown is seen not as a dappled pattern, but as part of the canopy texture. Not only is the total amount of information greater on the color photo, it is also better differentiated, and therefore more easily interpreted.
- By combining the color signature and the morphological characteristics the photo interpreter can establish a firm base for an objective method of species identification. However, it is apparent that ease of identification will vary depending on the extent to which particular features are unique to a particular species. Thus, for cedar (*Thuga occidentalis*) and red spruce (*Picea rubens*), the interpreter has the advantage of a unique color signature and specific morphological characteristics. White spruce (*Picea glauca*) and white pine (*Pinus strobus*) have partial overlap of their foliage colors, but the morphological

features are quite distinct. Foliage color is no help in identifying red pine (*Pinus resinosa*), but its crown morphology is unique. Balsam fir (*Abies balsamea*) and hemlock (*Tsuga canadensis*) are the most difficult species to separate, but even in this case there are differences in the mirror morphological features of the crown and in the color *value* of the foliage.

References

1. Evans, R., *An Introduction to Color*, Wiley, New York, 1948.
2. Only a few comparisons of panchromatic and color photography have been made in forestry and vegetation studies:
   Aldrich, R. C., *et al.*, "Large scale 70 mm. color photography techniques and their application to a forest sampling problem," PHOTOGRAMMETRIC ENGINEERING, Vol. 25, 1959, pp. 747–754.
   Anson, A., "Color photo comparison," PHOTOGRAMMETRIC ENGINEERING, Vol. 32, 1966, pp. 286–297.
   Avery, G., "Helicopter Stereo-photography of Forest Plots," PHOTOGRAMMETRIC ENGINEERING, Vol. 24, 1958, p. 617.
   Becking, R. W., "Forestry application of aerial color photography," PHOTOGRAMMETRIC ENGINEERING, Vol. 25, 1959. pp. 559–564.
   Colwell, R. N., "New technique for interpreting aerial color photography," *Journal of Forestry*, Vol. 48, 1950, pp. 204–205.
   ———, "Determining the prevalence of certain cereal crop diseases by means of aerial photography," *Hilgardia*, Vol. 26, No. 5, 1956, pp. 223–286.
   Goldman, L. M., "The use of color aerial survey in studying a region," *Transactions of the Central Research Institute of Geodesy, Aerial Survey and Cartography*, Moscow, Publication 137, 1960.
   Haack, P. M., "Evaluating color, infrared and panchromatic aerial photos for the forest survey of interior Alaska," PHOTOGRAMMETRIC ENGINEERING, Vol. 28, 1962, pp. 592–598.
   Heller, R. C., *et al.*, *Identification of tree species on large scale panchromatic and color aerial photographs*, Handbook No. 261, 1964, U.S. Dept. of Agriculture, Forest Service.
   Hindley, E. and Smith, J. H., "Spectrophotometric analysis of foliage of British Columbia conifers," PHOTOGRAMMETRIC ENGINEERING, Vol. 23, 1957, pp. 894–895.
   Lauer, D. T., "The feasibility of identifying forest species and delineating major timber types in California by means of high-altitude small-scale aerial photography," Progress Report May 1967, Forestry Remote Sensing Laboratory, Berkeley, California.
   Meinenberg, P., "Die Landnutzungskartierung nach Pan-, Infrarot- und Farbluftbildern," *Müncher Studien zur Sozial und Wirtschaftsgeographie*, Band 1, 1966.
   Mikhailov, V. Y., "The use of color sensitive films in aerial photography in the USSR," *Transactions of the Central Research Institute of Geodesy, Aerial Survey and Cartography, Moscow*, Publication 152, 1961.
   Mott, P. G., "Some aspects of color aerial photography in practice and its applications," *Photogrammetric Record*, Vol. 5, No. 28, 1966, pp. 221–239.
   Pope, R. B. "Effect of photoscale on the accuracy of forest measurements," PHOTOGRAMMETRIC ENGINEERING, Vol. 23, 1957, pp. 869–873.
   Rossetti, C., *et al.*, "Relations entre les caractéristiques de réflexion spectrale de quelques espèces végétales et leur images sur des photographies en couleur, terrestres et aeriennes." Transactions 11e Int. Symp. Photo Interpretation, Paris 1957, Editions technip.
   Schulte, O. W., "The use of panchromatic, infrared, and color aerial photography in the study of plant distributions," PHOTOGRAMMETRIC ENGINEERING, Vol. 17, 1951, pp. 688–714.
   Schultze, W., *Farbenphotographie*. Springer Verlag, Berlin, 1953.
   Sims, W. G., "Observations on colour aerial photography," *Cartography*. Vol. 6, No. 4, 1968, pp. 165–168.
   Smith, J. T. "Color—A new dimension in Photogrammetry," PHOTOGRAMMETRIC ENGINEERING, Vol. 29, 1963, pp. 999–1013.
   Thorley, G. A., "Some uses of color aerial photography in Forestry," in *Manual of Color Aerial Photography*, American Society of Photogrammetry, 1968, p. 393.
   Wear, J. F., and Lauterbach, P. G. "Color photographs useful in evaluating mortality of Douglas fir," *Proc. Soc. Am. Foresters*, 1955, pp. 168–171.
   Wear, J. F., and Dilworth, J. R., "Color photos and salvage," *Lumberman*, Dec. 88–89, 1955, pp. 132–133.
3. Rowe, J. S., *Forest Regions of Canada*, Bulletin 123, 1959, Forestry Branch, Canada, Dept. of Northern Affairs and National Resources.
4. Olson, C. E., and Good, R. E., "Seasonal changes in light reflectance from forest vegetation," PHOTOGRAMMETRIC ENGINEERING, Vol. 28, 1962, pp. 107–114.
5. Bäckstrom, H. and Welander, E., "An investigation into the diffuse reflection capacity of leaves and needles of different species," *Norrlands Skogs-Förb. Tidskrift*, 1953, pp. 141–169.
   Billings, W. D., and Morris, R. J., "Reflection of visible and infrared radiation from leaves of different ecological groups," *American Journal of Botany*, Vol. 38, 1951, pp. 327–331.
   Krinov, E. L., "Spectral reflectance properties of natural formations," Lab. Aero., Akad. Nauk S.S.S.R. 1947. (Tech. translation TT-439, National Research Council Canada 1953).
   Skull, C. A., "A spectrophotometric study of reflection of light from leaf surfaces," *Botanical Gazette*, Vol. 87, 1929, pp. 583–7.
   Steiner, P. and Gutermann, T., "Russian Data on spectral reflectance of vegetation, soil and rock types," Final Technical Rept., 1966, European Research Office, U. S. Army.
6. Gregory, R. L. *Eye and Brain, the psychology of seeing*, McGraw Hill, New York, 1961, p. 122.
7. Brayshaw, T. C. *Key to the Native Trees of Canada*, Bulletin 125, 1963, Canada Dept. of Forestry.
8. Sayn-Wittgenstein, L. "Recognition of tree species on air photographs by crown characteristics," Technical Note No. 95, 1960, Forest Research Branch, Canada Dept. of Forestry.
9. ——— *Munsell Color Charts for Plant Tissues*, 1963, Munsell Color Co., Baltimore.

10. Gates, D. M., *et al.*, "Spectral properties of plants," *Applied Optics*, Vol. 4, 1965, pp. 11–20.
11. Evans, R. M., *et al.*, *Principles of Color Photography*. John Wiley and Sons, New York, 1963, p. 223.
12. Eastman Kodak Co., "Kodak Data for Aerial Photography," Publication No. M 29, 1967.
13. Heller, R. C., *et al.*, *op. cit.*
14. De Laubenfels, D. J. "The external morphology of coniferous leaves," *Phytomorphology* Vol. 3, No. 1, 1953, pp. 1–20.
15. ——— *Native Trees of Canada*. 6th Ed., 1963, Queen's Printer, Ottawa, p. 36.

Articles for Next Month

Hon. George P. Miller, Congressional view of the space program.
Brig. Gen. E. T. Podufaly, The Army's new TOPOCOM.
Prof. D. M. Richter, Sequential urban change.
Prof. R. K. Moore, Heights from simultaneous radar and infrared.
Carl E. Zaitz, Resources and cadastral mapping in Panama.
J. W. Hardy, et al. Electronic correlator for the Planimat.
Dr. Simha Weissman, Semi-analytical aerotriangulation.
Peter Bock and *Dr. J. G. Barmby*, Survey effectiveness of Spacecraft remote sensors.

Articles in Other Photogrammetric Journals

Photogrammetria, v 23, n 6, November 1968

A. Holden, Engineering soil maps from airphotos.
J. Bodechtel, G. Papadeas, Tectonic aerial interpretation in the Mediterranean region exemplified by the metormorphic series of eastern Greece near Marathon.
B. Hallert, Some proposals for the organization of international congresses in the future.

Bildmessung und Luftbildwesen, v 37, n 2, March 1969

K. Schwidefsky, H. Kellner, The representation of lens distortion by power series.
G. Hildebrandt, Derivation of stem diameters in stands of beech trees through the interpretation of aerial photographs.
B. Hallert. Determination of the outer and inner perspective centers of close-up photogrammetric cameras.
R. Burkhardt, Measurement of the flatness of photogrammetric plates.
Klaus Linkwitz, The 12th Congress of the International Federation of Surveyors (FIG), 1968, in London.

New Publication

La Photographie Aérienne (Aerial Photography), Raymond Chevallier. Three sets of eighteen 35-mm slides packaged in heavy plastic. Editors: DIAPOFILM, 1 rue Villaret de Joyeuse, Paris 17, France.

This collection of 54 slides, designed as visual aids, illustrate the photogrammetric subjects archaeology, ethnology, rural living, city planning, military applications, cartography, property surveys, civil engineering, aeronautics, geology, hydrography, calciology, etc. An explanatory text is in French. The author is the recent past president of Comm. VII, Photo interpretation, of the International Society of Photogrammetry.