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AERIAL PHOTOGRAPHIC INTERPRETATION OF FOREST DAMAGE: AN ANNOTATED BIBLIOGRAPHY

by
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FOREST MANAGEMENT INSTITUTE
OTTAWA, ONTARIO
INFORMATION REPORT FMR-X-16

FORESTRY BRANCH
DEPARTMENT OF FISHERIES AND FORESTRY
MARCH, 1969

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ABSTRACT

The purpose of this annotated bibliography is to place under one cover as many pertinent references as possible that deal with air photo interpretation of forest damage.

RÉSUMÉ

Le but de faire cette bibliographie annotée est de recueillir aussi nombres de références que possible que traitent de l'interpretation de photographies aeriennes de dommages de forêts.

FOREWORD

The detection and evaluation of forest damage on aerial photographs requires a knowledge of

1) the various types of forest damage,
2) the manifestation of the damage and its appearance on aerial photographs,
3) the factors affecting the appearance of the image on the photographs, and
4) film reaction to spectral reflectance.

This bibliography therefore contains references on spectral reflectance, species identification, films, filters, cameras, aerial photographic techniques, air photo interpretation techniques, and damage detection and evaluation on aerial photographs.

The annotations after each reference are highly selective: they are restricted to airphoto interpretation of forest damage. Thus, the annotations are not précis of the original papers. When the abstract has been quoted, it is noted as such. Otherwise, the annotation may be a quote from the article or a summary of pertinent material. Although an effort was made to review all relevant references, some have probably been overlooked. Some references contain material on more than one topic but are only listed in one category.

Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the Institute or the author.

To ensure accuracy, the scientific names and authorities for the various species of trees, etc. are only given if they were used in the original references.

Spectral Reflectance Studies

BILLINGS, W. D. and R. J. MORRIS. 1951. Reflection of visible and infrared radiation from leaves of different ecological groups. Amer. J. Bot. 38 (5): 327-331.

Near-infrared reflectance was just as high from the green portion as it was from the white portion of a variegated geranium (*Pelargonium zonale*) leaf. Visible reflectance increased as the site became more xeric; plants from the desert site were more highly reflective at all wavelengths than plants from the tree-shaded portion of a campus. "Averages showed that the desert species reflected the greatest amount of visible radiation, followed by the sub-alpine, west-facing pine forest, north-facing pine forest, and shaded campus species in that order." Near-infrared reflectance was highest from the desert species and lowest from the shaded campus species.

COBLENTZ, W. W. and R. STAIR. 1929. The infrared absorption spectrum of chlorophyll and xanthophyll. Phys. Rev. II, 33: 1092.

Chlorophyll is transparent to infrared in the .7 to .9μ range. There are absorption bands at 1.3, 3.05, 3.5, 3.8, 4.7, 6.0, 6.2, 6.5, 6.9, 7.3, 7.8, 8.2, 8.6, 9.1, 9.6 and 10.1μ.

Xanthophyll absorption bands are at 1.3, 3.05, 3.45, 4.3, 6.0, 6.9, 7.3, 8.05, 8.45, 8.8, 9.05, 9.6, 9.75, 9.9 and 10.4μ.

COCHRAN, G. W., G. W. WELKIE and J. L. CHIDESTER. 1960. Direct infrared spectral analysis of the cucumber mosaic virus infection process. Nature 187: 1049-1050.

Absorption of infrared showed a greater difference near the 1 and 2 micron ranges and increased with the incubation period of the virus.

COLWELL, R. N. 1965. Spectrometric considerations involved in making rural land use studies with aerial photography. Photogrammetria 20 (1): 15-33.

The author presented basic spectrometric considerations involved in land use studies employing aerial photography.

DADYKIN, V. P., V. P. BEDENKO and Ju. A. DAVYDOVA. 1959. O zavisimosti optičeshih svojstv listév rasteij otudobrenija počuy. Dokl. Akad. Nauk. SSSR 128 (6): 1305-1308.

[English Summary: The relationship between the optical properties of plant leaves and soil fertility. Forest. Abstr. 21 (3): 361, 2731.]

Abstract: "Measurements were made of the transmission and reflection of radiant solar energy by leaves of 8-year-old *Fraxinus pennsylvanica* and *Quercus robur* grown without fertilizers, or with NK or NPK; 2-year-old *Pyrus malus* and *Corylus avellana* given NPK, NP_3K or, in the case of *P. mallus* no fertilizer. The spectral transmission and reflection curves are shown and discussed. Greatest reflection and transmission, i.e. least absorption were found in the leaves of unfertilized control. Increased doses of P reduced both reflection and transmission."

DRAKE, H. L. 1963. A spectral reflectance study using a wedge spectrograph. Photogram. Eng. 29 (4): 684-689.

The wedge spectrograph was described as a convenient instrument for making field measurements of spectral reflectance because it only weighs 3.5 pounds.

GATES, D. M. 1964. Characteristics of soil and vegetated surfaces to reflected and emitted radiation. Univ. Michigan, Ann Arbor, Proc. 3rd Symp. Remote Sens. Environ. pp. 573-600.

"The character of reflected or emitted light will depend upon the nature of the surface, and will also depend upon the intensity and the spectral quality of the radiation incident upon the surface.

"...because of the finely divided needle structure of the pine branches as compared with the broad leaf structure of the poplar, the intensity of the reflected radiation from a conifer stand will be considerably less than the intensity from a deciduous broad leaf stand. Conifers should appear darker than deciduous trees in both visible and near infrared photographs."

The author maintained that the spectral quality of reflected visible light was largely dependent on leaf pigments, and that near-infrared reflectance was "...caused by the internal critical reflection of the light rays within the leaf cell structure." He also added that "the intensity of near infrared radiation reflected from a vegetated surface is very much a function of leaf shape, size, and orientation and leaf density in the canopy."

GATES, D. M. 1965. Energy, plants, and ecology. Ecology 46 (1 and 2): 1-13.

Radiant energy was discussed. Spectral reflectance analysis indicated high (40%) reflectance in the near infrared. During crepuscular times, sun-light became rich in red and near-infrared. The spectral absorptance, reflectance and transmittance of a *Populus deltoides* leaf were described.

GATES, D. M. *et al*. 1965. Spectral properties of plants. Appl. Opt. 4 (1): 11-20.

Reflectance and absorption of light by plants, and the mechanism by which radiant energy interacts with a leaf were discussed. The spectral properties of desert plants were compared with those of more mesic plants. The evolution of the spectral properties of plant leaves during the early growing season was given as well as the colorimetric behavior during autumn. "It is probable that the near-infrared reflectance is a function of the cell shape and size as well as the amount of intercellular space."

GATES, D. M. and W. TANTRAPORN. 1952. The reflectivity of deciduous trees and herbaceous plants in the infrared to 25 microns. Science 115 (2997): 613-616.

The authors reported on the infrared reflection spectrum from 1.0μ to 25μ for several plants. (This spectral range is beyond the photographic region.) At these wavelengths, "The upper surface reflects more than the lower, old leaves more than young, and shade leaves more than sun leaves. In each instance the inverse is true in the visible and near-infrared. The structure of the leaf surface and the covering by the cuticle appear to be the factors determining the reflectivity." The authors also state, contrary to one of their cited references (Rabideau, French and Holt, 1946), "Chlorophyll is very transparent in the red and photographic infrared...."

GIRS, G. I., A. S. ISAEV and Yu A. PROKUDIN. 1965. Spektral'naya otrazhatel'naya spos ob nost listennetsy sibirskoi v svyazi s fiziologicheskim sostoyaniem dereva. Izv Sibirsk Otd. Akad. Nauk. SSSR (Ser. Biol. Med. Nauk.) 3: 28-32. [English Summary: Spectral reflectivity of Siberian larch in relation to physiological condition of the tree. Bio. Abstr. 48 (17), 87941]

"The spectral brightness of the needles and crown can serve as an index of the physiological state of the tree and its resistance to the attack of trunk pests. The most distinct congruence of the optical properties and condition of the tree was demonstrated when the crown was subjected to spectrophotometric measurements, since the character of the spectral brightness here was affected not just by the composition and structure of the needles but also by the structure of the crown which represents the specificity of disturbance of the vital process of the tree. The differences in the reflectivity of healthy, weakened, and dying trees opens the way for using

the method of spectrophotometry for forest pathological diagnosis of the condition of stands."

HARIN, N. G. 1963. Spectrophotometric investigations of the vegetation of the Tuva region. Tr. Inst. Les. Akad. Nauk. SSSR (Sibirsk. Otd.) 66: 29-42.
[English Summary in Forest. Abstr. 25 (1): 121, 1130.]

"On spectrozonal photographs, hardwoods and Larch have increased brightness, and Pine and Spruce reduced brightness, in the infrared region of the spectrum; Pinus sibirica is intermediate. Stands damaged by Dendrolimus sibiricus or by fire can also be clearly distinguished."

HINDLEY, E. and J. H. G. SMITH. 1957. Spectrophotometric analysis of foliage of some British Columbia conifers. Photogram. Eng. 23 (5): 894-495.

The authors noted

1) a wide variation of near-infrared reflectance within a species,
2) small interspecific differences, and
3) a decrease in near-infrared light with an increase in altitude of the collecting areas.

The intraspecific comparisons were made across a variety of sites and up an altitudinal gradient.

HOFFER, R. M., R. A. HOLMES and J. R. SHAY. 1966. Vegetable, soil and photographic factors affecting tone in agricultural remote multispectral sensing. Proc. 4th Symp. Remote Sens. Environ. pp. 115-134.

Causes of marked tonal variation of primary importance

were listed as follows:

1) crop species and variety;

2) relative size and maturity of crop;

3) soil type, moisture content, and relative amounts of soil and vegetation observed;

4) geometric configuration of the crop.

Spectrophotometric curves on individual leaves do not always indicate accurately the relative reflectance observed on multispectral imagery.

KEEGAN, H. J. and H. T. O'NEILL. 1951. Spectrophotometric study of autumn leaves. J. Opt. Soc. Amer. 41: 284.

The authors compiled data useful for interpreting color air photos of southern hardwoods taken in the fall. The color sequence changes were stated as follows:

1) green, yellow, red, brown;

2) green, yellow, brown;

3) green, olive, red.

Daylight reflectance data and color notations were given for each leaf.

KEEGAN, H. J., J. C. SCHLETER and W. A. HALL. 1955. Spectrophotometric and colorimetric change in the leaf of a white oak tree under conditions of natural drying and excessive moisture. Nat. Bur. Stand. Rep. No. 4322.

The greatest change in the reflectance of the wet leaf was in the 750 to 900 mμ range. The daylight reflectance of the wet leaf decreased from 8 to 4% over one year, and that of the dry leaf increased from 8 to 19%. In the dry leaf the greatest change in reflectance was in the 670 to 680 chlorophyll-band range associated with the disappearance of chlorophyll. The greatest change in the reflectance of the wet leaf was in the 750 to 900 $m\mu$ range, which is associated with the penetration of water into the leaf.

KEEGAN, H. J. *et al*. 1955. Spectrophotometric and colorimetric study of foliage stored in covered metal containers. Nat. Bur. Stand. Rep. No. 4370.

Beech, dogwood, white oak, mountain laurel, and milkweek were kept in sealed containers for periods ranging from 17 hours to 12 days. The major changes were from 500 to 600 $m\mu$ and 750 to 900 $m\mu$ in the thin leaves. Thick, leathery leaves showed little, if any, change.

KEEGAN, H. J. *et al*. 1956. Spectrophotometric and colorimetric study of diseased and rust resisting cereal crops. Nat. Bur. Stand. Rep. No. 4591. 121 p.

Plants infected with wheat rust are redder than non-infected plants. The maximum difference between diseased and non-diseased specimens was found to be in the spectral regions from 600 to 700 $m\mu$.

KEEGAN, H. J. *et al*. 1956. Spectrophotometric and colorimetric record of some leaves of trees, vegetation, and soil. Nat. Bur. Stand. Rep. No. 4528.

Reflectance from leaves of several deciduous trees was measured with a spectrophotometer in the 400 to 1080 $m\mu$ range. The results were illustrated, and colorimetric values

were presented.

KEEGAN, H. J. *et al*. 1957. Spectrophotometric and colorimetric study of color transparencies of some natural objects. Nat. Bur. Stand. Rep. No. 4794.

Photos of natural scenes of tree leaves in the shade tended to have a higher dominant wavelength than the same scenes in the sun. Spectral reflectance of an object cannot be deduced from the spectral transmittance of the color transparency of the object.

KLESHNIN, A. F., I. A. SHUL'GIN and M. I. VERBOLOVA. 1960. Ob optisheskikh svoistvakh list'ev rastnii. Bot. Zhur 45 (4): 492-506.
[English Summary: Optical properties of plant leaves. Biol. Abstr. 36 (18), 1595.]

Absorption in the green range of the spectrum depended on the ecological group the plants belonged to. The least absorption was found in mesophytes and aquatics, and the most in succulents, evergreens with xeromorphic leaf structure, and plants containing anthocyanin.

KRINOV, E. L. 1947. Spectral reflectance properties of natural formations. [Transl. by G. Belkov, 1953] Nat. Res. Counc. Can., Tech. Transl. 439.

This paper provided a basic review of spectral reflectance studies done in Russia in the late 1930's and early 1940's. A series of reflectance curves was included for various species found in the following natural formations:

1) forests and shrubs;

2) grass;

3) mosses and lichens;

4) field and garden crops;

5) outcrops and soils;

6) roads;

7) water surfaces, water bodies, and snow.

A fir forest has a higher reflectance than a meadow when measured on the ground, but a lower reflectance than the meadow when measured from the air. It was noted in the report that the closer the sensor is to the reflecting body, the higher is the measure of reflectance.

LOOMIS, W. E. 1965. Absorption of radiant energy by leaves. Ecology 46: 14-17.

"Leaves of common plants absorb 80 - 90% of the blue (400-500$m\mu$), 60 - 80% of the green (500-600$m\mu$), 80 - 90% of the red (600-700$m\mu$), and 5% of the near-infrared (800-1200$m\mu$)." The high reflection of broad-leaf plants in the near-infrared (800 to 1200$m\mu$) is shown in infrared photography. The young needles of conifers show less reflection because of their shape, but old needles absorb strongly and appear dark in infrared photographs."

LOSEE, S. T. B. 1951. Photographic tone in forest interpretation. Photogram. Eng. 17: 785-799.

The factors controlling the amount and quality of light reflected from tree crowns, such as the color of the surface

and the nature of the surface (glossy, rough, broken) are discussed. On a rough surface there are "contained shadows" -- the effect produced by many small shadows of objects too small to register individually; thus conifers appear darker than hardwoods.

McCLELLAN, W. D., J. P. MEINERS and D. G. ORR. 1962. Spectral reflectance studies on plants. Proc. 2nd Symp. Remote Sens. Environ. pp. 403-413.

Near-infrared reflectance was greater from soybeans grown where soil moisture was low. Near-infrared reflectance was greater from mildewed barley than from unmildewed barley.

MOSS, R. A. and W. E. LOOMIS. 1952. Absorption spectra of leaves. 1. The visible spectrum. Plant Physiol. 27: 370-391.

The absorption spectra of leaves was not predictable from the spectra of their extracts. Reflection from leaves is made up of two components: 1) that occurring at the first air-cuticle interface and which was fairly uniform throughout the spectrum; 2) that occurring at the interfaces within the leaf.

NARAYANMURTI, D. and U. SANJIVA. 1958. Reflection and transmission of infrared rays by Indian timbers. Bull. Res. Counc. Israel, Sect. C. Tech., 6c (2): 109-112.

The authors noted that infrared reflectance decreased as moisture content increased.

OBATON, F. 1941. Sur la réflexion du proche infrarouge par les surfaces végétales. Acad. Sci. Compt. Rend. 212: 621-623.

The author reported that

1) reflection was greater in near-infrared,

2) reflection was not due to epidermis or cuticle, and

3) visual color was of little or no importance.

______ 1944. La réflexion des radiations de grande longeur d'onde par les plantes [sic] de haute montagne. Acad. Sci. Compt. Rend. 218: 721-723.

"Ces valeurs sont en général deux foix plus élevés que celles qui ont été obtenues pour les plants de plaine (Obaton, 1941)."

The author also reported that glabrous leaves reflected infrared equally as well as pubescent leaves.

OBATON, F. 1949. Le pouvoir réflecteur des Coniferes pour rayonnement infrarouge. Acad. Sci. Compt. Rend. 228 (ii): 939-941.

"Le coefficient de réflexion infrarouge pour les Conifères ci-dessus est remarquablement constant. Il est deux à trois fois plus élevé que celui des Cryptogames cellulaires et deux à trois fois moins fort que celui des Angiospermes.

"Chacune de ces feuilles est séparée de la voisine par un espace vide qui forme une umbre souvent plus large que la feuille. L'image enregistrée à distance est la résultante de ces phénomènes."

OLSON, C. E., Jr. 1961. Aerial photography depends on reflected light. Ill. Res., Spring 1961: 12-13.

Hardwood foliage reflected less visible light in late

July than in early May. Conversely, pine foliage reflected more visible light in late July than in early May. [Reference to Olson (1962) and Steiner and Gutermann (1966) would probably reveal that the early May pine reflectance curves were from 1-year-old foliage and the late July curves from 2-month-old foliage.]

OLSON, C. E., Jr. 1962. The energy profile in remote sensing. Proc. 2nd Symp. Remote. Sens. Environ. pp. 187-199.

Young red pine needles are more reflective than older needles and young oak leaves. "...the parameters of the net reflectance leaving a red pine target would be controlled by the proportion of the reflectance that came from old needles as opposed to that from the new needles. This proportion is not constant but varies with camera location, altitude of the sun, wind velocity at the surface, and the actual age or stage of development of the new foliage. Since foresters cannot provide specific data related to these variables, why are they surprised when they cannot explain the results they get when they take aerial photographs."

OLSON, C. E., Jr., and R. E. GOOD. 1962. Seasonal changes in light reflectance from forest vegetation. Photogram. Eng. 28 (1): 107-114.

Light reflectance measurements varied widely from one month to another. In September, pines had a higher reflectance than hardwoods. There was a greater variation in reflectance from hardwoods than in that from conifers, but there was not enough variation within species on one date to invalidate an average. Good reflectance contrast was found in the early spring.

O'NEIL, H. T. and W. J. NAGEL. 1957. The diachromoscope: an instrument for increasing constrast between a colored object and a different colored background on color photographs. Photogram. Eng. 23 (1): 180-185.

The article described how to construct the instrument and its application.

PEREVERTUM, M. P. 1957. Spectral-reflective capacity of certain plant species in the 650-1200 mμ area. Tr. Sectora Astrobot. Akad. Nauk. Kaz. SSSR 1957 (5): 138-314. [English Summary in Biol. Abstr. 35 (9), 24891.]

"The IR-effect arises through the complete internal reflection and dispersion of IR-rays from the air-gas bubbles in the spongy parenchyma stratum.

"As the leaf fibers become water saturated the leaf's reflective capacity diminished by 12-15%.

"Since chlorophyll is transparent to IR-rays, and carotinoids and xanthophylls almost transparent, the reflective capacity of plants in near IR-rays (725-800 mμ) depends not upon the pigment properties but upon the water-gas regime of the plants."

POKROWSKI, G. I. 1925. Über die Lichtabsorption von Blättern einiger Bäume. Biochem. Zeitschr. 165: 420-426.

"Es wird gezeigt, dass die Verschiedenheiten in den

Reflexionsspektran untersuchter Blätter durch verschiedene Oberflächenreflexion und Zerstreuungsfähigkeit der Blätter erklärt werden können."

For visible wavelengths, reflection, transmission and absorption values were given for six species of hardwood. Reflection was found to range between 4 and 5% in the blue region, 8 and 17% in the green, and 4 and 11% in the red.

RABIDEAU, G. S., C. S. FRENCH and A. S. HOLT. 1946. The absorption and reflection spectra of leaves, chloroplast suspensions, and chloroplast fragments as measured in an Ulbricht sphere. Amer. J. Bot. 33: 769-777.

Absorption and reflection spectra for eight plant species, including _Tilia americana_, were presented. Variation in the curves was attributed to "...differences in thickness or total pigment content."

REIFSNYDER, W. H. and H. L. LULL. 1965. Radiant energy in relation to forests. U.S.D.A., Forest Serv., Tech. Bull. No. 1344. 111 p.

Basic physical and biological principles related to the interaction of radiant energy with the forest were discussed.

RYKER, H. C. 1963. Aerial photography, method of determining timber species. Timberman 34 (5): 11-17.

Based on a knowledge of wavelength absorption, tree species identification by tone characteristics was discussed.

SEYBOLD, A. 1948. Zur Klärung optischer Probleme der Blätter. Biol. Zentralbl. 67 ($\frac{1}{2}$): 71-77.

Reflection from the individual conifer needle is about

the same as the reflection from a leaf of a deciduous tree, but the arrangement of the needles is responsible for the decreased reflection of light from the crown of the tree.

SHAKHOV, A. A., V. S. KHAZANOV and S. A. STANKO. 1961. Ob istinnykh spektral'nykh svoistvakh rastenii. Bot. Zh. 46 (2): 222-233. [English Summary: The inherent spectral properties of plants. Biol. Abstr. 39 (3), 11770.]

Fertilization with N, P, and K resulted in decreased reflection of near-infrared energy.

SHUL'GIN, I. A., et al. 1960. An investigation of the optical properties of leaves of woody plants using the SF-4 spectrophotometer. Plant Physiol. [A translation of the Soviet journal Fiziol. Rast.] 7: 247-252.

"The optical systems of leaves of the majority of woody plants ... are practically identical; this is due to a homogeneity in leaf structure and to similar chlorophyll content levels."

Reflection and transmission curves were similar, the reflection curve was "...characterized by higher values in all regions of the spectrum." A shiny, or dull leaf surface did not affect the reflection or transmission pattern.

SHUL'GIN, I. A. and V. S. KHAZANOV. 1961. On the problem of light conditions in plant associations. [English Translation.] Dokl. Akad. Nauk. SSSR 141 (6): 1493-1496.

When the sun angle is low (less than 45°), mesophytic leaves reflect about the same amount of light from the surfaces of the leaf as from the interior. At sun angles greater than 45°, the reflection consists mainly of surface reflection which is similar in spectral composition to solar radiation.

SHULL, C. A. 1929. A spectrophotometric study of reflection of light from leaf surfaces. Bot. Gaz. 87: 583-607.

"Leaves discolored by disease or adverse physiological conditions, mildews, infections or induced chloroses, etc., showed increased reflection and decreased absorption of light" at visible wavelengths.

The author discovered the following facts:

1) the shiny cuticle of Morus rubra added little to normal reflection;
2) hairiness or smoothness of the cuticle did not always result in high reflection;
3) reflection decreased with the age of the leaf; the decrease was associated with chlorophyll development
4) visible reflection increased with autumn coloration;
5) there was a higher reflectance from the lower surface than the upper surface in autumn colored leaves;
6) mildewed leaves had a higher visible reflectance.

STEEN, W. W. and J. C. LITTLE. 1959. A new portable reflectance spectrophotometer for the selection of film and filters for aerial photography. Photogram. Eng. 25 (4): 615-618.

The construction of the spectrophotometer was described, and some of the results were presented.

STEINER, D. 1963. Technical aspects of air photo interpretation in the Soviet Union. Photogram. Eng. 29 (6): 988-998.

The following topics were discussed:

1) spectral reflectance studies;

2) cameras and lenses;

3) films and filters;

4) evaluation and interpretation of the aerial photographs.

"...there is an increasing trend towards more objective methods. This involves the utilization of instrumental means instead of the mere visual investigation...."

The author suggested that the results presented in Krinov (1947) had become obsolete.

STEINER, D. and T. GUTTERMANN. 1966. Russian data on spectral reflectance of vegetation, soil and rock type. Dep. Geogr., Univ. Zurich, Zurich, Switz. 232 p.

The results from many recent Russian spectral reflectance studies were presented. In many of the studies comparative air and ground measurements were given.

TEUBNER, F. G. _et al_. 1959. Portable spectrophotometer for measuring the spectral distribution and energy of natural and artificial light. Plant Physiol. 34 (Suppl.): XIX.

Two spectrophotometers were discussed, one for measuring ultraviolet and the other for visible light. "Each instrument is comprised of a commercially available grating monochrometer and an attached compartment containing the battery operated photometer which employs a photo multiplier tube of wide spectral response."

THOMAS, J. R. *et al*. 1966. Factors affecting light reflectance of cotton. Proc. 4th Symp. Remote Sens. Environ. pp. 305-318.

Abstract: "Field and greenhouse experiments were conducted to determine the effects of plant height, percentage of ground cover, and soil salinity on the spectral characteristics of cotton. Comparison of Ektachrome infrared and black-and-white infrared photographs indicated that salt-affected cotton could be detected earlier in the season with the Ektachrome infrared film. Density of both film types was significantly correlated with plant height, percentage of ground cover, and salinity. The degree of correlation changed as the crop matured, and with the type of filter used in measuring the film density. Reflectance of individual leaves was affected by leaf age, moisture content, nitrogen fertilization and salinity. An increase in the total moisture content or relative turgidity of the leaf significantly decreased infrared reflectance, while salt increased reflectance."

TURREL, F. M. *et al*. 1961. Chlorophyll content and reflection spectra of citrus leaves. Bot. Gaz. 123: 10-15.

The authors reported that reflectance and transmittance were inversely proportional to chlorophyll concentration, i.e., "...the greater the chlorophyll concentration, the greater the light absorption." They also stated that "Chlorophyll concentration in citrus leaves...is highly variable: on the basis of leaf color, it is affected by light intensity; major element, minor element, and nitrogen nutrition; virus diseases, sprays and dusts, desiccation; excessive heat; freezing; and genetics."

WILLSTÄTTER, R. and A. STOLL. 1913. Untersuchungen über Chlorophyll: Methoden and Ergebnisse. Verlag von J. Springer, Berlin. 435 p.

The various aspects of chlorophyll, its extraction from the leaf, its derivatives, and the absorption spectrum of chlorophyll and its components in the visible spectrum were discussed. However, no discussion or diagram of the reflectance of near-infrared from spongy mesophyll could be located.

WILLSTÄTTER, R. and A. STOLL. 1913. Investigations on chlorophyll: Methods and Results. [English Transl. by F. M. Schertz and A. R. Merz. 1928.] Science Press Printing Co., Lancaster, P.A. 396 p.

This is a complete translation of the previous reference.

Addenda

DADYKIN, V. P. and V. P. BEDENKO. 1960. Concerning the geographical variability of optical properties in plant leaves. [English Transl.] Dokl. Akad. Nauk. SSSR 130 (3): 674-677.

Reflection and transmission curves were given for Salix spp., Corylus Auellana L. and Tilia cordata Mill., from samples obtained across a geographic north-south gradient. The authors observed that "...the greatest amount of reflection [near-infrared] was noted in southern most localities...." and "the least amount of reflected radiant energy [near-

infrared region] was recorded for leaves of plants from far northern points." It was concluded that "...as the severity of the climate increases the amount of radiant energy reflected and transmitted by leaves decreases."

DADYKIN, V. P. and V. P. BEDENKO. 1960. The connection of the optical properties of plant leaves with soil moisture. [English Transl.] Dokl. Akad. Nauk. SSSR 134 (4): 965-968.

Studies on Quercus robur L. leaves and Tilia cordata Mill. seedlings revealed that as the soil moisture capacity decreased, near-infrared reflectance increased. The authors concluded that "...soil moisture is still one factor of the external environment that determines the absorption of light energy."

KLESHNIN, A. F. and I. A. SHUL'GIN. 1959. The optical properties of plant leaves. [English Transl.] Dokl. Akad. Nauk. SSSR 134 (1-6): 108-110.

Fifteen tree species, including Populus alba L. and Quercus robur L., were among 71 plant species for which reflection and transmission curves were obtained. Average absorption, reflection, transmission, and optical density curves were given. Absorption and optical density curves were similar, and reflection and transmission curves were similar.

SHUL'GIN, I. A. 1960. The optical characteristics of xeromorphy and succulence of plant leaves. [English Transl.] Dokl. Akad. Nauk. SSSR 134 (4): 972-975.

"...the greater the filtration of light energy, the lower the R/T [reflection/transmission] relationship, which characterizes xeromorphy of the leaf structure.

"Thus the relationship between the reflection and transmission of light energy by the leaf can be viewed as a new, more general simple characteristic of the degree of xeromorphy of the leaf structure."

SHUL'GIN, I. A., V. S. KHAZANOV and A. F. KLESHNIN. 1960. On the reflection of light as related to leaf structure. [English Transl.] Dokl. Akad. Nauk. SSSR 134 (2): 471-474.

The spectral reflectance of 23 plant species was studied; the various species possessed a variety of leaf types ranging from "thin, wrinkled" to "shiny, succulent".

Leaves with a xeromorphic structure appeared to have the highest intensity of reflection and the lowest variability, while leaves of mesophytic structure had a wide range of reflectance values. However the "...coefficient of intensity increases as leaf thickness increases."

TAGEEVA, S. V., A. B. BRANDT and V. G. DEREYANKO. 1960. Changes in optical properties of leaves in the course of the growing season [English Transl.] Dokl. Akad. Nauk. SSSR 135 (5): 1270-1273.

Betula verrucosa and Tilia cordata leaves were studied over the course of a growing season. Light absorption data for both species was presented. The authors reported that "...water infiltration in both experiments, both on July 20 in the most active growth period of the leaves, and in the period of dying-off in the fall, led to a significant decrease in light absorption, especially in the low-absorbing green region and somewhat less in the red."

The authors suggested that water infiltration into the leaf and the consequent saturation of air cavities with water effected a change in the optical properties of the leaf. Thus "...it is evident that intercellular cavities in the mesophyll play an important role, not only as air reservoirs, but also as multiple reflectors of light inside the leaf...."

[No specific reference was made to intracellular cavities.]

WILLSTÄTTER, R. and A. STOLL. 1918. Untersuchungen über die Assimilation der Kohlensäure. Verlag von J. Springer, Berlin. 448 p.

The reflectance pattern of "light" within the plant leaf was depicted. The authors believed that in a white leaf, the cellular structure caused more light to be reflected than transmitted. However, in a green leaf, some of the internally reflected light was absorbed. Thus, green leaves appeared darker than white leaves.

No statements were made concerning the reflectance of near-infrared energy from the mesophyll.

Tree Species and Forest Type Identification

AVERY, T. E. 1960. Identifying southern forest types on aerial photographs. S. Forest. Exp. Sta. Pap. 112.

Good infrared photos taken during spring or early summer are usually superior to panchromatic prints for forest type delineation.

AVERY, T. E. and C. B. SERNA. 1965. Photo Interpretation keys for identifying vegetation. Proc. Soc. Amer. Forest. 1965: 159-162.

The authors discussed the desirable aspects and usefulness of keys. The paper was concluded with a survey of several keys.

BIGELOW, G. F. 1963. Photo interpretation keys -- a reappraisal. Photogram. Eng. 29 (6): 1042-1051.

The faults of keys, and the need for them to be updated and streamlined for automation were discussed.

HELLER, R. C., G. E. DOVERSPIKE and R. C. ALDRICH. 1964. Identification of tree species on large-scale panchromatic and color aerial photographs. U.S.D.A. Agr. Handbook No. 261. Beltsville, Maryland. 17 p.

The authors noted that color film was superior. They also stated that "Further study of hardwoods, especially to associate their crown and foliage characteristics with age and physiographic feature, should be helpful in improving identification of these tree species."

LAUER, D. T. 1967. The feasibility of identifying forest species and delineating major timber types by means of high altitude multispectral imagery. Annu. Prog. Rep. School of Forestry, Univ. Calif., Berkeley, California. 108 p.

Appendix III in the report contained excellent examples of photo interpretation keys. The study area was located in Florida.

O'NEILL, H. T. 1953. Keys for interpreting vegetation from air photographs. Photogram. Eng. 19 (3): 422-424.

A general discussion on the usefulness of keys was presented.

SAYN-WITTGENSTEIN, L. 1960. Recognition of tree species on air photographs by crown characteristics. Can. Dep. Forest., Res. Br., Tech. Note No. 95. 56 p.

Keys for the air-photo interpretation of conifers and hardwoods in summer and of hardwoods on large-scale winter photographs were provided. Each species discussed was illustrated with aerial photographs and crown drawings.

______ 1961. Phenological aids to species identification on air photographs. Can. Dep. Forest., Forest. Res. Div. Tech. Note No. 104. 26 p.

"The commonly used panchromatic summer photographs often show only a few or no useful tone variations between [sic] species, but spring or fall photographs may provide excellent opportunities for distinguishing species or groups of species." The author suggested that "Probably the best time for identification is immediately after all deciduous species have leafed out."

SIMONTACCHI, A., G. A. CHOATES and D. A. BERNSTEIN. 1955. Considerations in the preparation of keys to natural vegetation. Photogram. Eng. 21 (4): 582-588.

Keys should be constructed for a specific purpose, and the purpose involves consideration of what, where, and who. Organization of the keys may be by "selection" or "elimination."

ZSILINSZKY, V. G. 1963. Photographic interpretation of tree species in Ontario. Ontario Department of Lands and Forests, Toronto. 80 p.

"This publication describes the identification of the principal tree species in Ontario on these medium scale [1:15840] summer verticals [aerial photographs] taken with a six-inch focal length aerial camera using a minus blue filter on a medium-grain and medium speed panchromatic film developed to low gama. Interpretation is carried out on double-weight glossy prints produced on a contact printer having some method of automatic exposure-control." Examples of tree species are illustrated with stereo pairs of aerial photographs.

Cameras, Films, Filters, and Aerial Photographic Techniques

ALDRED, A. H. 1968. Potential of satellite photography in forestry. Can Dep. Forest. and Rural Develop., Forest Manage. Inst. Inform. Rep. FMR-X-11. 18 p.

Abstract: "Satellite photographs collected for weather forecasting purposes have suggested possible uses in non-meteorological fields. The potential advantages in forestry are discussed, present conditions are listed and a future resource satellite program is outlined that may offer opportunity for specific experiments." [Forest damage from insects and fire is listed and discussed.]

ALDRED, A. H. and L. SAYN-WITTGENSTEIN. 1968. Tropical tests of the forestry radar altimeter. Can. Dep. Forest. and Rural Develop., Forest. Manage. Inst. Inform. Rep. FMR-X-12. 28 p.

Abstract: "Trials of the forestry radar altimeter over a tropical rain forest proved that the instrument is accurate enough to be useful, although it does not entirely penetrate tropical vegetation. When the altimeter was used over closed stands at altitudes between 500 and 1100 feet, vegetation introduced a systematic error of approximately -22 feet in the altimeter readings. Superimposed upon this systematic error was a random mean-squared error of approximately 13 feet. Erratic results were obtained below 500 feet."

The authors also noted that "...no undeveloped exposed negatives should be shipped across international boundaries;

BECKING, R. W. 1959. Forestry applications of aerial color photography. Photogram. Eng. 25 (4): 559-565.

The most natural color balance was achieved on clear mornings 1) without a haze filter and at flying altitudes of 1,500 to 2,000 feet, or 2) with a 1A filter at flying altitudes of about 5,000 feet. Low altitude photography at scales of 1:8,000 to 1:12,000 had the greatest value for intensive management purposes. Foliage coloration was found to be vital for identifying tree species. Spring and fall color photography was advantageously applied, especially to hardwood species.

CHAVES, J. R. and R. L. SCHUSTER. 1968. Color photos for highway engineering. Photogram. Eng. 34 (4): 375-379.

The authors favored the Aero Neg System over the false-color system since Aero Neg was more versatile.

CHENHALL-JONES, W. M. 1966. Color aerial photography-systems and consideration of available materials. Austral. Forest Res. 2 (3): 46-50.

The advantages and disadvantages of positive and negative systems were presented. The main advantage of the negative color system was that "After processing, this material becomes an ideal medium for production of contact prints, enlargements or diapositives in color or black and white." However, "A further photographic stage of color reproduction is necessary before the project can be assessed for its color fidelity."

Two advantages of the "positive" system were as follows:

1) "Provided processing is carried out to rigid specifications and laboratory controlled conditions, the processed color film is immediately ready for interpretation and assessment for color fidelity."

2) "A duplicate B & W film negative ... can be inexpensively produced from the original color positive...."

Two disadvantages of the "positive" system were

1) "To achieve maximum color fidelity, ... haze compensating filters and/or height compensating filters...." must be used where necessary.

2) Color prints larger than 16 by 20 inches are impractical to obtain.

COLWELL, R. N. 1961. Some practical applications of multiband spectral reconnaissance. Amer. Sci. 49 (1): 9-36.

"Multiband spectral reconnaissance consists in using two or more cameras, or other sensing devices, located remotely from the area being investigated, each sensor being especially suited for the sensing of energy in its own spectral area." Such a technique could integrate several color photographic images.

________ 1962. Platforms for testing multisensor equipment. Proc. 2nd Symp. Remote Sens. Environ. pp. 7-49.

Some testing should be done from a stable platform, e.g. earthbound platforms such as cliffs, etc., or erected platforms, such as fire towers or water towers. Thus, optimum

sensor specifications could be arrived at quickly and economically, and testing could then be done from mobile platforms.

COLWELL, R. N. and L. F. MARCUS. 1961. Determining specifications for special purpose photography. Photogram. Eng. 27 (4): 618-626.

The authors described methods used to determine specifications for photography of wildland areas, and provided recommendations for such photography. [These methods could be adapted for damage surveys.]

COOPER, C. F. and F. M. SMITH. 1966. Color aerial photography: toy or tool? J. Forest. 64 (6): 373-378.

A general discussion of color aerial photography compared with black and white photography is presented. The article outlines features and problems encountered by the authors.

CURRENT, I. B. 1967. Sensitometry in color aerial photography. Photogram. Eng. 33 (10): 1143-1151.

"Sensitometry is useful for the practical determination of film speed and setting correct exposure, control of processing conditions, adjustment of color balance, and control of printing. Measurement of densities and plotting of characteristic curves provides data for carrying out these aims."

DUDDEK, M. 1967. Practical experience with color photography. Photogram. Eng. 33 (10): 1117-1125.

The author noted that 6-inch Aviogon or 6-inch Universal Aviogon lenses were well suited for color photography.

The procedure which finally brought consistently good results with different types of Kodak color films was outlined, with an emphasis on color reversal and color negative films.

EASTMAN KODAK COMPANY. 1962. Instructions for exposing and processing Kodak Ektachrome Infrared Aero Film (Process E-3). Kodak Pam. No. 53461, Rochester, N.Y. 4 p.

A Wratten No. 12 filter was recommended for the film. "A more recent and general use of the film is forest survey, in which diseased foliage can be identified and distinguished from healthy foliage by interpretation of the infrared reflectance of the foliage as recorded on the film."

______ 1963. Infrared and ultraviolet photography. 3rd ed. Kodak Publ. No. M-3. Rochester, N.Y. 48 p.

The section on infrared discussed the taking of infrared photographs and their use.

______ 1965. Kodak Wratten filters for scientific and technical use. Kodak Publ. No. B-3. Rochester, N.Y. 77 p.

Diagrams were included to illustrate the different spectral windows of the various filters.

______ 1966. Kodak Ektachrome Infrared Aero Film, Type 8443. Kodak Pam. No. 57619, Rochester, N.Y. 2 p.

This leaflet was actually the data sheet provided with rolls of 35 mm Ektachrome Infrared Aero Film. Basic biological interpretations for the photographic results were given.

EASTMAN KODAK COMPANY. 1966. Color as seen and photographed. 2nd ed. Kodak Publ. No. E-74. Rochester, N.Y. 68 p.

This booklet described the basic principles involved in the design and manufacture of color films.

[An understanding of these processes can greatly increase the interpretability of the image colors as seen on aerial color photographs.]

______ 1967. Kodak data for aerial photography. Kodak Publ. No. M-29. Rochester, N.Y. 83 p.

Various films used in aerial photography were discussed; also included were

1) description of the film,
2) aerial exposure index,
3) filter requirements,
4) processing information, and
5) some aspects of interpretation.

______ 1967. Kodak Aero-Neg Color system. Kodak data book No. M-40. Eastman Kodak Co., Rochester, N.Y. 49 p.

A basic description of the negative color system was provided. The emphasis was on developing and printing the film.

FRITZ, N. L. 1967. Optimum methods for using infrared sensitive color films. Photogram. Eng. 33 (10): 1128-1138.

Results of false color film may be optimized through a knowledge of some of its special characteristics and by using photographic techniques which take advantage of these properties. The various characteristics of the film were discussed in detail.

FLEMING, Elizabeth A. 1964. Solar altitude nomograms for aerial photography. Surv. and Mapping Br., Can. Dep. Mines and Tech. Surv. Publ. No. 64-3. 20 p.

This publication illustrated the sun angles for various latitudes and longitudes in Canada.

GULLICKSEN, S. O. 1967. Continuous strip photography. Photogram. Eng. 33 (3): 278-287.

High altitude strip photographs can serve as a substitute for planimetric maps.

[It seems that an operation recorder may be successfully used with strip photography.]

HELLER, R. C., R. C. ALDRICH and W. F. BAILEY. 1959. Evaluation of several camera systems for sampling forest insect damage at low altitudes. Photogram. Eng. 25 (1): 137-144.

Large-scale color photographs were used to appraise damage caused by several forest insects. Fast shutter speeds were used to avoid blurring large-scale photographs.

LYONS, E. H. 1961. Preliminary studies of two camera, low-elevation stereo-photography from helicopters. Photogram. Eng. 27 (1): 72-76.

Lyons described a method of obtaining flying-height above ground from the photo-measured base length of two cameras mounted one at each end of a 15-foot boom suspended beneath a helicopter.

MARLAR, T. K. and V. N. RINKER. 1967. A small four-camera system for multi-emulsion studies. Photogram. Eng. 33: 1252-1257.

70 mm film used with four Hasselbladt 500 El aerial

cameras equipped with 80 mm lenses provided the greatest diversity of film type. A Model NC-1 intervalometer was used. Cost figures were presented.

MEYER, M. P. and L. H. TRANTOW. 1959. A comparison of 6 inch Planigon lens with conventional 8.25 inch lens aerial photography for forestry purposes. J. Forest. 57 (9): 634-636.

"...panchromatic photography flown at a scale of 1:15,840 with a distortion-free 6-inch lens can be expected to produce better overall stereoscopic image detail than is obtainable with a conventional 8.25 inch lens at the same scale."

______ 1961. A test of Polaroid variable-color filters for forest aerial photography. Photogram. Eng. 27 (5): 703-705.

Abstract: "Polaroid variable-color filters were used with Tri-X film to examine northern Minnesota conifer-deciduous tree tonal relationships in the green and yellow portion of the spectrum. Although some improvements over summer panchromatic were obtained, the variable-filter photography was inferior to conventional summer infrared minus-blue and fall panchromatic minus-blue photography of the area tested."

MIKHAILOV, V. Y. 1960/61. The use of color sensitive films in aerial photography in U.S.S.R. Photogrammetria 17 (3): 99-104.

Two types of color negative film were used in making aerial surveys in the Soviet Union: a conventional three-layer film, and a two-layer film which has been dubbed a "spectrozonal film". [In the true sense of the word, all

color films are spectrozonal films because they have dye-forming layers sensitive to definite spectral zones.
The authors noted that the cost of field interpretation was three or four times as high as that of aerial photography proper, and that the use of color photographs greatly reduced the amount of fieldwork.

MOLINEUX, C. E. 1965. Multiband spectral system for reconnaissance. Photogram. Eng. 31 (1): 131-143.

A special nine-lens camera was used with filters to take simultaneous photographs in several regions of the spectrum. The camera operated from the 0.35μ to the 5.0μ region.

MORAIN, S. A. and D. S. SIMONETT. 1967. K-band radar in vegetation mapping. Photogram. Eng. (7): 730-740.

Techniques included tri-color image combinations, the generation of a probability-density function to quantify variations in the gray-scale level between vegetation types, and a data space sensor employed to help distinguish between vegetation types.

MUNN, L. C., J. B. McCLELLAN and L. E. PHILPOTTS. 1966. Airphoto interpretation and rural land-use mapping in Canada. Photogrammetria 21 (3): 65-76.

The authors discussed the use of Plus-X and Infrared Aerographic film, and gave several advantages of these films for mapping agricultural lands in Canada.

NORTON, G. L. 1968. Aerial cameras for color. Photogram. Eng. 34 (1): 36-48.

To handle increased requirements for color, an aerial camera system must be equipped with a distortionless lens providing good image quality, and illumination must be fully corrected over the wide angular field.

SHAIN, W. A. and J. P. ROSTRON. 1964. An aerial camera pod to reduce photogrammetry cost. J. Forest. 62 (5): 341-342.

A pod attached to the belly of a Cessna 172 reduced the cost of aerial photography to approximately one-eighth that of contract photography.

SIMS, W. G. 1966. A comparison of color and black-and-white copies from aero film for purposes of interpretation. Austral. Forest. Res. 2 (1): 28-34.

On color prints, a shift in color from the original took place. The author listed his order of preference for the materials he reviewed, with special regard for the presentation of extractable information, as follows:

1) enlarged color diapositives;
2) contact color copy diapositives;
3) original color transparency;
4) enlarged color prints;
5) enlarged black and white prints;
6) contact black and white diapositives;
7) contact black and white prints.

SOREM, A. L. 1967. Principles of aerial color photography. Photogram. Eng. 33 (9): 1008-1018.

The addition and subtraction of three primary colors are basic concepts in the design and use of color photographic material.

SPECHT, M. R., N. L. FRITZ and A. L. SOREM. 1966. The change of aerial camera exposure with solar altitude. Photogr. Sci. Eng. 10 (3): 150-155.

Abstract: "The relationship between solar altitude and apparent scene luminance for aerial photography has been determined by the evaluation of a series of aerial photographs made of specific scenes at solar altitudes ranging from 68 degrees to -1 degree. Variations as a function of solar altitude, in the apparent luminance of individual details, as well as in luminance distributions, were obtained from microdensitometer measurements on the negatives. The results are compared with the curves relating solar altitude with illuminance on a horizontal plane and with Jones and Condit's luminous density. Significant differences among these relationships are noted."

A pair of 35 mm cameras was used for the test.

SUITS, G. H. 1960. The nature of infrared radiation and ways to photograph it. Photogram. Eng. 26 (5): 763-772.

Suits concentrated on infrared radiation at 1.5 μ and longer, but he also gave a general discussion on infrared radiation, including near-infrared.

TARKINGTON, R. G. 1953. An aspect of color photography and interpretation. Photogram. Eng. 19 (3): 418-420.

The author described Kodak Ektachrome Aero Film and pointed out that there was no direct relationship between the spectrophotometric characteristics of the object and those of the colors formed on the photo. Spectral transmittance of the reproduction did not match spectral reflectance of the original.

TARKINGTON, R. G. 1959. Kodak panchromatic negative films for aerial photography. Photogram. Eng. 25 (5): 695-699.

Fast panchromatic films, e.g. Tri-X were described.

TARKINGTON, R. G. and A. L. SOREM. 1963. Color and false color films for aerial photography. Photogram. Eng. 29 (1): 88-95.

The paper described the differences between Kodak Ektachrome Infrared Aero film and Ektachrome Aero film, and compared the new product with the old. The new films have higher speed, improved definition and less granularity.

WILLINGHAM, J. M. 1959. Obtaining vertical aerial photographic coverage with a 35 mm camera. J. Forest. 57 (2): 108-110.

A 35 mm camera was adapted for vertical aerial photography. The desired coverage was obtained and delivered in a finished form in a minimum amount of time. Small areas were covered quickly, and at a very small cost.

WILSON, R. C. 1967. Space photography for forestry. Photogram. Eng. 33 (5): 483-490.

Space photography for overall forest mapping may compliment the use of aerial photography for appraising forest detail.

YOST, E. F. and Sondra WENDEROTH. 1967. Multispectral color aerial photography. Photogram. Eng. 33 (9): 1020-1040.

The authors described a system whereby black and white positive transparencies are used to produce color and false-color pictures.

ZALIK, S. and R. A. MILLER. 1959. Filters that isolate narrow regions of the spectrum for plant growth studies. 9th Int. Congr. Bot. Proc. 11: 440.

Abstract: "The spectral characteristics of different kinds of colored plastic sheets were determined. Plexiglass sheets of the selected colors were fabricated into filters which contain 10 cm. aqueous layers of desired salt concentration. This filter system provides a means of isolating fairly narrow bands of the spectrum. These filters are seated in light-tight growth boxes. Construction and operation of the filters, the light source, and the boxes, and the required air-conditioning will be discussed."

Photo Interpretation Techniques

ANSON, A. 1966. Color photo comparison. Photogram. Eng. 32 (2): 286-297.

A comparison of panchromatic, Ektachrome Infrared, and color photos showed that

1) Ektachrome Infrared was best for mapping,
2) Ektachrome Infrared showed almost twice the vegetative cover that could be interpreted from the other two emulsions which were compared,
3) land use details were clearest on Ektachrome Infrared,
4) soils which were based on texture showed up equally well on all photos, and
5) slightly more conformation on culture was found on color photographs than on black and white, but Ektachrome Infrared photos were easier to use.

_______ 1967. The stereoscopic effect of color. Photogram. Eng. 33 (4): 371-376.

"If an image is photographed through an optical wedge, a displacement occurs which is related both to the wedge angle and to the wave length of reflected light.

This technique could prove to be a useful tool for making crude distinctions of color, even for color-blind observers. The photographic emulsion is not a necessary requirement for the system, and the difference in parallax might be measured by other sensors by recording or enhancing media."

AVERY, T. E. 1962. Recent trends in forest photogrammetry. J. Forest. 60: 458-461.

This survey paper discussed the following topics:

1) development in surveying and mapping because of better equipment;
2) eliminating keys for tree species identification;
3) air photo uses in industry;
4) future aspects.

______ 1966. Forester's guide to aerial photo interpretation. U.S.D.A., U.S. Forest Serv., Agr. Handb. 308. 40 p.

"This handbook was written as a practical reference on techniques of aerial photo interpretation in forest inventory. This manual emphasizes stereoscopic interpretation of vertical aerial photographs available from various agencies...."

BEREZIN, A. M. and N. G. KHARIN. 1960. Kroopnomashtabnoou aerofotosiomkoo vh prouzvomsmvo (Large-scale aerial photography in production.) Lesnoe Khoz. 1960. (5): 15-18.

On 1:15,000 to 1:25,000 scale photography, 25 to 30% of the total number of trees could be counted individually; on 1:10,000, 65% could be counted in this manner, and on 1:5,000, 72 to 80%. A field check of 1:2,000 photography revealed that loss of volume for unaccounted trees amounted to 5 to 7% of the total volume. On 1:3,000 SN-2 spectrazonal film, the average stand height could be measured within an accuracy of 6%.

A linear regression between the visible crown diameter and the dbh of individual trees was given for *Pinus* spp., *Abies* spp., *Betula* spp., and *Almus* spp.

BEREZIN, A. M. and I. A. TRUNOV. 1965. Interpreting forests for the purpose of mapping. *In* Aerial photography used in mapping vegetation and soils. Aerospace Technol. Div. Rep. T-65-29: 4-23.

Summer color spectrozonal aerial photographs at a scale of 1:10,000 gave the best definition of contours in the forest area, and provided the most information on internal content. "The reliability of forest mapping depends upon the rational selection in the type of aerial film, the scale of aerial photographing, consideration as to the season of the surveying and the aerial photographic gear used. The correct combination of the listed factors is determined by the concrete conditions of the geographic landscapes."

BRAUNNSCHWEILER, D. H. 1957. Seasonal changes of the agriculture pattern: a study in comparative airphoto interpretation. Photogram. Eng. 23 (1): 131-139.

"Most crops and all land use types have specific pictorial characteristics which are a function of time rather than place...."

COLWELL, R. N. 1950. New techniques for interpreting aerial color photography. J. Forest. 48: 204-205.

Colwell advocated the use of filters to emphasize details present on color transparencies.

COLWELL, R. N. 1954. A systematic analysis of some factors affecting photographic interpretation. Photogram. Eng. 20: 433-453.

The factors governing the quality of photo images were given as follows:

1) tone and color characteristics;

2) image sharpness;

3) stereoscopic parallax.

______ 1963. To measure is to know -- or is it? Photogram. Eng. 29 (1): 71-83.

The author presented a series of interesting examples, and pointed out that measurement, along with photo interpretation (photo recognition), often aids in the correct interpretation of aerial photographs.

______ 1964. Pictures don't lie -- but the bigots can't be bothered. Photogram. Eng. 30 (2): 266-273.

The paper gave an example of an infrared photo showing diseased (damaged) trees not visible on panchromatic photos.

______ 1967. Remote sensing as a means of determining ecological condition. Bioscience 17 (7): 443-449.

Specific examples were given to show the usefulness of remote sensing to determine various ecological conditions. The author concluded that "The relatively new techniques of extracting ecological information from an analysis of remote sensing imagery should be considered as complimentary to, rather than competitive with, the time-honored techniques that involve direct on-the-ground observation of ecological factors."

COLWELL, R. N. 1968. Remote sensing of natural resources. Sci. Amer. 218 (1): 54-69.

Panchromatic and black and white infrared aerial photographs of trees damaged by sediment deposition in a mangrove swamp were compared. The damaged trees appeared much darker on the infrared photos.

DOVERSPIKE, G. E., F. M. FLYNN and R. C. HELLER. 1965. Microdensitometer applied to land use classification. Photogram. Eng. 31 (2): 294-306.

It was concluded that color density alone does not offer a solution to differentiate land use on color aerial photographs.

DUTTON, J. A. 1967. Comparative photo interpretation from panchromatic, color, and color IR photography. M.S. Thesis, Ohio State Univ., Columbus, Ohio. 181 p.

"The ground truth was not available to the interpreters nor could they compare the three types of photography simultaneously. Therefore, the comparisons made in this study are of a relative nature."

After the test of the interpreters, a review of the literature, and a questionnaire, the author concluded that color photography is superior to panchromatic photography for photo interpretation.

The author also recommended that "Information derived from this study should be used as a reference for planning future studies, and not as conclusive evidence that any one of the three types of photography is superior in performance in any one of the comparisons."

However, color photography was recommended for 1) mapping cultural features, 2) military photo interpretation, 3) mapping agricultural field crops by types, and 4) mapping soils. Color infrared was recommended for 1) studies of canals, waterways, etc., 2) forestry studies, particularly if tree disease or differentiation by species was concerned, 3) mapping of vegetation features, and 4) mapping drainage patterns.

The photographic scales used in the study were 1:60,000, 1:40,000, and 1:20,000.

EASTMAN KODAK COMPANY. 1965. Practical densitometry. Kodak Pam. No. E-59. Rochester, N.Y. 23 p.

This booklet provided a brief description of optical densitometry and its application to black and white, or color photographs.

HAACK, P. M. 1962. Evaluating color, infrared, and panchromatic aerial photos for the forest survey of interior Alaska. Photogram. Eng. 28 (4): 592-598.

"With estimates of commercial forest area and timber volumes as foremost aims of the extensive forest survey of interior Alaska, evidence points to infrared film with a minus blue filter as the best type suited for the inventory."

HAMILTON, L. S. 1960. Color standardization for foliage descriptions in forestry. J. Forest. 58: 23-25.

Hamilton emphasized the need for standardized color description and suggested that the best suited is the Munsell color system using hue, value and chroma.

JACKSON, K. B. 1959. Factors affecting the interpretability of air photos. Can. Surv. 14 (10): 454-464.

The author stated that to obtain maximum interpretable detail on a black and white panchromatic aerial photograph, the following were necessary:

1) maximum sharpness in the negative;
2) optimum density and contrast in the positive;
3) adequate visual acuity in the stereoscope.

JENSEN, H. A. and R. N. COLWELL. 1949. Panchromatic vs infrared-minus blue aerial photography for forestry purposes in California. Photogram. Eng. 15 (2): 201-233.

Spectral reflectance diagrams for hardwood and coniferous foliage were included. The near-infrared spongy mesophyll reflectance theory (Clark, 1946) was presented to explain the higher reflectance from hardwoods, which made them appear much lighter on the infrared photos.

JOHNSON, P. L. 1965. Radioactive contamination to vegetation. Photogram. Eng. 31 (6): 984-990.

It was demonstrated that the optical density of transparencies of different film types was related to distance from a point source of radiation damage and that there was a relationship between the intensity of forest damage and the optical density of the photographs.

KALMBACH, E. R. 1949. A scanning device useful in wildlife work. J. Wildl. Manage. 13 (3): 226-227.

Kalmbach described a device which facilitates counting assembled grouped populations visible on aerial photographs.

MALILA, Wm. A. 1968. Multispectral techniques for imagé enhancement and discrimination. Photogram. Eng. 34 (6): 556-575.

Proper techniques can produce increased image contrasts. Their use gives the potential for automatic recognition of objects through processing and computational techniques which exploit the spectral differences that can produce the increased contrasts.

MARUYASU, T. and M. NISHIO. 1960. Experimental studies on color aerial photographs in Japan. Tokyo Inst. of Ind. Sci. Rep. 8.

It was concluded that color aerial photographs were superior to monochromatic photos in all respects.

MEYER, M. P. 1963. The quantitative method in forest air photo interpretation research -- approaches and limitations. Photogram Eng. 29 (6): 937-941.

Problems of communication and implementation were discussed and a number of sample studies were described. The author was opposed to too much quantitative description and analysis.

MOESSNER, K. E. 1955. A sample test for stereoscopic perception. Photogram. Eng. 21 (3): 331-339.

Moessner provided examples for testing stereo vision.

MYHRE, D. W. and M. P. MEYER. 1961. Tree image recovery on aerial photographs as affected by printing method and film. J. Forest. 59 (2): 97-99.

The photo interpreters showed a definite personal preference for the panchromatic photos over the infrared photos and a general preference for the standard method of printing.

MYHRE, D. W. and M. P. MEYER. 1961. Variations in aerial photo image recovery resulting from difference in film and printing technique. Photogram. Eng. 27 (4): 595-599.

The photo interpreters showed a definite personal preference for the panchromatic photos over the infrared photos and a general preference for standard coventional contact prints over full-scan electronic prints.

OLSON, D. P. 1964. The use of aerial photographs in studies of marsh vegetation. Maine Agr. Exp. Sta., Tech. Serv. Bull. 13. 62 p.

The author concluded that knowledge of ground conditions was more important than formal training as a photo interpreter for the interpretation of aerial photographs.

REIDEL, C. H. 1967. Parkinson's law for foresters. J. Forest. 65 (4): 240-242.

Work expands to fill the time available for completion.

ROTH, E. R., R. C. HELLER and W. A. STEGALL. 1963. Color photography for oak wilt detection. J. Forest. 61 (10): 774-778.

A comparison of aerial observation and aerial color photography in locating oak trees infected by Ceratocystis fagacearum in Tennessee revealed that photography proved more efficient when photos were interpreted by an experienced technician. Its costs, however, were 20 times that of visual observation, and with untrained photo interpreters it proved no more efficient. It was also reported that infrared color film was very sensitive to any off-color trees and therefore brought in many commission errors, and that Anscochrome gave fewer errors at a large scale than the false-color film.

SAYN-WITTGENSTEIN, L. 1966. The best season for aerial photography Trans. 2nd. Int. Symp. on Photo-Interpretation, Paris. pp. 51-58.

The author concludes a discussion of seasonal aspects of photography by writing that "Grave errors will be committed by those who blindly follow interpretation keys and rules. There is no substitute for a thorough understanding of the factors that influence the appearance of objects being photographed. Nothing affects the appearance of the world's surface more than seasonal changes. One must therefore observe and understand these changes to be a successful photo-interpreter."

SCHNEIDER, Wm. J. 1966. Water resource studies in the everglades. Photogram. Eng. 32 (6): 958-965.

Color, infrared and panchromatic photographs showed salient features that permitted evaluation of the overall water resources picture. The use of color and time lapse photos was advocated.

SCHULTE, O. W. 1951. The use of panchromatic, infrared and color aerial photography in the study of plant distribution. Photogram. Eng. 17 (5): 688-712.

The author equated color and panchromatic black and white photography; he indicated that both were inferior to black and white infrared for plant species identification. At scales less than 1:2,000 crown texture was more important than tone.

SMITH, J. T. 1963. Color -- a new dimension in photogrammetry. Photogram. Eng. 29 (6): 999-1013.

The author described U.S. Coast and Geodetic Survey techniques for color aerial photography and laboratory processing. Excellent examples of color air photographs are presented.

SPURR, S. H. 1949. Films and filters for forest aerial photography. Photogram. Eng. 15 (3): 473-481.

Tonal contrast in infrared photography seems to be greater in the late summer than in the spring or early summer.

TAUBENHAUS, J. J., W. N. EZEKIEL and C. B. NEBLETTE. 1929. Airplane photography in the study of cotton root rot. Phytopathology 19: 1025-1029.

"The elevation at which pictures are to be made depends on the purpose of the work...." Aerial photographs provide a view of the extent of the damage, that only a tedious ground survey would reveal. Damaged areas stand out, even on panchromatic black and white photographs. The authors based their description of damaged areas on the presence or absence of vegetation.

VAN ATTA, G. R. 1936. Filters for the separation of living and dead leaves in monochromatic photographs with a method for the determination of photographic filter factors. J. Biol. Photogr. Assoc. 4: 177-191.

"...ordinary monochromatic photos usually show the greens and browns of living and dead foliage as undistinguished shades of the same color." Filters emphasize the differences.

WEAR, J. R. 1960. Interpretation methods and field use of aerial color photos. Photogram. Eng. 26 (5): 805-808.

Color-interpretation techniques, film handling procedures, and a description of the new light tables for field or office use are presented.

WELCH, R. 1968. Film transparencies vs paper prints. Photogram. Eng. 34 (5): 490-501.

The definition of objects near the threshold of detection is much higher with positive film transparencies than with paper prints.

Forest Damage Detection

ALDRICH, R. C., W. F. BAILEY and R. C. HELLER. 1959. Large scale 70 mm color photography techniques and equipment and their application to a forest sampling problem. Photogram. Eng. 25 (5): 747-754.

A survey for white pine weeviled trees in New York State indicated weeviled trees could be counted with 90% accuracy at a scale of 1:600. The authors decided that large scale 70 mm photography was useful since it was possible to sample.

1) tall trees when damage is hard to see on ground,
2) more trees per plantation, and
3) remote areas in large plantations.

ALDRICH, R. C. and A. T. DROOZ. 1967. Estimated Fraser fir mortality and balsam woolly aphid infestation trend using aerial color photography. Forest. Sci. 13 (3): 300-313.

A scale of 1:7920 was more practical for determining mortality.

"...best relationship between photo counts and ground counts of dead fir and total-spruce-fir was that based on dominant, codominant and intermediate trees."

ALDRICH, R. C., R. C. HELLER and W. F. BAILEY. 1958. Observation limits for aerial sketch-mapping southern pine beetle damage in the Southern Appalachians. J. Forest. 56 (3): 200-202.

The authors recommended that

1) "observation strip width should be restricted to ½-mile when infestations of 2-5 trees or single trees are to be

mapped," and that

2) "for best results, flying should be done at an altitude of 1,000 feet above the terrain and at speeds not greater than 100 miles per hour."

ANSCHUTZ, G. and A. H. STALLARD. 1967. An overview of site evaluation. Photogram. Eng. 33 (12): 1381-1396.

The authors discussed photo interpretation aspects of land-form analysis; transportation, utilities and access; geology; hydraulics, hydrology, and drainage; land use and cost analysis.

BAJZAK, D. 1967. Detection and appraisal of damage by balsam woolly aphid on <u>Abies Balsamea</u> (L.) Mill. by means of aerial photography. Ph.D. Thesis. N.Y.S. College of Forestry, Syracuse.

The author concluded that "The Kodak Ektachrome Infrared film at 1:720 scale provided the most accurate estimation of various damage variables and injury classes of trees. The second best was the same film at 1:1,200 scale, resulting in somewhat lower accuracy in estimating the number of trees by injury classes on one-tenth acre sample plots." [The injury classes were based on morphological descriptions of the damage levels.]

BARANYAY, J. A. 1963. Detection of dwarf mistletoe-infected stands by aerial photography. Dep. Forest., Forest. Entomol. and Pathol. Br. Annu. Rep. 119 p.

In a preliminary ground test "...isolated groups of dwarf mistletoe-infected trees were distinguished as darkened areas on the photographs."

BAWDEN, F. C. 1933. Infra-red photography and plant virus diseases. Nature 132: 168.

Diseased leaves show up on infrared photos. "The infra-red plates are so sensitive to necrotic changes in the potato that clear photographs can be obtained of commencing necrosis barely visible to the eye...."

BENSON, M. L. and W. G. SIMS. 1967. False-color film fails in practice. J. Forest. 65 (12): 904.

Ektachrome Infrared Aero film does not show or reveal anything that cannot be seen on normal color film. [See Cochrane (1968)]

BLYTHE, R. and Ellen KURATH. 1967. Infrared and water vapor. Photogram. Eng. 33 (7): 772-777.

"To find individual plants suffering from ailments which interfere with their ability to transpire, one should take IR imagery on similar days, but at a time when the plant is known to have adequate water, such as after a rain, because both plant health and water availability affect the appearance of the IR image."

CIESLA, W. M., J. C. BELL, Jr. and J. W. CURLIN. 1967. Color photos and the southern pine beetle. Photogram. Eng. 33 (8): 883-888.

The authors found that Ektachrome Infrared Aero film was the best suited for their study. Even though the authors were unable to detect beetle infested pine trees with green foliage, they reported that the false-color photographs greatly facilitated species identification.

CLERUM, C. and J. L. FARRAR. 1965. A note on internal frost damage in white spruce needles. Can. J. Bot. 43: 1589-1591.

Internal frost damage, which appeared as a collapse of living cells, was easily recognized when mesophyll tissue was viewed longitudinally, but not when viewed transversely. The collapse was evident immediately after thawing.

COCHRANE, G. R. 1968. "False-color film fails in practice." Photogram. Eng. 34 (11): 1142-1146.

The author presented a rebuttal to Benson and Sims (1967).

COLWELL, R. N. 1956. Determining the prevelance of certain cereal crop diseases by means of aerial photography. Hilgardia 26 (5): 223-286.

Colwell demonstrated that infrared sensitive films are the most practical for disease detection studies. The author, referring to Clark (1946), also hypothesized that the decrease in near-infrared reflectance from the foliage of a plant was due to either 1) the plugging of the cells with fungal hyphae, or 2) the collapse of the spongy mesophyll because of water loss. The author reported that the disease was detected first on photographs from near-infrared sensitive film.

______ 1960. Some uses of infrared aerial photography in the management of wildland areas. Photogram. Eng. 26 (5): 774-785.

The use of color-infrared film in making surveys of damage to forest stands by insects was described. The author indicated that since subject and atmospheric conditions vary so widely, exposures on infrared and panchromatic aerial negative films provide a more adequate basis for interpretation. He also reported that the human eye was capable of perceiving 200,000 color combinations as compared with the 200 shades of grey it can detect on panchromatic photos.

COLWELL, R. N. 1964. Aerial photography -- a valuable sensor for the scientist. Amer. Sci. 52 (1): 17-49.

This article surveyed the uses of aerial photography in various scientific disciplines. However, several colored plates were presented; part of the caption for Plate 2 stated that "Since camouflage detection film has a red dye that is activated by infrared light (wavelength range 700-900 milli-microns) highly infrared-reflective objects, including healthy plants, appear bright red on such photography, while objects lacking infrared reflectivity, including unhealthy plants, appear some color other than red -- usually blue-green...." Reference to Tarkington and Sorem (1963) will reveal the mistake in the above statement. It is not the red dye but the cyan dye-forming layer that is influenced by near-infrared energy.

COLWELL, R. N. et al. 1963. Basic matter and energy relationships involved in remote reconnaissance. Photogram. Eng. 29 (5): 761-799.

Basic characteristics of the electromagnetic spectrum that are important in the remote sensing process were discussed. A discussion of spectral reflectance from healthy and unhealthy plants and its relation to spongy mesophyll was presented.

COOPER, G. R. and F. E. MANZER. 1964. Further development of aerial photographic techniques for potato late blight detection. Phytopathology 54: 127. (Abstract only)

"Monochromatic infrared and infrared-Ektachrome aerial photographs of blighted potatoes were compared with their respective non-infrared counterparts. Infrared-Ektachrome film appeared to have distinct advantages over monochromatic infrared film...." [See Manzer and Cooper (1963; 1967).]

CRAIG, R. D. 1920. An aerial survey of forests in northern Ontario. Can. Forest. Mag. 16: 516-518.

Discoloration because of spruce budworm defoliation was mapped from aircraft as early as 1920.

CROXTON, R. J. 1966. Detection and classification of ash dieback in large-scale color aerial photography. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Sta. Res. Paper PSW 35: 13 p.

Ash trees were divided into five dieback rating classes:

1) healthy, leaves dark green;
2) top thin, leaves tending to clump at ends of twigs, foliage paler green than normal;
3) twigs dying back, less than 50% of crown dead;
4) branches dying back, more than 50% of crown dead;
5) tree dead.

A dichotomous key containing 13 species and all classes of ash dieback was used for photo interpretation tests. Once they had identified ash, interpreters could classify ash dieback disease well and consistently on photos at a scale of 1:1584, but not on those at 1:7920.

HARRIS, T. H. 1951. Use of aerial photographs in control of forest diseases. J. Forest. 49: 630-631.

In this article, Harris emphasized mapping forest types and identifying species.

HELLER, R. C. 1965. Aerial remote sensing research in forestry. 1965, Proc. Soc. Amer. Forest. pp. 162-168.

The author discussed the two popular visual systems for damage surveys: 1) sketch mapping, and 2) use of an operation recorder. It was reported that a recent test (September, 1964) in North Carolina to detect <u>Fomes annosus</u> in a white pine plantation, showed that significantly more diseased trees were detected on Ektachrome Infrared Aero film than on Anscochrome color film. However, only two-thirds of all known infected trees were detected. [No description was provided for the infected trees.]

——— 1968. Previsual detection of ponderosa pine trees dying from bark beetle attack. Proc. 5th Symp. Remote Sens. Environ. pp. 387-433.

<u>From Abstract</u>: "Studies are underway in the Black Hills of South Dakota to determine the ground instrumentation, aerial sensing equipment, and technique required to detect vigor loss and previsual signs of tree mortality caused by bark beetles in coniferous timber stands.

"To date, no aerial sensor has been successful in detecting stressed conifers before the foliage discolors. No difference in photo interpretation accuracies have been found between color and false-color films. However, interpreters, viewing color transparencies, were able to pick out three times as many dying trees in May as ground observers."

HELLER, R. C., R. C. ALDRICH and W. F. BAILEY. 1959. An evaluation of aerial photography for detecting southern pine beetle damage. Photogram. Eng. 25 (4): 595-606.

The authors reported that

1) interpretation on color film was more accurate than that on panchromatic film,

2) infrared black and white film had previously proved to be of no value,

3) a scale of 1:7,920 was the best compromise of accuracy and cost, and

4) ground cruising proved to be the most expensive and time-consuming method.

The authors concluded that color photography was most useful where it was necessary to map the location of infested trees with a high degree of accuracy -- particularly on expensive bark beetle control operations.

HELLER, R. C., J. L. BEAN and J. W. MARSH. 1952. Aerial survey of spruce budworm damage in Maine in 1950. J. Forest. 50 (1): 8-11.

The operation recorder was used to record the intensity of spruce budworm defoliation in a plane travelling 90 to 100 mph at 200 feet. Visual identity of damage by predetermined characteristics helped in assessing the level of damage.

HELLER, R. C., J. L. BEAN and F. B. KNIGHT. 1959. Aerial surveys of Black Hills beetle infestations. U.S. Forest Serv., Rocky Mount. Forest. Range Exp. Sta. Publ. No. 46. 8 p.

On Ektachrome Aero photographs at a scale of 1:7,920, experienced interpreters were able to count the faded trees on color transparencies within a 5% error.

HELLER, R. C. <u>et al</u>. 1967. A test with large scale aerial photographs to sample balsam woolly aphid damage in the Northeast. J. Forest. 65 (1): 10-18.

The authors found that a scale of 1:1,188 was best for detecting and estimating damage. The number of trees killed because of severe aphid stem attacks was estimated with an accuracy of 95% or better. Super Anscochrome color film was used since the experience of the authors in other studies showed color film to be a superior sensing medium for detecting discolored targets. They concluded that

1) the "...best time to take photographs was either before or after fall coloration of hardwoods...."
2) a large scale (1:1,188) was the best for gout detection.

A scheme for sampling balsam woolly aphid damage by color aerial photography was outlined.

HILDERBRANDT, G. and H. KENNEWEG. 1968. Beispiele forstlicher Interpretations möglichkeiten falschfarbiger Luftbilder. Paper presented at 11th Congress of the Int. Soc. Photogram., Lausanne, Switzerland. 17 p.

On false-color photographs, the authors delineated four levels of damage on the basis of color:

1) healthy to light damage as red-magneta;

2) medium damage as red to purple;

3) heavy damage as greenish white;

4) dead as green.

IVES, R. L. 1939. Infrared photography as an aid in ecological surveys. Ecology 20: 433-439.

The author noted that "...mature and drying grasses and unhealthy cacti are poorer reflectors of infrared radiation."

JOHNSON, N. E. and K. H. WRIGHT. 1957. The balsam woolly aphid problem in Oregon and Washington. U.S. Forest. Serv., Pacific Northwest Forest and Range Exp. Sta. Res. Paper 18. 34 p.

This report had excellent photographs of gouted fir twigs and branches. The authors noted that aerial sketch maps do not provide sufficiently detailed information for planning and doing operations. Aerial color photographs were used to assess damage.

KNIPLING, E. G. 1967. Physical and physiological basis for differences in reflectance of healthy and diseased plants. 24 p. Proc. Workshop in Infrared Color Photography in Plant Sciences. Florida Dep. Agr., Div. Plant Ind., Winterhaven, Florida.

The physical and physiological basis for reflectance variation was discussed, and a viewpoint was presented on the reaction of Ektachrome Infrared Aero film to reflected radiation. The author concluded "...that color differences of vegetation on Ektachrome Infrared Aero photographs also can be seen on conventional color photographs of the same vegetation" and that "... the film probably does not reveal differences that are completely invisible to the human eye, as is claimed by many workers."

LANGLEY, P. G. 1959. Aerial photography as an aid in insect control in white pine and mixed conifer forests. J. Forest. 57. (3): 169-172.

Langley reported that 1) camouflage detection film revealed a definite color contrast between healthy, dying and dead trees, and 2) the ground survey cost twice as much as the aerial survey. He also discussed scale, season of the year, method of use and the altitude of the camera station.

He recommended that either color or false-color film, or both, be used for salvage operations and that scales of 1:10,000 and 1:12,000 be used for assessing large timber and 1:5,000 to 1:8,000 for small timber. If detailed analysis of individual crowns were desired, scales of 1:2,500 or 1:5,000 should be used. On false-color photos, "...healthy trees appeared bright red, dying trees pink to white, while 'red tops' appeared their natural color."

LINZON, S. N. 1967. Ozone damage and semimature-tissue needle blight of eastern white pine. Can. J. Bot. 45: 2047-2061.

Excellent pictures showing progressive collapse of spongy mesophyll tissue in conifer needles were presented.

MANZER, F. E. and G. R. COOPER. 1963. Infrared photography of potato late blight (Phytophthora infestans). Phytopathology 53: 350.

Tests were being planned to compare optical density measurements of negatives with disease readings.

MANZER, F. E. and G. R. COOPER. 1967. Aerial photographic methods of potato disease detection. Maine Agr. Exp. Sta., Orono, Maine, Bull. 646. 14 p.

Infrared sensitive films were considered best to locate disease centers.

MEYER, M. P. and L. CALPOUZOS. 1968. Detection of crop diseases. Photogram. Eng. 34 (6): 554-557.

Scales smaller than 1:4,000 had not proved useful for the purpose of the study. The authors decided "...further investigations into aerial photography (e.g. variations in exposure, focal length, altitude) and photo interpretation techniques will make detection of this disease (Cerospora leaf spot disease) by means of Ektachrome Infrared film a practical possibility."

MEYER, M. P. and D. W. FRENCH. 1966. Forest disease spread. Photogram. Eng. 32 (5): 812-814.

The rate at which dwarf mistletoe spread in black spruce forests was assessed through sequential aerial photographs.

______ 1967. Detection of diseased trees. Photogram. Eng. 33 (9): 1035-1040.

"A number of areas in Minnesota were photographed using Kodak Ektachrome Infrared (false-color) film at a range of flight elevations, with and without stereoscopic coverage at different times of the year. Comparison of photo interpretation results with observations on the ground indicate that there are problems of application, but at the same time suggest this technique can serve as a practical means of disease detection."

MURTHA, P. A. 1968. Near-infrared detection of simulated animal damage on conifers. Ph. D. Thesis, Cornell Univ., Ithaca, N.Y. 87 p.

Analysis of red filter optical density readings taken on the false-color transparencies revealed that the image of the damaged conifers had a denser cyan dye layer than the undamaged conifers. Analysis of green filter optical density readings taken on normal color did not indicate or differentiate damaged trees. Thus damage to conifers was recorded on false-color film before it was recorded on normal color film.

MYERS, V. I., L. R. USSERY and W. J. RIPPERT. 1963. Photogrammetry for detailed detection of drainage and salinity problems. Amer. Soc. Agr. Eng., Trans. ASAE 6 (4): 332-334.

The authors were able to detect loss of vigor in cotton plants from excessive soil salinity by aerial photography with infrared sensitized film.

NORMAN, G. G. and N. L. FRITZ. 1965. Infrared photography as an indicator of disease and decline in citrus trees. Proc. Florida State Hort. Soc. 78: 59-63.

Preliminary tests and a complete understanding of the false-color film indicated that deteriorated or damaged citrus trees could be detected. "However, the effects on the photography of many variables, such as atmospheric and photographic conditions, must be evaluated before detection of disease by this means can be used with assurance of accuracy and dependability."

POPE, R. B. 1958. The role of aerial photography in current balsam woolly aphid outbreak. Forest Chron. 33: 263-264.

"Photo interpreters have been able to make accurate counts of dead and damaged trees on 1:2,500 scale photographs taken with either color or camouflage detection film." One hundred and sixty plots were used to estimate the number of dead trees evident on color transparencies taken at a scale of 1:4,000. Forty-nine ground plots were also checked.

SIMS, W. G. and M. L. BENSON. 1966. Color aerial photography in forest photo interpretation. Austral. Forest Res. 2 (2): 43-48.

"The effect of a fire of a limited area in _Eucalyptus miphaphilia_ which occurred twelve months before photography was more readily seen on IR than on Ektachrome. On Ektachrome photo the tones of healthy snow gum and fire damaged trees were somewhat similar, whereas the color difference on IR was almost dramatic, showing healthy trees as red and fire damaged trees as gray. Recovery from fire can be seen on IR as a faint red cast, but cannot be detected on Ektachrome."

However, the authors concluded that "If the interpreter is aware, from past experience or field inspection, of the photo appearance of the range of species in the area under examination, a natural color film is of greater value than is a false color."

SMITH, J. H. G. 1957. Forest history from aerial photographs. Forest. Chron. 33 (4): 390-392.

A comparative series of photos showed that "...it is possible to separate the influences of logging from that of the wildfire which did so much damage after logging was completed."

SPURR, S. H. 1946. Aerial forest survey. In W. Clark (ed.). Photography by infrared. Wiley, New York. 472 p.

Spurr reported that damaged and defoliated trees appeared much darker on black and white infrared photographs.

STELLINGWERF, D. A. 1968. The usefulness of Kodak Ektachrome Infrared Aero film for forestry purposes. Paper presented at 11th Congr. Int. Soc. Photogram. Lausanne, Switzerland. 5 p.

The author provided descriptions of trees damaged either by flooding or attack by defoliators. In general, the author estimated damage by "...delineation of the heavy and less heavy attacked crowns and the counting in sample plots on the photographs in these two strata which consist of two degrees of damaged crowns.

"The coniferous dead trees are visible by their blue-green color. The light gray looking crowns are also here an indication of a disease which is present but not always visible on the crown in nature."

VAN SICKLE, G. A. 1966. A field manual of tree diseases in the Maritimes Region. Forest. Res. Lab., Fredericton, New Brunswick. Inform. Rep. M-X-1. 47 p.

In this photographic essay Van Sickle described the important tree diseases in the Maritimes. "The diseases are classified according to the portion of the tree injured, i.e., crown, stem, or root." The marked similarity in the effect of insect and disease attacks was also pointed out.

WATERS, W. E., R. C. HELLER and J. L. BEAN. 1958. Aerial appraisal of damage by spruce budworm. J. Forest. 56 (4): 269-276.

Direct aerial observation and airphoto interpretation were compared. Close agreement between aerial and ground assessment was found, but there was a significant difference among the observers' estimation of defoliation and the dead-top tree counts. The authors used three levels of defoliation: light -- 12.5%; medium -- 50%; heavy -- 87.5%.

The authors concluded that "the aerial observation method gave more accurate appraisal of the budworm defoliation, while airphoto interpreters gave a more accurate assessment of top-killing and dead trees."

WEAR, J. F. and J. W. BONGBERG. 1951. The use of aerial photographs in forest insect surveys. J. Forest. 49 (9): 632-633.

Panchromatic, infrared, color, and color infrared aerial films at scales of 1:2,500, 1:5,000 and 1:7,500 were used to assess damage caused by the western pine beetle. The authors found that color and color infrared at 1:5,000 were the most efficient for their survey, but that interpretation from the 1:2,500 photographs was more accurate. However, they concluded "Tests in the Pacific Northwest showed that color photography does not show marked advantages over panchromatic photography for distinguishing insect induced tree mortality in Douglas fir stands."

Forest Damage Evaluation

ALDRED, A. H. and F. W. KIPPEN. 1967. Plot volumes from large-scale 70 mm air photographs. Forest Sci. 13 (4): 419-426.

Plot volume estimates were made by measuring individual trees on large-scale 1:1,200, 70 mm air photographs. Accuracy was ±15% of plot volume with a 95% confidence level.

IVES, W. G. H. and L. D. NAIRN. 1966. Effects of defoliation on young upland tamarack in Manitoba. Forest. Chron. 42 (2): 137-142.

The authors noted that physiological damage could be inferred from morphological change when different growth responses were measured for different levels of treatment.

SACKSTON, W. E. (Chairman). 1968. Assessment of plant disease losses. Can. Plant Dis. Surv. 48 (2): 56-76.

This is a collection of eight papers on plant disease losses presented at a National Research Council of Canada panel discussion in February, 1967. Topics discussed ranged from present survey methods, to reports on experimental approaches to disease losses.

Most of the authors concluded that more basic information was required before an accurate assessment of loss could be made.

WEAR, J. F., R. B. POPE and P. G. LAUTERBACK. 1964. Estimating beetle killed Douglas fir by aerial photo and field photo. J. Forest. 62 (5): 309-315.

"Color and panchromatic aerial photographs provide a reliable means for estimating epidemic [sic] tree killing by

Douglas-fir beetle (Dendroctonus pseudotsugae (Hopk.)).

"A procedure is outlined for conducting aerial photographic surveys of Douglas-fir beetle epidemics"

[See epidemic, epizootic, and epiphytotic in dictionary.]

WEAR, J. F., R. B. POPE and P. W. ORR. 1966. Aerial photographic techniques for estimating damage by insects in western forests. U.S. Forest Serv., Pacific Northwest Forest and Range Exp. Sta. 79 p.

The paper described the use of aerial photography in two types of surveys:

1) sampling to estimate amounts of damage or mortality;

2) sample coverage to locate dead or damaged trees for salvage operations.

WEBER, F. P. 1965. Aerial volume table for estimating cubic foot losses of white spruce and balsam fir in Minnesota. J. Forest. 63 (1): 25-29.

On 70 mm, large-scale (1:1,584), color aerial photographs, a parallax bar and a dot template were used to derive volume estimates. Average stand height of dominant and codominant host species and crown closure were measured. The authors also reported that interpreters could measure the heights of trees on the photos within 1 to 2 feet of the ground height.

WERT, S. L. and B. ROETTGERING. 1968. Douglas-fir beetle survey with color photos. Photogram. Eng. 34 (12): 1243-1248.

Abstract: "Large-scale color aerial photographs (1:8,000) and a stratified two-stage probability sampling design together provided an efficient survey of trees killed by the Douglas fir beetle. The survey showed that a net total of 535 million board feet of timber had been killed over an area of 1.6 million acres. The survey cost $0.005 per acre. Compared to other methods of obtaining mortality data the survey technique proved to be the best on the basis of accuracy, time, required, and costs."

WESTBY, R. L., A. H. ALDRED and L. SAYN-WITTGENSTEIN. 1968. The potential of large-scale air photographs and radar altimetry in land evaluation. In G.A. Stewart (ed.), Land evaluation. Macmillan of Australia. pp. 376-383.

Large-scale 70 mm air photographs allowed detailed examination of trees. Coupled with a radar altimeter, accurate and precise measurements could be made of the tree image. The result would be a more accurate estimate of timber volume. The signal from the radar altimeter was successful in penetrating the forest canopy to the forest floor of North American forests.

MANY OTHER references could be added, all dealing with the forestry mensurational aspects of aerial photography. Lists of references can be found in the following: American Society of Photogrammetry, (1960); Avery (1968); Spurr (1960).

Miscellaneous

GAMBLE, S. G. 1964. Aerial photographic coverage of Canada. Photogram. Eng. 30 (4): 573-578.

Gamble discussed past and present aerial photographic techniques and speculated on the future of photography in Canada.

GERRARD, C. W. 1951. An annotated bibliography of aerial photographic applications to forestry. M.S. Thesis, published as New York State College of Forestry, Syracuse, N.Y., Bull. 26, 24 (12): 88 p.

WHITCHER, G. H. 1965. Canada's Air Photo Library. Photogram. Eng. 31 (5): 807-809.

The National Air Photo Library of Canada offers a complete, rapid, reference service to all users of the most comprehensive storehouse of aerial photography in existence.

WILSON, R. C. 1966. Forestry applications of remote sensing. Proc. 4th Symp. Remote Sens. Environ. pp. 63-70.

Wilson gave a brief survey of various aspects of aerial photography in forestry.

WRIGHT, M. S., Jr. 1960. What does photogrammetric mapping really cost? Photogram. Eng. 26 (3): 452-454.

Abstract: "This paper was prepared by compiling cost data obtained from questionnaires filled out by a number of photogrammetric companies. Profit and overhead figures for the average company are set forth and also the average prices for various types of highway and city mapping projects. Comments are presented on the general state of the profession."

General References

ANON. 1965. Aerial photography used in mapping vegetation and soils. Aerospace Technol. Div., Library of Congress, ATD Rep. T-65-29, Washington, D.C. 237 p.

The various articles are devoted to elementary studies in mapping vegetation and soils from aerial photographs.

AMERICAN SOCIETY OF PHOTOGRAMMETRY. 1966. Manual of photogrammetry. 3rd ed. George Banta Co., Menaska, Wisc. 1199 p.

The manual is devoted to the art of measurement on aerial photographs, the procurement of aerial photography, a discussion of various aerial cameras, and a discussion of the mathematical concepts involved in aerial photography.

______ 1960. Manual of photographic interpretation. George Banta Co., Menasko, Wisc. 868 p.

This manual is devoted to the application of photo interpretation in fields of study ranging from agriculture, through forestry, to wildlife management. The section on forestry discusses subjects from classification of forest stands and types, to forest protection and damage assessment.

______ 1968. Manual of color aerial photography. George Banta Co., Menaska, Wisc. 550 p.

This manual deals with the procurement and use of aerial cameras, the technical aspects of aerial color film, and the photo interpretation of color aerial photographs in selected fields of study.

AVERY, T. E. 1968. Interpretation of aerial photographs. Burgess Publ. Co., Minneapolis, Minnesota. 324 p.

Avery discusses the elementary aspects of aerial photography and interpretation. Special chapters range from forestry uses to urban planning. Detection of diseased or damaged plants is briefly mentioned.

CLARK, W. 1946. Photography by infrared. John Wiley and Sons, N.Y. 472 p.

Although old, this book contains many worthwhile examples; especially interesting is the section dealing with plants.

FLORIDA DEPARTMENT OF AGRICULTURE. 1967. Workshop: infrared color photography in the plant sciences. Div. of Plant. Ind., Winter Haven, Florida. 108 p.

A series of papers and discussions on the various applications of infrared color photography are presented. The problems encountered by numerous investigators are included.

GRAVES, M. 1953. Color fundamentals. McGraw Hill, Toronto. 206 p.

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SPURR, S. H. 1948. Aerial photographs in forestry. Ronald Press, N.Y. 340 p.

Spurr briefly mentions the use of aerial photographs to map insect attack, fire damage and disease incidence.

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Chapters 19 through 24 are concerned with forestry aspects of air photo interpretation, particularly mapping and mensuration. In Chapter 24, the author maintains that damaged trees will not be visible on air color photographs unless the foliage has changed color.

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Results of black and white, and color infrared photographic tests revealed that indications of the disease appeared first on infrared photographs.