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PHOTO INTERPRETATION OF VEGETATION

A Literature Survey and Analysis to Determine the Capabilities of Existing Photo Interpretation Techniques of Evaluating Physical Properties of Vegetation.

by
Virginia P. Finley

U. S. ARMY SNOW ICE AND PERMAFROST RESEARCH ESTABLISHMENT
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Purpose and Scope

The objective of this study, as stated in WESSE letter dated 15 April 1957 is to determine by survey of literature the applicability, capabilities and limitation of existing air photo interpretation techniques in determining certain physical properties of vegetation. The study concentrates on interpretation of tree and scrub stands with emphasis on measurement of trunk diameter and spacing, canopy height and coverage, density and height of undergrowth, and type of foliage. Quantitative values have been determined in so far as possible. When values can be determined only in a relative manner, this has been noted and analyzed. Determination of accuracy of measurements as related to scale, photo characteristics, seasonal effects and light condition (time of day) is discussed.

The available literature pertaining to photo interpretation of vegetation was surveyed and the pertinent data extracted. Literature items in related fields were surveyed for all information of value. Foreign language literature was included insofar as possible. Translation problems hindered exhaustive review and intelligent evaluation of some foreign works.

The largest volume of quantitative material relating to forest photo interpretation has been compiled in the past 8 to 12 years. Pertinent work done previously has, for the most, been well summarized and brought together in "Aerial Photographs in Forestry" by Stephen S. Spurr. For this reason, unless an item is of significant interest or was not documented by Spurr, the pre-1948 literature has not been analyzed in detail for this report.

The recent trend in reporting quantitative investigations of forest photo interpretation problems indicates the increased interest in, and recognition of, the need for precise photo measurements and knowledge of photographic capabilities and limitations. In spite of this interest, the significant quantitative work which has been done is limited in quantity and scope. No aspect of forest photo interpretation has been thoroughly investigated quantitatively, and some phases have barely been touched. The tests reported in the literature have been performed primarily for a specific need or with a specific problem in mind. They have been geared to forest industry where the prime interest is economic. The need for large volumes of data to be collected in a short period of time for forest inventories and forest management practices has stimulated the greatest amount of research in the field. Watershed management, soil conservation and recreation are also considered important, but, particularly in the development of forest photo interpretation techniques, the economic aspect of forest resources has been the motivating factor.

The criteria used in testing and the methods of analyzing test data have varied considerably. Some authors gave detailed descriptions of methods of testing and reducing data, others gave only results. Because of this variance, it was sometimes difficult to evaluate the findings reported. An attempt has been made to convert all findings into terms meaningful to one another without losing the quantitative values.

Vegetation and Military Problems

Vegetation may directly affect the conduct of military operations in a variety of ways: (a) it may facilitate or impede the movement of troops and mechanized equipment; (b) it may accentuate or conceal evidence of military activity; (c) it may govern the ease of military construction; (d) it may serve as a source of fuel, food, or construction material; and (e) it may serve as an aid in gathering terrain intelligence for planning purposes if properly used. Each of these five items are of considerable significance to the military effort.

Whatever the military problem is, the real effects of plant life are related to the physical characteristics of the individual species both alone and in association stands. Each major class, timber, brush, grasses, etc., has certain ways of affecting a military situation. For example, among the physical characteristics of individual trees are such important influencing items as size, shape, diameter of trunk, root pattern, crown size and shape, branching habit, and leaf pattern. When occurring in stands in association with other trees then the physical characteristics of the stand predominate and become exceedingly important. Among stand characteristics are such factors as distribution and density, size and density of stems, crown diameters and closure, height of trees, height to lowest branches, and the branching habit, and characteristics of the understory. Information must be obtained about these items before the real significance of influence can be determined when a specific problem is present. Even in deserts, where vegetation is generally sparse, certain species can be of considerable influence - either beneficial or detrimental. For example, certain plants may provide the only source of water for survival purposes while other thorny plants would seriously hinder - such as mass parachute dropping of troops.

Many of the physical characteristics of plants and plant association stands can be observed, measured, and their significance determined from study of air photos. However, photo requirements are very rigid if information of any degree of reliability is to be obtained. It is true that almost any scale or type of picture will enable one to determine the general vegetation class (grass, brush, timber, barren, etc.) and the distribution and areal extent of the stands. Furthermore, much can be obtained indirectly which will be of value through analysis of the terrain and visible evidences of environmental stresses in an area through the study of air photos. However, the most reliable data concerning identity and physical characteristics of any vegetation complex will only be possible from photos obtained to rigid specifications, printed to high quality and which are faithful representations of actual conditions. This, then, becomes the first major problem.

The second major problem is concerned with methods of getting information from air photos. In instances where the physical characteristics of vegetation are required, the problem becomes one of making measurements. Thus, image, size, and clarity are of prime importance. If the information to be obtained can only be gotten through inference or from knowledge once identity is learned, then the images on photos must be of such proportions as to reflect the necessary associations, between plants and the indicators of environment. Here again, quality, scale, and sharpness are important but to these three is added photo coverage. Thus, to obtain all of the necessary information and to the same general degree of reliability it is necessary to have large scale and good image quality for the minute features and smaller scale of good image quality for gross associations - both within a given band width of the spectrum.

Literature Review and Analysis Report

The following report represents a partial survey of the literature for the purpose of finding out what has been done by various organizations and investigators in the field of photo analysis and photo interpretation of vegetation.

The analysis and evaluation of literature is presented in three major sections. The first of these concerns photographic factors of film/filter combinations, scale of photographs, and season and time of day. This is followed by a section relating to the physical characteristics of vegetation and their measurement on air photographs. The third section concerns vegetation identification and its significance as an indicator of terrain conditions. This section includes a discussion of photo interpretation keys.

Each section is supported by a set of summary tabulations which are included in the appendices. The tabulations were compiled by extracting information from the literature reports of tests, surveys, keys, etc. They include the photographic and vegetation criteria used, geographic area, methods of testing, and results and conclusions reached. Comments by the reviewer were added when warranted.

The report does not necessarily represent the view of USA SIPRE personnel.

II. PHOTOGRAPHIC FACTORS AS THEY AFFECT VEGETATION IMAGES

The final picture is the tool used in the identification and analysis of the vegetation position of the terrain. The quality of the picture determines to a large extent the information content which can be obtained. Not all users will obtain the same amount or type of information as this rests wholly within the province of the interpreter. The picture must be a faithful representation of the terrain and its condition at the time of photography. It is difficult to define what faithfulness of representation actually is as there are so many end use perspectives - so many user backgrounds - so many variations for making pictures.

It is to be stressed that the final appearance of the terrain and particularly the vegetation mantle is the result of a complexity of natural situations and how they are sensed or recorded on an emulsion designed to utilize a fixed span of the spectrum. Thus, such photographic parameters as emulsion type, mechanism, optical systems control the imagery and to a marked degree its faithfulness - but only under the conditions operating at the instant of exposure. Added to this are the factors related to processing and printing which are also of importance but are secondary.

The following discussion is concerned with three important factors: film/filter combinations, scale, and season/time of exposure.

Film-Filter Combination

The selection of the aerial photographic film and filter combination is important for vegetation interpretation purposes. To obtain the optimum information from the photographs it is necessary to have good tonal contrasts and image clarity. These are conditioned by spectral reflectance of the vegatation and spectral sensitivity of the film. Discussion of the reflectance and resolution characteristics of aerial films and the advantages and limitations of the various film/filter combinations have been discussed in many reports (Spurr, 1948), Spurr & Brown 1946, Manual of Photogrammetry).

The three accepted types of aerial film are panchromatic, infrared, and color. The filters used with panchromatic and infrared film will influence the resulting tone contrast and image resolution on the photograph within the wave length band capabilities of the filter and the emulsion.

Panchromatic film produces black and white contact prints which appear normal to the eye. Image details are clear and shadows are penetrable facilitating tree measurements, determination of shapes and sizes for identification, and understory estimation. Tone gradations, representing the variety of shades of green, are indistinct however, and most green foliage is registered in the same tone. This may hinder distinction of forest types. A minus-blue filter used with panchromatic film will minimize haze and accentuate tonal differences, however, must be used with caution in heavy shadow areas.

Infrared film registers many tonal variations between trees and other vegetation forms. Softwoods are easily differentiated from hardwoods.

Shadows are dense, often black on infrared photos. This is an advantage when an object is to be identified by shadow alone, but a disadvantage when shadows obscure detail needed for interpretation.

Water surfaces photograph black on infrared film. Moisture differences in soils can be detected but not quantified. Infrared film also has a greater capacity to penetrate haze so can be used at times when haze is too thick for panchromatic film even with a minus blue filter. Filters used with infrared film are dark red, medium red and minus blue. The red filters increase the tonal contrast, but in some instances reduce detail clarity, thus, forest types may be more clearly distinguished but image detail is lost. The minus blue filter used with infrared film reduces the degree of contrast between tones, but allows for better resolution of image detail.

Color film gives a fairly good color rendition under proper light conditions but has a number of disadvantages which limit its use to special purpose photography. Proper exposure of the film is difficult. It is affected by atmospheric haze to a greater extent than the black and white films. This limits its usefulness at small scales. Transparencies rather than prints must be used to obtain effective results.

A number of tests have been performed to determine the best film/filter combination for local use and for specific interpretation problems. Some of test results for specific problems such as tree measurements and species identification are noted elsewhere in the report.

Analysis of film/filter combinations for regional interpretation purposes have been reported by Schulte (1951) for Eastern Canada, Young (1953) for Maine, Jensen and Colwell (1949) for California, and Spurr and Brown (1946) for sections of Eastern United States.

Schulte (1951) stated: "In order to make a comparative study of three kinds of film used in aerial photography, panchromatic, infrared and color, it is necessary that the same subjects be photographed in identical kinds of cameras, and at the same time and place. This insures equality of all factors that affect the photographic results."

Simultaneous photography, using the three film types was obtained at 1:7,200 scale in the Val David, Quebec area. Schulte presented details relating to photography, weather, vegetation, and geography of the area. He discussed in detail and in laymans language, the properties of infrared, panchromatic, and color films, vegetation as a photographic subject, and vegetation on aerial photographs specifically. He drew general conclusions about the various films and presented a key based on the photos taken for his study. He neglected, however, to present any pertinent data or analysis of results of the study. The general conclusions were: (1) For recognizing plant species in Eastern Canada, infrared photos (89A Filter) are preferable to either color or panchromatic (minus blue filter). (2) Color and panchromatic films are about equal when used for species identification. (3) Color photography would be useful when spring and fall color differences are foremost among the identifying factors. (4) Panchromatic film had better detail for interpretation of low shrubs, grass, rocks, soils, and cultural features. It was also superior for estimating forest density.

Spurr and Brown (1946) examined and analyzed photography made from various film/filter combinations in Maine, Massachusetts, Quebec, North

Carolina and Alabama. Infrared film was used with Wratten 89A, 25, 12 (minus blue) filters. A minus blue filter was used with the panchromatic film. Infrared film, used in combination with any of three filters, gave better results than panchromatic photos for species differentiation. Color photography was not as satisfactory as infrared, but when properly exposed was superior to panchromatic photographs. In the northern forests (spruce-fir region) the trees characteristically occur in mixtures and could not be recognized except on relatively large scale photos. The Central New England white-pine hardwood forest types could be distinguished on the infrared photos, and some hardwood subdivisions could be identified. On the North Carolina Coast cypress and cedar were identifiable on the infrared film, all forest types were recognizable and the hardwoods could be differentiated by topographic position. In Southern Alabama panchromatic film was valuable in differentiating forest types, but species within types were not identifiable. The infrared photos are useful in classifying the southern pines into age groups - the older trees photographed in darker tones. The panchromatic film produced excellent photos in all cases, and these were found to be preferable to infrared for tree and stand measurements.

The Schulte (1951) and Spurr and Brown (1946) reports, concern the generally accepted statement that in Eastern Canada, northeastern United States and Lake States region, where differentiation of conifers and hardwoods is of primary interest, infrared is the preferred film type. The most frequently specified filter is minus blue. A number of recent publications (Carow 1955, Young 1955) indicate a trend favoring the panchromatic-minus blue film/filter combination. According to Young (1955) there is no longer the need for sharp contrast between conifers and hardwoods because many foresters have become skilled in photo interpretation and can differentiate the types with less contrast. The panchromatic film with minus blue filter provides better detail and more information can be extracted from the photos.

The Jensen-Colwell (1949) study on panchromatic versus infrared photography in California was based primarily on the specific need of the California forest survey. Five major aspects of forest photo interpretation were considered: (1) vegetation-cover and land use, (2) age class, (3) density, (4) timber cropland, and (5) species identification. The panchromatic minus-blue photography had a definite total advantage over the infrared minus blue. For some specific uses, however, the infrared film/filter combination was superior. Panchromatic film with a green filter was tested also. For the most part it compared to the panchromatic-minus blue. Where there was a difference, it favored the minus blue filter.

The literature review indicated the general acceptance of the panchromatic/minus blue combination throughout the west. Pope (personal communication) and Savage (1955) explain that distinctions between conifers is important, rather than between conifers and hardwoods as in the northeast. An experienced interpreter can make accurate type differentiations, shadow detail is not lost and species identification by crown detail is possible. Jensen and Colwell (1949) suggest also, that west coast photography is usually taken when the grass is yellow or brown and appears light in tone on the panchromatic film. On infrared film the grass is the same tone as many of the trees and shrubs. In the east where grass is usually green during the photo season, it will contrast more favorably to other vegetation on infrared film.

Color Photography, when compared to panchromatic and infrared, has not proven to have sufficient advantage over the others to be used in large areas or for general photo interpretation purposes. For photo measurements it has little or no advantage over panchromatic film at the same scale. Great hopes were expressed for use of color film in species identification, but Pope (1957) found that the differentiation in green tones at scales smaller than 1:8,000 were no more distinct than gray tones on panchromatic types. At scales larger than 1:8,000, the detail of tree structure and crown shape were sufficient to identify trees on the handier and less expensive panchromatic photos. Color photography may be useful in identification of types and species during spring and fall coloration periods, but no comparitive tests were reported.

The most significant use of color aerial photography for a special purpose was reported by Wear and Lauterbach (1955) in the Pacific North-east. Color photos were employed to advantage in location and count of beetle-killed Douglas fir trees. Analysis of the cost/time/accuracy data indicated that the possibility of using color for other specialized purposes should be investigated. One relevant suggestion pertained to the potentialities of color photos for locating fallen trees, and snags, and studying understory conditions.

The possibilities of using spectrophotommetric characteristics of vegetation as a means of identification on infrared and color film has been mentioned frequently in the literature. Colwell (1956) used spectrophotometric properties of farm crops to detect diseased fields by aerial photography. Hindley and Smith (1957) assessed the reflectance of nine species of conifers in British Columbia. They found wide variations in reflectance within a species, relatively small differences among species, and striking differences with a change in elevation. Improved infrared film with a longer tonal range would be needed for more accurate identification by this means.

Tarkington (1953) pointed out that there is no direct relationship between spectrophotometric characteristics of vegetation photographed and those of the dyes forming the image on color photography. O'Neill (1953) used color filters related to the spectral properties of both the vegetation and the dyes in color film in some of his studies. He reported some success with both types of filters, but no conclusive evidence was presented.

Very few studies have been reported pertaining to tests on use of various photo papers in photo interpretation. The advantages of glossy prints for obtaining maximum detail and semi-matte prints for field use have been mentioned frequently in the literature. The only test results reported, however, were by Meyer (1957) and Meyer and Trantow (1957). In the preliminary tests, Meyer printed 6 different emulsion-surface-tone combinations from one set of negatives. Parallax measurements and tree counts were made. No signifficant difference was found in accuracy of parallax measurements on any of the papers. The tree count proved more accurate on glossy paper with warm (brown) tones. The same paper/tone combination was preferred by the interpreters from a personal standpoint. They reported a lack of eye fatigue and a feeling of confidence that images were clear and well defined. The preliminary tests were followed by tests on dull finish paper to ascertain the effects of warm (brown) and cold (blue-black) tones on image quality. From these tests Meyer and Trantow concluded that cold tone prints produced significantly better results, and some of the dull surface papers were superior to others. These limited tests suggest that further investigation would be worthwhile.

Young's (1953) film/scale studies included the use of positive transparencies for tree count accuracy in Maine. He found no significant differences in accuracy between the transparencies, infrared and color film used. Howlett and Carman (1949), however, stated that positive transparencies are preferable to glossy prints particularly if testing for amount of detail available from photography using different filters, emulsions and lens.

Scale Factors-Image

Spurr (1948) has adequately summarized the value of various aerial photographic scales for forestry purposes (p.50-52). The normal range of photographic scales for vegetation interpretation purposes is from 1:24,000 to 1:5,000. A scale of 1:15,840 is accepted as the ideal scale for all-round forestry work. Investigations of scale limits for specific purposes have concentrated on these scales.

Resolution of photographic detail and capacity of the human eye will limit the size of an object which can be measured. Resolution of most aereal camera film types is greater than the capacity of the human eye, but the effect of image movement, photo processing and tonal contrast, etc. seldom permit maximum resolution. The photo interpretation literature contains no evidence that absolute values for any tree measurement can be fixed at any scale.

Test results and analysis of data relating to scale and photographic measurements are often reported in relative or empirical terms. Where fairly definitive limits have been established, the conditioning factors may render applicability to other areas, regional or problematical, inadvisable.

Aerial photographic scale is determined by the flying height of the airplane and focal length of the camera. The photogrammetric principles of these factors are discussted in the Manual of Photogrammetry and other standard references. Both focal length and flying height are individual factors affecting aspects of photo interpretation of vegetation. These are discussed in the sections concerned.

A discussion of airplanes, cameras, lens systems and mounts, and other physical equipment used in procurring aerial photography is not included here. The following statement, however, is of relevent interest: "There is no optimum focus of the aerial camera lens system. First decide on smallest photo image desired to be discerned individually. If lens is focused for maximum clarity of this size (scale of photography having been specified) smaller images would not be individually discernible. Large images would be discernible, though not at maximum sharpness." (Colwell 1954).

Sources of error in making any photographic measurement are many. The testing and data analysis methods varied, and there was little consistency in form of presenting results. These factors make it difficult to estimate the validity of the results of the various tests, either individually or comparatively.

Where the major purpose of tests were not concerned with the scale factor directly, an attempt was made to deduce approximate scale-measurement limits. It is emphasized that these limits are drawn from the literature reports. They are the apparent limits.

Crown diameters as small as 4 feet can be measured on 1:18,000 photographs, as small as 5 feet on 1:22,000 photographs. Tree diameter class determination is the extent of accuracy to be expected at small scales, however. Crown diameters can be consistently classified to within 5-foot classes on 1:20,000, 3-foot classes at 1:15,840, and 2-foot classes at 1:12,000 scale (Spurr 1958). At 1:12,000 scale, the standard error of visible crown diameter measurement for hardwood trees is equal to 3 to 4 feet (Worley and Meyer 1955). Conifer trees with small crowns (under 10 feet in diameter) can be measured to within a foot on 1:1,200 scale photos, but at 1:7,200 scale they cannot be measured accurately. Crown diameter measurement accuracy will increase with increase in scale.

Crown cover can be estimated to within 10% accuracy on scales as small as 1:20,000. At 1:12,000 scale hardwood crown cover can be measured within 5%, and 10% should be the maximum error (Meyer and Worley 1955). At 1:7,200 conifer crown cover can be measured within 1%, but the average error will be higher, 9%-10%. At 1:1,200 scale error of conifer crown cover measurements can be lower than 1%, but will average approximately 5% (Losee 1953). Accuracy of crown cover estimates will increase with an increase in scale, and will vary with species. No tests of relative accuracy of crown cover measurements of different species were found.

Tree crown count accuracy increases with increase in scale. At a given scale accuracy will vary with stand density and species. Increase in accuracy between 1:15,840 and 1:3,500 scale will be about 20%. Extrapolating from graphs, it appears that at 1:2,000 scale 85% of all trees can be counted, at 1:15,800 about 40% of the trees can be counted, but the count may be as low as 2%, depending on species composition and density of the stand (Young 1953). A scale of 1:10,000 is the smallest allowable scale at which trees should be counted if any approach to accurate total is desired.

The relation between accuracy of tree height measurement and photo scale is controversial. Latest findings indicate accuracy of height measurements do not depend upon scale within the normal range of scales (1:20,000 - 1:5,000). Tree heights can be measured within 10 feet of actual tree height on good quality photos. By computing the scale to correct for differences in elevation within the photo, conifer height measurements can be made to within 3-4 feet, hardwoods can be measured to within 2.4 feet.

Diameter of stem measurements will be affected by scale as they are computed from crown diameter or crown cover measurements and tree height measurements. The accuracy of crown measurements increase with scale. Thus, it can be assumed that diameter computations will increase in accuracy with increased scale. Foresters use the DBH measurement to compute timber volume. The literature contains some information on accuracy of volume estimates made from airphotos. The accuracy of DBH measurements was not discussed, however, and the relationship between accuracy of height - crown - volume measurements has not been determined.

Scale of photography is significant in identification of tree species. (Usable scales will vary with local forest conditions.) On 1:20,000 scale photos species identification is limited to 20% at the most. Increasing the scale to 1:15,000 will result in insignificant increase in identification accuracy. Between 1:20,000 and 1:10,000, however, there is a significant increase in accuracy of species identification for western coniferous forests. At 1:5,000 78-90% of the mature trees, and 28 to 30% of the immature trees can be identified (extrapolated from graphs by Pope 1957). In eastern Canada and northeastern United States, particularly in dense stands, larger scales are needed for individual species identification. It was found that 1:2,000 is the smallest usable scale for identification (Schutte 1951).

From the standpoint of making measurements alone, it is determined that 1:20,000 is the smallest scale. A scale 1:10,000 would provide significant increase in accuracy for measurement and identification values combined and would appear to be the smallest scale advisable for computations of forest dimensions for military operations.

Some low altitude continuous strip photography was tested by Mignery (1951) and Rogers (1952). The accuracy of measurements made on these large scale photos was not much better than on conventional smaller scale photos. Improvement in interpretation techniques and use of a longer focal length were suggested as possible means of improving some strip photos for special purposes.

Season and Time of Day

Optimum time conditions, both seasonal and diurnal, for obtaining aerial photography for interpretation purposes depend upon geographic location and interpretation objectives. No records were found in the literature reporting tests to determine time factors relating to photography, either in terms of optimum period or maximum span of time. Frequent mention is made of time of day in terms of the sun altitude (for example -photography should be taken when the sun is at least 3-1/2 hours above the horizon).

Increase in altitude and latitude will increase the problems associated with obtaining photography. The Manual of Photogrammetry covers the general problems adequately and includes a solar altitude diagram for determining duration of the minimum solar altitude of 30° for any part of the U. S. at any time of the year.

Andrews (1948) briefly described the problems of obtaining photography in a northern latitude at high altitudes. In northern British Columbia, effective flying weather consists of the 4 months from June through September with an average of 26 flying days during that time. There is usually snow cover extending into June; and even in June there are only 6 midday hours when photography is possible. Fog frequently remains in the valleys until midday, and cumulus clouds begin building up at midday.

In specifying photography for tree height measurements by the shadow method (Spurr 1948) stated that on photos taken in early morning or late afternoon shadows would be too long to measure accurately; taken at midday, shadows may be too short. Most satisfactory measurements can be made when the shadow is within 50% of the height of the tree. The frequent reference to the use of shadows for measuring and identification purposes and the general lack of data suggest additional research pertaining to limits of interpretating in relation to time of day would be valuable and interesting.

Reference to preference for seasonal photography is abundant but definitive limits again have not been set. The variables encountered in seasonal factors are numerous. Season of photography is usually determined by a combination of location, forest type and interpretation objective. As Colwell (122) stated "Requirements are so variable in this respect as to defy the making of broad generalizations."

Spurr (1948) and Colwell have discussed the advantages and disadvantages of each of the four seasons for various photo interpretation purposes. A number of additional references include preference for seasonal photography for various reasons. Where conclusions regarding seasonal photography have been pertinent to the objectives of the report, they have been included in the tabulations accompanying each section.

It is interesting to note that a 1950 Air Force Report stated the need for a basic tabulation of positive and negative information obtainable from air photos at each season of the year. The same report suggested a study "...based on aerial photography of a given area at time intervals during a given day..." to study variability of image characteristics due to sun angle and quality of light - particularly in color film. No reports of this type are available in easily obtainable literature, and no references to such studies were found in the Department of Defense Project Cards or other government agency listings.

Several reports dealing with seasonal aspects of farm crops are included in the bibliography. These were interesting in their objectives and approach (Boesch -1958, Brunnschweiller -1957, Goodman -1954, and Goodfellow -1955). The Brunnschweiller report concluded that for recognition of agricultural patterns in Switzerland, no single flight date is best; each of the months can be ideal for specific interpretation purposes. The most interesting item in the Goodman report related to the development of a densitometer for measuring gray tones of a known item whose tone would remain constant throughout the seasons, as for example a roof top. The relation of changing tones of crop vegetation to the constant item provided a comparison to compensate for lack of uniform tones due to film emulsion, processing, etc.

III PHYSICAL CHARACTERISTICS OF VEGETATION FROM AIRPHOTOS

The most direct and often easiest information which can be obtained from airphotos about vegetation is that pertaining to the physical characteristics. These are the measurable items - those which can be seen directly, which can be described, and which can be measured. Included are tree heights, stand heights, crown diameter, crown closure, and area covered by a stand. There are some indirect measurements which can be made. These include diameter and density of the stems and the character of the understory. A variety of instruments are available for accomplishing these tasks. Their use is pointed out in the following discussion.

Direct Measurements

Tree height measurements. Tree height measurements are important to foresters as timber volume is related to tree height and stem diameter. Foresters, therefore, have made considerable investigation in the field of accurate tree height measurement on aerial photographs. Studies on both single or individual tree height measurement and over-all stand height measurements have been reported in the literature.

Tree heights may be estimated on single photos or on stereo-pairs if the interpreter has an intimate knowledge of the area and of the characteristics of the native vegetation. To accurately measure tree heights, on aerial photographs, there are three basic methods: (1) direct measurement of displacement on single photos, (2) the parallax method, and (3) the shadow method. Spurr (1948-1) and the Forestry Handbook (1956) describe and discuss these methods, their advantages and limitations, and the factors affecting the accuracy of tree height measurements.

The application and usefulness of the first method is so limited as to be of minor importance. It finds usefull application in instances where stereo-coverage is not available as on the end photo of a run. To measure tree heights by the displacement method the displacement formula is used:

$$\frac{d}{r} = \frac{h}{H} \quad \text{or} \quad h = \frac{dH}{r}$$

where: h = height of tree in feet
d = length of tree image in inches
r = distance from top of tree to nadir point in inches
H = height of plane above tree in feet,

The nature of displacement measurements requires an oblique view of the tree which is possible only near the border of vertical photos. Both the tip of the tree and the base must be observable. This also requires good resolution of the tree top, which is difficult or impossible for trees with tapering crowns, particularly on small scale photos. This method is also usable on large scale obliques provided the tilt angle or position of the nadir point is known or can be estimated. Large scale photos are also necessary for accurate measurements for if the measurable displacement is small, accurate measurements are doubtful. No further discussion or reports of experimental or statistical analysis, etc. were found in the literature pertaining to the displacement measurement method.

The shadow method of measuring tree heights on airphotos was originally developed and described by Canadian foresters (Seely-1942) and the method has been more extensively used in Canada and Northeastern United States than elsewhere. The shadow method requires computation of angle of the sun at the time of photography and utilizes the formula:

$h = L \tan X$

where h = height of tree in feet
L = length of shadow in feet
X = angle of elevation of sun in degrees

Conversion charts or graphs for converting shadow length to tree heights must be constructed. According to Rogers (1949-1) such graphs may be prepared for any area and are necessary only for each 2 degrees of latitude for satisfactory accuracy. Johnson (1954) stated that when classifying stands into 10 ft. height classes on photos at a scale of 1:15,840, the errors due to distance from the correct latitude and longtitude of an area with a 20 mile radius were small enough to disregard. Time of day of photography, date, longitude and latitude and scale of photography must be known for the sun angle computations. Spurr (1948-1), Seeley (1942), and Rogers (1949-1) give detailed instructions for computing the sun angles and include a number of conversion graphs. This method of determing tree height is simple and rapid once the sun angle has been computed and conversion graphs constructed. The usefulness of the method is not questioned for large inventory projects where a contiguous area is covered by hundreds or thousands of photographs. It is not efficient, however, for spot checking or for computing heights on occasional projects when relatively few photos are used.

The major limitations of the shadow method are: Shadows must be neither too short nor too long. The slope of ground affects length of shadows and will affect accuracy of measurements unless adjustments are made. Shadows must fall on open ground (only those near clearings in the forest or at the edges may be measured accurately). The base of the tree must be visible. It is often obscured by snow, other vegetation or it's own foliage, etc.

A number of specific experiments using the shadow method of tree height measurements have been reported. Rogers (1949-1) reported studies of white pine, northern hardwood and spruce-fir forest in the northeastern United States. On 1:20,000 photos, an experienced interpreter can estimate tree heights within 7 feet 2 out of 3 times. (250 men were trained in the method).

A. J. Nash (1949) conducted experiments at the Valcartier Forest Experiment Station in Canada. Both vertical and oblique photos were used and the photography was taken in the winter when hardwoods were leafless and a snow cover was present. Nash concluded that the differences between interpreters' were insignificant. A standard error of estimate of $\pm$ 2.2 feet was obtained on the verticals, and $\pm$ 2.3 feet on the obliques. The sources of error were slope of ground, snow depth calculations, measuring devices, interferring tree crowns, imperfections of photographic resolution, penumbration, scale inaccuracies and change due to growth between photo date and interpretation date.

Direct measurement of tree heights by the parallax method is applicable under a larger variety of conditions than the shadow method, and development of parallax wedge devices has simplified the process. Differences in parallax are measured and converted to tree height using the standard parallax formula: $h = \frac{HdP}{P + dP}$

Tree height measurements and tests of their accuracy have received more attention in forest photo interpretation literature than most other aspects. This is particularly true of quantitative reports of measurable items on air photos. Spurr, (1948-1) the Forestry Handbook (1956) Avery (1957) and others have described the parallax method and discussed measuring instruments used. The Manual of Photogrammetry (1952) also explains parallax and parallax measuring methods.

Instruments for measuring tree heights by parallax range from simple wedges to large expensive machines such as the Stereoplanigraph. Spurr and Brown (1946) have described most of these instruments. The general consensus of opinion is that the simpler and speedier wedge-type devices will give satisfactorily accurate height measurements for forestry purposes. Tests made of tree height measurements in varying geographical and forest - type regions indicated that the wedge was as accurate as the bar. Moessner, et al (1950) working in the Central Hardwoods of the midwest and Moessner and Rogers in the Rocky Mountains (1957), Johnson (1958) in Tennessee, and Worley and Landis (1954) in the Upland Oak Forests of Pennsylvania arrived at this conclusion. A more complete list with details of results is included in the tabulation of tree height literature.

A pamphlet published recently by Moessner and Rogers (1957) sumarizes investigations of tree height measurements by parallax during the past twelve years. It includes detailed instructions for use of the parallax wedge, graphs and tables for aiding computation conversions, and a summary of relative cost and accuracy of the method, as well as an untabulated report of tests made using the wedge. Some of the major conclusions were:

1. Any parallax problem can be visualized as a problem in triangulation with a base line defined by the two camera stations and angles represented by the parallax difference of the tip and base of the tree to be measured. Basic formulas may be solved by use of graphs or tables. (The graphs and tables in the report are for normally encountered scales and parallax differences).

2. Flying height of the photo plane affects parallax computation accuracy at low flying heights over rough topography. When flying height exceeds 4,000 feet both graphic and tabular techniques produce satisfactory measurements on trees of all heights. Reducing the flying height from 13,500 feet to 2,000 feet increased the standard error of estimate from 0.7' to 1.9' for trees less than 100 feet high. Axelson (1956), testing accuracy of forest measurements in Sweden at different scales, found errors due to difference in flying altitude. In these tests the scales (1:16,500 to 1:33,800) were varied by flying at different altitudes, using one camera/film combination. The test measurements were made on 1:15,000 scale enlargements of all negatives. No comparable studies were found in U. S. literature.

3. Adjustment for elevation differences is important. These can be made by using graphs or tables. When elevations varied from -543 to +636 feet from mean datum the standard error of estimate for tree heights was 10.6 feet without adjustment for elevation. This was reduced to 3 to 4 feet when elevation adjustments were made.

4. The accuracy of simple wedges is comparable to that of the more expensive, complex instruments. This is to be expected since the wedge is calibrated in 0.002 inch (0.05 mm) divisions; this corresponds to about the minimum unit of depth of perception for most individuals.* Therefore, the limiting factor is the interpreter's depth perception and the addition of finer calibrations is not likely to increase accuracy.

Johnson (1958) suggests that in addition to the human limit of parallax perception, wedge measurements will be as accurate as those made with a bar because the wedge involves a minimum of lateral motion over the surface of the photo, so the effect of instrument tilt is negligible. Worley and Landis (1954) checked tree height measurements using both the Harvard wedge and the Abrams Academy Height Finder (Bar). The results indicated a higher degree of accuracy with the wedge. The authors mentioned three possible factors for error source: (1) the sloping line of dots on the wedge may form a better reference for judging tree top readings than a single dot; (2) the particular bars used may have been affected by a systematic error, and (3) errors may have been due to instrument-interpreter combination rather than instrument alone. The interpreters using the wedge did not use the bar, and vice versa.

The factors affecting accuracy of tree height measurements include photo characteristics, vegetation and environmental characteristics and personal or interpreter factors. Perhaps the most controversial photographic characteristic affecting tree height measurements is that of scale. Until the past few years it was generally accepted that accuracy of measurements increased with increase in scale. Several recent

*For substantiation of this statement see: Johnson, E. W., 1957, The limit of parallax perception, Photogrammetric Engineering, vol. 23, no. 5, p. 933-934.

investigations, however, indicate that photo scale is not a significant factor in errors on the scale ranges normally used in forestry.

Spurr (1948-1) stated that, accuracy of tree height measurements is directly proportional to scale provided other variables remain constant. Citing tests performed at the Harvard forest, he reported the average error of individual tree height measurements by parallax wedge were 3 feet at 1:6,000, 6 feet at 1:12,000, and 9 feet at 1:18,000. Tests made by Lossee (1953) in Canada also indicated an increase in accuracy at a larger scale. Both Pope (1957) and Johnson (1958) working independently in Oregon (conifer stand) and Tennessee (primarily hard-woods) respectively, concluded that scale was not a significant factor. The range of scales used in the two tests were similar, 1:20,000 to 1:2,500 in the former, 1:20,000 to 1:5,000 in the latter. As focal length is a function of scale, it is interesting to note the difference in lens used. The Tennessee photos were made with an 8.25" FL camera. A 12" FL was used for the Oregon photos except for the 1:2,500 for which a 24" lens was used. Pope commented that in order to reduce excessive parallax, it was necessary to increase the overlap from the usual 60% to 75-80%.

Another recent study by Axelson (1956) in Sweden reported no significant errors in tree height measurements on photos ranging in scale from 1:33,800 to 1:16,500. Rogers (1952) found large Sonne strip photos unsatisfactory for tree height measurements also. The nature of Sonne strip photography explains these inaccuracies. These tree studies would indicate that within the range of 1:30,000 - 1:5,000 scale is not significant when measuring by the parallax method. No recent reports of tests measuring by shadow method have been found, so the error/scale relationship are inconclusive. Nash (1949) did state that one contributing factor to success of tree height measurements was the large scale (1:6,980) of the photos used.

Focal length will affect tree height accuracy measurements in factors other than scale. With modern photo planes and camera equipment, tip and tilt are generally considered to be minor problems. However, both Pope (1957) and Axelson (1956) have mentioned the effect of tip and tilt on tree height measurement accuracy due to focal length used. Pope points out evidence that it is a major source of error on large scale photos where the 24 inch lens was used. A 3° tilt along the line of flight with a 6 inch lens results in errors of about 9%, but this increases to about 35% with a 24 inch lens.

In discussing focal length as related to parallax measurements Moessner (1955) pointed out that using a 6 inch camera, photos of 1:4,000 scale would have a factor of about 0.6 foot elevation change per 0.001 inch parallax difference; using an 8.25 inch focal length camera, photos at 1:20,000 scale would have a 4.5 feet change for each 0.001 parallax difference, which would result in spot heights with an error of estimate approximately seven times as great.

It is obvious then, that for tree height measurements by the parallax method, accuracy will be higher with a shorter focal length camera. For the shadow method, however, the opposite is the case, according to Spurr (1948-1). This is explained by the fact that tree shadows can be measured more accurately when the tree top is displaced the least and the tree base more likely to be centered under the crown. For a given scale the plane will fly higher with a longer FL camera, and the higher the flying height, the less displacement of tree top. No other comments on focal length and accuracy of tree height measurements by the shadow method were found.

The other photographic characteristic affecting height measurement accuracy is that of film. In most forest areas standard high-speed panchromatic film with a light yellow filter will result in photos with great clearness of detail. Modified infra-red with a light yellow filter is practically as useful (Spurr 1948-1). Infrared film with a medium or dark red filter will produce extremes of tone resulting in loss of detail particularly in shadows, and in the dark conifer crowns. Sammi (1953), however, found that slightly more accurate results could be had by using positive transparencies of infra-red photos (red filter) than from the semi-matte prints. Accuracy was still low for individual measurements and results were considered inconclusive as readings of only one interpreter were involved. In the Pacific northwest Pope (1957) found no significant difference between panchromatic and color film for tree height measurements by parallax.

The character of vegetation, both individual species, and type of forest complex will affect accuracy of height measurements. Tall trees with tapering crowns are the greatest culprits. Narrow tree crowns will not resolve on photos. Minimum size of objects that can be seen on photos at various scales are:

3 ft. at 1:20,000
2.5 feet at 1:16,000
2 feet at 1:12,000
1 foot at 1:6,000

←Spurr (1948-1) has constructed a table for "Corrections of Tree Height to Compensate for Lack of Resolution" (page 236).

In addition to the problem of tapering crowns, large crowns may obstruct the view of the tree base, thus making accurate measurement difficult. Various aspects of tree shadows will affect measurements by both parallax and shadow method. Clear, well-defined shadows, of course, are necessary for good shadow measurements. Overabundance of dense shadows may obstruct determination of ground points for either method. Rogers (1949-1) has clearly presented shadow problems caused by vegetation and topography. Both Rogers (1949-1) and Pope (1957) stress the importance of brush and grass as ground obsuring factors.

Sammi (1953) and Worley and Landis (1954) found indications that accuracy of tree height measurement decreased with increase of tree height. These results were presented as a trend noticed in test analysis and both authors stressed that further investigation was necessary to substantiate or repudiate the findings.

The character of the forest itself, will determine whether openings can be found where ground level can be determined. Thus, the density of the stand and the amount and character of undergrowth are important. Young (1953) found the spruce-fir stands in northern Maine too dense to obtain either tree height or crown diameter measurements on photos with scales ranging from 1:15,840 to 1:3,500.

Worley and Landis (1954) reported that analysis of tests indicate little difference in accuracy of individual measurements of forest grown and open trees. However, in measuring stand height versus individual tree height, the test results indicate that the former are more accurately measured than the later (Johnson 1958, Worley & Landis 1953 & Axelson 1956). Johnson (1956) accounts for this by the fact that stands contain a variety of crown shapes, each of which contributes a different bias in determining average stand height. In the averaging operation, a certain amount of compensation takes place and bias is reduced.

Although the character of a forest will affect accuracy of measurements, Moessner (1955) contends that conifers and hardwoods can be measured with equal accuracy. He states that: "---- generally easy to determine top of dense flat-topped crowns common to hardwoods, but much more difficult to see and measure the ground line. The same effects occur in dense evenaged stands of conifers where tips resolve but few holes can be found through which to match ground level. On the other hand, tip of crowns in open conifer stands are hard to define but ground level is usually quite obvious. One condition tends to compensate the other ......"

Topography has its affect upon tree height measurements. The primary problem concerns the difference of scale found within a photo where considerable change of elveation occurs. To compute an actual height from photo measurements, the "true scale" of the photo at the site of the tree must be known. This is true for either parallax method or shadow method. A number of publications give conversion tables for correcting scales, and have been included in the tabulated reports. Uneven ground is not always determinable under a forest growth and the general tendency is to underestimate height of trees in depressions and overestimate those on knolls or ridges. Length of shadows will be influenced by the slope on which it falls and this must be taken into consideration when measuring by the shadow method (Rogers 1949-1).

Tree height measurements, then, will be more accurate, and certainly easier to obtain in areas of level terrain. Goodspeed (1949) has devised a method for converting parallax differences into tree heights using a parallax wedge and alignment chart readings to solve a modified parallax formula. This method is apparently satisfactory for use in a relatively flat country (designed for use in Iowa) where the difference in datum elevation and tree base elevation is insignificant. The alignment chart is constructed for readings on 1:15,000 - 1:25,000 photos taken with an 8.25 focal length camera. It can be used for photos at the same scales taken with different focal lengths by simple conversion of chart readings.

Time of day of photography has little effect on height measurements when using the parallax method. It is important, however, for shadow method measurements, particularly in extreme latitudes. If shadows are too long or too short, accuracy will be difficult to obtain particularly in hilly areas. The most satisfactory measurements are obtained when the shadow length is within 50% of the height of the tree (Spurr 1948-1).

Tree height measurement accuracy may be affected by wind movement of the tree top. This was mentioned by both Pope (1957) and Axelson (1956). Pope noted evidence of this where tree shadows appeared to be floating above the ground. He noted that while it is probably neither frequent nor serious, it was interesting to consider as it is not generally (if ever) mentioned in photo interpretation literature. Axelson, evidently discovered similar effects of wind motion independently in his studies in Sweden.

Method of measurement and personal or interpreter factors are the other items affecting tree height measurement accuracy.

Spurr (1948-1) indicates that the parallax method is more accurate than the shadow method. In tests in the Harvard forest he found that parallax measurements had about half the standard deviation when compared with ground measurements as did the shadow method measurements. The preference for the parallax method throughout the United States would indicate it has some merit. Most reports of tests made, however, were between parallax instruments rather than between methods.

Some Canadian agencies prefer the shadow method. However, little has been found regarding the accuracy. MacAndrews (1955) stated that in the Forestry Branch (of Canadian Department of Northern Affairs and Natural Resources) the parallax method was seldom used because of the time involved. Johnson (1954) suggested the shadow method could be useful -- in flat country -- for those unable to use the parallax method.

Spurr (1948-1) points out that more skill is needed for the parallax method, but familarity with the area is more important in the shadow method as slight errors in judgement will effect readings to a greater degree.

Accuracy of height measurements by either method depends upon the ability of the observer to evaluate such factors as effect of slope, brush, size of crown, and variations in ground level. Foresters performing tests on accuracy of height measurements concluded that the interpreter is one of the greatest factors.

In analyzing data for effect of scale on tree height measurements and comparison of accuracy of the wedge versus the bar, Johnson (1958) noted a "wildness" tendency in one interpreter. Speculating on this he suggested the possibility of psychological reaction toward making measurements for a test such as set up rather than measurements made under daily work conditions.

Worley and Meyer (1955) stated that: "It is only possible to ascertain the relative consistency of photo measurements between and within different interpreters." Pope (1957) in concluding that errors depend more on individual interpreters than scale or film type, stated: "Variation from interpreter to interpreter emphasizes importance of this link in the P I chain and it points up the danger of drawing conclusions from the results of one interpreter. ... More must be learned about this human element... and how to obtain more consistent results with him."

Tree Crown Measurements. Three elements of the forest canopy, or crown cover can be measured directly on photographs - crown diameter, crown closure (proportion of an area covered by tree crowns) and number of trees. Crown closure and crown diameter have direct application to such military activities as weapons firing and concealment. They are of further importance indirectly in that they indicate the unmeasurable factors of stem size and density, which are significant when considering troop or vehicle movement or trafficability problems. Crown count, or density will give an indication of number of trees found in a specific area, thus indicating obstacle density.

Crown closure measurements can be made using transparent grid devices or crown density scales (Spurr-1948-1), Moessner (-1949-1), and Worley and Meyer -1955). Spurr expresses a preference for the density scale as it is more rapid and dots simulate tree crown size at a given scale. Worley and Meyer found the dot grid more satisfactory than the density scale but difference in results were not significant. They believe, however, the dot grid has more potentiality for refinement and will net more precise closure estimates.

Worley and Meyer, (1955), Lossee (1953), and Tryon, Hale and Young (1955) suggest methods of implementing the dot grid system. Moessner, (1949-1) and Spurr (1948-1) indicate that crown closure or density can be consistently estimated to within 10% accuracy for scales as small as 1:20,000. Tests made by Worley and Meyer (1955) had the same results. They stated: "---- crown cover estimates may be affected by systematic errors of 5 to 10 percent." Lossee (1953) reported tests of crown density measurements on large scale photos (1:1,200 and 1:7,200) resulted in errors ranging from -36.3 to +27.3 percent for 12 different forest types. Averages were: for 1:7,200 scale -1.3% ± 9.9% at 0.95 probability and for 1:1,200 scale, -0.3% ± 5.5% at 0.95 probability.

One of the important problems inherent in estimating crown closure is that of small openings in the stand. Small openings may not resolve on small scale photos, openings may be overlooked by interpreter. This may be partially remedied by viewing the photos in reverse "stereo" so the openings will stand up as elevations. Shadows may hide or completely obscure openings. Spurr (1948-1) states that: "---- a safe rule is to assume that the shaded part of the tree is equal in size to the lighted portion and that the shadow beyond this area lies over an opening." (Spurr, P. 211) Trees of varying heights within a stand will cause shadow problems as well as add to the difficulty of determining understory and overstory closure percentages. This may be of importance in determining the ratio of different size stems in a forest.

A crown count of the actual number of tree crowns visible on a given area will indicate the relative density of tree trunks to be encountered. When used in conjunction with other factors such as height, species, and site conditions, the size of the stems may also be estimated. One of the most important factors to remember in considering tree crown counts, is the principle of resolution of the image. For example, a tree must have a crown diameter of at least 2 feet to resolve on photos at 1:12,000 scale, and 4 feet at 1:20,000. Because of this factor most airphoto crown counts will be low. It is obvious that the larger the scale, the more accurate will be the crown count. The shape of the individual crown will affect the distinctness of its photo image, therefore, accuracy of crown count will vary with species.

Spurr (1948-1) has discussed a number of tree count tests performed between 1925 and 1948. While these are interesting, and some have been listed in the bibliography, they need not be detailed here. Recent improvements in films, cameras, photo-processing equipment, and methods of interpretation have made more accurate tree counts possible. Meyer (1955 and Meyer and Trantow (1957) have worked with various photo paper emulsions and tones to determine the effect upon clarity of the photo image. Using 1:15,840 scale fall panchromatic photos they concluded that glossy paper with a warm tone (brown) gave best results, both in accuracy and interpreter satisfaction. In testing the cold (blue-black) versus warm tones on semi-matte paper, the cold tones produced significantly more accurate results.

Young (1953) tested the accuracy of tree counts on aerial photography of the spruce-fir forests in Maine. Infrared film and color film with a minus blue filter were used. Black and white prints and positive transparencies were made from the infrared negatives. All three media were used at scales from 1:15,840 to 1:3,500. The test data indicated no significant increase in tree count accuracy on the three media. There was, however, a significant increase in accuracy with increase in photo scale. Increase in scale from 1:15,840 to 1:3,500, increased count accuracy by about 20 percent. Young also noted that tree count accuracy was reduced with increased stand density.

A number of methods or devices developed for simplifying the tree counting process have been reported. Most of these consist of templates or "spot-lighting" devices which enable an interpreter to keep count more rapidly or avoid duplication in counting. Most are useful in any interpretation process where dots are to be counted as in area estimation. Thornton's (1954) dot counting aid is the only device reported which was statistically tested. His results indicated a faster dot counting rate when using a specially designed template. No tests or arguments between devices were found.

When counting tree crowns to determine number of stems per a unit area, differences in elevation must be kept in mind. The change in photo scale with difference in elevation can seriously affect the density or number of stems per area if correction is not made. Spurr (1948-1) has adequately and clearly covered the procedure for converting for elevation (p. 214-219).

Determination of stem density can be made by either the crown closure or crown count measurements. The choice of method to use will generally be determined by the factors listed as follows:

Crown Closure	Crown Count
Medium and small photo Scale	Medium or large photo scale
Uniform stand height and density	Heterogenious stand
Individual crowns not distinct	Individual crowns stand out
Middle-age and dense timber	Overmature timber and open stands

Crown diameter measurements can be valuable in themselves for such military problems as weapons firing. There is a significant correlation between crown diameter and stem size (DBH)*. Stem size can not be measured directly on airphotos and the crown diameter measurement is the most valuable photo indicator of stem size. Measurement of crown diameters as visible on air photos can be made using any micrometer measuring device. The micrometer or shadow wedge and the dot type scale are most commonly used. Losee (1953) reported using a parallax bar with the fixed mark removed for obtaining crown diameters on large scale Canadian photos. Discussion of crown diameter measurements in Russian literature indicate they use a parallax bar or stereo-micrometer device, and Axelson (1956) used a parallax bar in Swedish tests.

The wedges and dot type scales are simple to use and construct and facilitate rapid interpretation. Wedges have been constructed for use with some photo scales which read directly into crown widths. The

*Diameter at breast height = 4.5' from ground.

majority of wedges used are the multi-purpose shadow wedges. These are graduated in thousandths of an inch on the photo and must be converted into actual crown diameter by use of conversion tables or by computation. The dot-type scale involves comparison of the tree crown image on the photograph with dots of various sizes on a template or transparent overlay.

Accuracy of crown diameter measurements depends upon scale and quality of photos and skill of the interpreter. Factors influencing accurate measurements include interlocking branches and overlapping crowns. Multiple stem trees, are not always discernable. Only that part of the crown observable from above can be measured. Shadows may be mistaken for part of the crown, or they may mask out a smaller crown. Small, thin branches will not resolve, particularly at smaller scales. Crowns at photo edges will be exaggerated - these should be measured at right angles to the radial line from principle point to the tree. Irregularly shaped crowns cause inaccurate measurements. The diameters of these should be measured in several directions and averaged. It is difficult to match a dot-scale circle precisely to an irregularly shaped crown and choice between two is sometimes arbitrary. The wedge lines merging with tree edges may cause inaccuracies in reading diameters on this type scale. Differences in elevation must be kept in mind in converting photo measurement to actual crown diameter size. Difference from base of tree to top is not important on small scale photos, but would be on large scale photos (Roggers 1952).

Most reports on crown diameter measurements state level of accuracy in general terms. Spurr (1948-1) mentioned that tests in the Harvard

Forest indicate. "----- crowns can be consistently classified to within 2-foot classes at 1:12,000, 3-foot classes at 1:15,840, and 5-foot classes at 1:20,000." Detailed results of crown diameter accuracy tests were reported by Lossee (1953) Jensen (1948) and Worley and Meyer (1955). Lossee reported on results in a primarily coniferous area in Canada, using large scale photos. The largest crown diameter in the test area were under 10 feet, therefore even on large scale photography, the results were not satisfactory. At 1:1200 scale the average error was -0.09' ± 0.33' with a probability of 0.95. Crowns were too small to measure at 1:7200 scale.

Both Jensen and Worley and Meyer reported good results when testing accuracy of diameter measurements in the Central Hardwood Forest. Jensen's tests were on small scale photos, 1:18,000 to 1:22,000, and Worley and Meyers on medium scale, 1:12,000, photos. They disagreed, however on the method of measurement. Conclusions reached from the two reports indicate that the dot-type scale is perferable for measurements on small scale photos, as the small photo image of crowns at these scale blend with the merging lines of the wedge on the medium scale photos, however, the wedge gave more accurate results due to difficulty of matching circles on the dot-scale with irregularly shaped crowns, particularly in open grown stands. Neither report indicated a serious difference in results from one instrument to another.

Jensen's report includes a chart for converting photo measurements, in thousandths of an inch, to actual crown width for photography at scales 1:18,000, 1:19,000, 1:20,000, 1:21,000, and 1:22,000. The conversion table should be used with a tolerance for interpolation. A photo measurement of 2.5 thousandths of an inch is converted as a 4-foot crown width on all but the smallest scale.

Volume tables in a report by M. J. Ferree (1953) may also be used to make such conversions. The photo measurements are in hundredths of inches and scales included range from 1:12,000 - 1:24,000. These volume tables further convert to stem size (DBH) for a number of forest types and sites.

Correlation between crown diameter and diameter at breast height is reiterated throughout forest photo interpretation literature, but quantitative data is scarce. The ratio of CD to DBH differs between species and within species, between age and forest site conditions. No single or simple formula for converting crown diameter to DBH is possible. Spurr (1952) states: "----- a rough rule of thumb, approximately true for middle-diameter classes of eastern American species, is that the stem diameter in inches is equal to three quarters the crown diameter in feet. For Pacific Coast species, the rule of thumb is that stem diameter in inches is equal to the crown diameters in feet." Such a statement gives little hope for precise and accurate values. To be precise, the ratio must be computed for each set of forest conditions.

Foresters use the CD/DBH measurements primarily for obtaining timber volume estimates. The measurements are statistically converted to volume tables which infrequently include both the measured crown diameter value and the corresponding computed stem diameter (DBH). The 24 volume tables included in Ferree's report do contain both values and a number of other volume tables may be used by interpolating data or computing "in reverse."

Although aerial volume tables as such are not of primary interest in this study, Spurr's (1952) discussion in Chapters 11 and 12 of volume tables, their construction, accuracy and use, merits a special note.

Tabulations of results of crown diameter measurements, as found in the literature, are not for single trees, but for plots or stands of trees. If stem size of single or individual trees is desired, the standard error of single tree estimate will be higher than the results would indicate.

Crown diameter measurement tests have been performed on photography of varying scales by different persons. There was little mention of difference in film-filter combinations, or other photographic criteria. The Jensen and Worley and Meyer reports were primarily testing of measuring devices and methods, and checking on expected accuracy of volumes obtained by using the methods. Worley and Meyer maintain that on 1:12,000 scale photos, there is no significant difference in accuracy of crown measurements for different types of trees (hardwood and soft woods) nor for trees of different sizes. They also point out that visible crown diameters as depicted on aerial photos cannot be checked by ground measurements, therefore, relative accuracy must be determined by analysis of variations in interpreter differences.

Pope's (1957) studies in the Pacific Northwest indicate the most thorough treatment of forest airphoto measurements at varying scales and with different films. However, analysis of crown measurement data has not been published as yet.

Stereo-viewing is important for all crown measurements. In estimating crown closure, it is important for detecting small openings, understory, etc. For crown count, stereo-vision can aid in separating trees, one from the other and in determing multiple stem clumps. In crown diameter measurements the stereo-view is necessary to avoid exaggerating diameter of any crown not directly on the principle point of the photo.

Area Measurement. The measurement of areas may be made directly on aerial photographs. Area is important to the interpretation of vegetation on air photos as related to trafficability and other military problems, where it concerns number of stems or crowns per unit area. The vegetation does not determine the area measurements, however, and thorough instructions and discussion of area measurements are available in such publications and the Manual of Photogrammetry (1952), Aerial Photographs in Forestry (Spurr 1948-1) and various military air photo interpretation manuals. For these reasons determination of areas will not be discussed further in this report.

<u>Indirect Measurements</u>.

From the measurements obtainable on air photos other measurements may be computed or obtained through correlation. Foresters have made a number of studies to determine methods of accurately computing stem diameter, basal area, stand density, stem form, stem quality, and tree and stand volumes. Of these only stem diameter and stand density need to be considered in detail and these have been discussed under crown and height measurements. Basal area is the sum of the space occupied by stems at breast height. It is useful in computing stand volume and stand density. As the military problem here considered is concerned with size and number of trees per unit area stand basal area computations, are extraneous. Basal area for individual trees is computed using the formula $BA = \frac{d^2}{576}$

where BA = basal area in square feet

d = stem diameter in inches.

DBH, in itself, is an indication of the tree size, and the crown closure or crown count measurements should give a satisfactory density measurement for our purposes. Stem-form and stem quality are factors used in estimating volumes. They are derived from the other factors of interest, but are not otherwise pertinent.

IV. VEGETATION IDENTIFICATION AND ITS SIGNIFICANCE AS AN INDICATOR OF TERRAIN CONDITIONS

Ecological science has established that the mature plant community when undisturbed by man is an excellent indicator of the environmental conditions. The vegetation in an area provides a single expression into which are integrated all of the significant physical, chemical and biological factors brought to bear upon it. The fully developed plant community is in equilibrium with the prevailing combination of factors operating largely by way of climate and soil. Vegetation expresses the environmental complex better than would the data derived from any combination of recording instruments. It is not presently known how to integrate the various physical measurements into one meaningful expression that gives each factor its proper weight and still represents the resultant of all environmental influences.

General Factors

Influences which control the natural distribution of vegetation are many and interlocking. Growing plants vary considerably in their requirements of the basic environmental factors of heat, light, water, and nutrients. Some species are capable of surviving under a wide range of conditions while others are more exacting in their demands. Within a region, local climatic conditions vary considerably through variations in slope angle and aspect. Thus, vegetation established on a particular site is governed by strictly local conditions. The already intricate problem can be complicated further by such natural disturbances as fires or by activities of man such as logging operations.

The vegetative cover that exists on a particular site today is not necessarily the same as it was many years ago, nor will it necessarily remain permanently. In order to employ plant cover as a soil indicator in an area, it is important that the air photo interpreter realize that vegetative composition may be constantly changing through the natural processes of plant succession. The ever changing vegetative cover may or may not be the climax, or ultimate cover type for an area in which the balance has been upset. A knowledge of the ecological habits of the various species encountered at different restoration stages will make it possible to make differentiations in vegetative cover which are not readily apparent.

Species Identification:

The complexity of vegetation occurrence and distribution may cause an air photo interpreter with little or no knowledge of the botanical sciences to shy away from using plant cover as an indicator of surface mantle types and conditions. Positive identification of tree species is probably the most desirable and difficult information to extract from air photos. Few quantitative tests have been reported in this field but much qualitative information is available. It is widely acknowledged that to identify and interpret vegetation on aerial photos it is necessary to have a general knowledge of the area concerned and the ecological relationships therein. The photo interpreter should be given background training dealing with the geography, geology, and plant ecology of the specific areas in which he is to make his interpretations. Evidence to support this theorem may be found in the "short course" in regional geography which accompanies most vegetation keys. In fact, the importance of site and vegetation associations for identifying vegetation on air photos is a contributing factor to the development of keys. As Spurr (1948) states, "few hard and fast rules can be laid down. Considerable training and experience are necessary."

Features of the individual tree which affect identification are shape and texture of crown, tone of foliage and seasonal changes, and shape of shadows (or shape of tree in oblique view). Other physical factors include site classification (soils, drainage, topography) and knowledge of forest associations and successions. Photographic factors affecting species identification include scale, film and filter combination and season of photography. Most of the reports dealing with species identification refer to photographic factors in general terms, usually stating a local preference for panchromatic, infrared or seasonal photography according to forest types and/or purpose of photography. Schulte (1951) stated that in Eastern Canada and Northeastern United States scales of 1:2,000 or larger are necessary for recognizing single species in mixed stands, and further, that panchromatic is superior to infrared because at larger scales crown texture detail is more important than tone. Schulte investigated the use of panchromatic, infrared, and color film in the study of plant distribution and drew a number of interesting conclusions. Results, however, were based on a personal analysis of the three types of film and no quantitative data were presented.

Young (1953) found it impossible to identify individual species on 1:3,500 scale photos in Maine, and Kelsh (1943) was unable to identify rubber trees on large scale photos in the Amazon region. Density of forest cover was the major factor in both cases, with the characteristics of the rubber tree itself an additional problem in the latter.

Scale/film/filter tests performed in California by Jensen and Colwell (1949) indicated that for species identification panchromatic with minus-blue filter was generally preferable, and there was only slight advantage of 1:15,000 scale over 1:20,000. The total number of identifiable tree species was greater on the panchromatic minus-blue combination than infrared minus-blue, while the opposite was true for brush and chaparral. For specific species or species groups, the best filter/film combination varied also. For example, on the infrared minus-blue combination, California black oak could be separated from the other species. On the panchromatic film, it could be separated from only some of the others. Also, while more chaparral species were identifiable on the infrared photos, the most significant indicator, chamise, was more easily identifiable on the panchromatic film. Identification of the tree species was limited to mature trees in all cases. Advantage of the 1:15,000 scale added only to the number of species identifiable. Sugar pine became partly separable from ponderosa pine (on panchromatic film) by virtue of definition of its branching habit. Panchromatic film with a green filter was also used on the 1:15,000 photos, and found to differ very little from the panchromatic minus-blue combination. Where a slight difference was found, it was negative.

The most recent species identification tests reported were those published by Pope (1957) for the Pacific northwest. He found no significant difference in species identification between interpreters or between film types (panchromatic and color). Differentiating tones on the color film were indistinct at the smaller scales. The vegetation was as easily identifiable by crown shape and texture on the large scale panchromatic photos. Thus, there was no significant advantage of using color film over panchromatic types. There was a great difference in species identification between mature and immature timber and significant difference between scales. Twenty per cent identification was the most that could be obtained on 1:20,000 scale photos. There was a substantial increase in accuracy of species identification between 1:20,000 and 1:10,000, and an indication of increase in accuracy with even larger scales. Pope also noted that 1:500 scale photos taken with a 12 inch lens (using an image motion compensating magazine) were excellent for identifying small trees, shrubs and brush.

No quantitative tests were reported on use of color film versus panchromatic specifically for identification of individual hardwood species. Seely (1947) suggested that variation in glossiness of broad-leaved foliage may provide a means of species differentiation on color photography.

The film/filter combinations most satisfactory for species identification will vary according to location and vegetation types. Some differentiation between hardwood and conifer stands can be made on scales smaller than 1:20,000. A scale of 1:20,000 is considered the smallest scale at which broad forest classification can be made. In some areas a few individual species can be identified on 1:20,000 photos. At 1:15,000 species identification is not increased considerably over that possible with scales of 1:20,000, but indications are that between 1:20,000 and 1:10,000 there is a significant increase in accuracy. The proportion of increase is unknown and will probably vary with complexity and number of species in the forest.

As previously stated, most of the literature pertaining to species identification is based on descriptions of vegetation and vegetation associations and their relation to topographic position and site requirements. These are found in reports on forest inventory methods, manuals, and keys. They usually include a description of photo appearance in terms of tone and texture, shape and shadows, and some supporting ecological data. Spurr (1948), for instance, includes description of the major species and species associations in each of the major forest regions of the United States (Spruce-fir Region, Eastern White Pine Region, Central Hardwoods, Southern Pine Region, and Western Forest Region). In reporting a specific forest inventory in Eastern Canada, Losee (1955) described photo identification characteristics of black spruce, tamarack, cedar, white spruce, balsam, jack pine, white and red pine, and other soft woods and stands of white birch-aspen, maple, yellow birch, beech and other hardwoods.

Most of the truly definitive narrative descriptions have been included in the KEY section tabulations. Statements from some additional reports are included because they are unique rather than for their species identification value.

Photo Interpretation Keys

The unanimous opinion of photo interpreters (either contacted in person or through literature review) is that keys are valuable aids but cannot be expected to replace personnel trained in both photo interpretation and the field for which the key was constructed (forestry, agriculture, geology, etc.). The opinions vary, however, on the degree of key usefulness.

Construction of vegetation keys has been adequately discussed by Colwell (1952-3), O'Neill (1953), Simontacchi, et al (1955) and Stone (1948). The two major considerations in key construction are purpose for which the key is to be used and type of key to be constructed. Contents of the key, or objects to be keyed-out are determined by the purpose for which it is to be organized.

Broadview Research and Development (1957) performed tests to evaluate photo interpretation keys and to determine the need for keys in the Armed Forces. A vegetation key was used as representative of a key for natural features. In reporting test results, DeLancie (1957) drew three major conclusions: (1) an elimination (dichotomous) key has no value over a selective key, (2) keys must be logically organized and

(3) inexperienced interpreters might be trained to do as well in identifying man-made objects as experienced interpreters, but in identification of natural features, general experience and training is valuable.

Colwell (1948) suggests that vegetation may directly affect the conduct of a military operation in four major ways: (a) it may facilitate or impede the movement of troops and mechanized equipment; (b) it may accentuate or conceal evidence of military activity; (c) it may govern the ease of military construction; and (d) it may serve as a source of fuel, food, or construction material. Ordinarily a vegetation type should not be keyed-out in a military photo interpretation key unless it signifies a special condition in terms of one of these four considerations of particular terrain conditions and/or types.

If a key is to be used solely for terrain analysis the considerations of significance become even more restrictive. The terrain analyst must not overlook the indirect significance of some kinds of vegetation as indicator species of particular terrain types and/or conditions. Vegetation as a terrain indicator becomes useful only after the salient features of the vegetation pattern have been set forth in a systematic fashion. Colwell (1953) suggests four component parts to a vegetation key: (a) vegetation site factors; (b) stereograms of vegetation types; (c) a dichotomous method of considering identifying characteristics of the vegetation; and (d) the ground conditions likely to be encountered in each vegetation type. Elements a, b, and d are photographic representations.

Because of the vast numbers of possibilities of constructing keys for each scale, film/filter combinations, etc., the volumes needed for a complete set of keys for all types of vegetation and/or vegetation regions, are impracticable. Therefore, the factors most valuable to an interpreter must be weighed and the keys constructed accordingly. Discussion of existing keys will be limited to those vegetation keys for use in trafficability and related military problems.

According to Colwell (Manual of Photogrammetry, p. 553), a photo interpretation key should be designed to aid interpreters in rapid and accurate identification of objects from a study of their photographic images, and ideally, a key should contain word descriptions and illustrative examples. Unfortunately, very few vegetation keys meet these standards. By far, the large percentage of keys are verbosely descriptive, with too few illustrations. They tend to read more like a text book in regional environment than an identification key, thus impeding the "rapid and accurate" identification of objects or conditions. Key authors or key constructors are not entirely to blame for this. There are a number of contributing factors. First, it is universally accepted that a good interpreter must be familiar with, or have a background which will enable him to interpret in the area under consideration. Many authors of keys, then, are attempting to provide the background. Also, the combination of variables possible in a field as dynamic as vegetation, preclude a simple and consistent tabular keying out of each species, or condition. Dr. William E. Powers (1952-1953), in preparing land form keys under an ONR contract found that the same method of preparing keys in two different geographic areas was unsatisfactory. He points out the following: "the areas (Lake Michigan Region) analyzed were presumed to be dominated by glacial land form features of numerous distinctive types, and the small size of many of these permitted individual land forms to be analyzed and identified through a fixed procedure based on the presence or absence of exact criteria. Such a method is not well adapted to the Montana Great Plains area.... Here the land form types do not, in general, consist of individual forms different from those surrounding them, but rather are grouped in extensive areas in which many individual features collectively comprise the land form type." Differences are exhibited in vegetation types, too, and a key organized for one type may not be suitable for another.

One of the earliest vegetation keys for photo interpretation purposes was that prepared by Colwell for the Tropical Pacific Area. This key has frequently been used as an example. It is concise, definitive, and easy to use. If all photo interpretation vegetation keys could be of this caliber and usefulness, the problem of keys would be minor. However, (1) the key was constructed by an expert in photo interpretation and in forestry (2) the Tropical Pacific Area, while it has an abundance of species variaties, is predictable in types of vegetation to be found on varying sites. Seasonal variations are practically negligible, and vegetation types readily distinguishable. Some of the same criteria apply to Polar and Sub-polar regions.

In these areas, seasonal variations may be of greater importance, but the number of species is more limited. In other words, it is easier to prepare a vegetation and vegetation association key in regions of extreme climatic regimes. The mid-latitude forests contain in a greater number of variables - species, site conditions, seasonal variations and the combined effects of one upon the other. It is difficult to construct elimination keys combining the brevity and completeness of the Tropical Pacific Key.

G. A. Choate (1957) has published an annotated list of vegetation keys which contain a brief description of most of the readily available keys. They vary from one page elimination keys to lengthy, descriptive texts. Most of the keys prepared under contract to Department of Defense agencies contain volumes of information relative to purpose and scope of the contract and descriptions of the methods used, choice of areas and photos, etc., which are not always directly pertinent to the key itself. In many instances, condensing the information in these reports to usable key form would be of great service to interpretation. Another drawback to these "contract keys" is the limited distribution assigned to them. The contractors were generally required to furnish a specific number of copies, usually in a quantity small enough to prepare a mimeographed report and paste in photo copies of the illustrations. Copies of these keys may be obtained, but they will be photostatic copies and the illustrations practically useless. Quality reproduction must be a prime consideration if usable keys are to be made available. Even in the better or "slick paper" publications, illustrations exhibit loss of clarity through reproduction processes.

The non-contract keys are those prepared by Forest Service agencies for photo identification of species or forest types in specific regions. These include Moessner's "Stereograms illustrating Forest Sites" (1949), which consists of a series of aerial and ground stereo-views, with no textural description. At the other extreme of key types is "Key to Forest Types in the Vicinity of Lansing, Michigan when using Panchromatic 1:20,000 photos taken in June and September" by Chase, which is an elimination key with no illustrations.

Stereograms have been prepared by K. E. Moessner for both Central States (1949) and Intermountain (1956) Forest Experiment Stations. The Central States hardwood area booklet contains seven stereograms, illustrating forest types based on topographic position and soil type. The information included is excellent, but due to the fact that the stereograms have been reproduced lithographically much of the detail is last, and use for aid in identifying or classifying similar areas is limited. The 18 stereograms prepared for the Intermountain area are of better quality as they are printed on glossy photo paper and are probably first generation prints. In addition to the usual views they include a number of horizontal ground stereograms illustrating points on the verticals. This combination is helpful in determining trafficability problems as is the slope information printed on each stereogram. Data pertinent to soils are not included, thus limiting the value. Stereograms such as these could be valuable used as illustrative material in more informative elimination or selective keys. As published they are more like tempting appetizers. The amount of useful data is not complete on either set.

One of the best all around keys found is "Boreal Fringe Areas of Marsh and Swampland" prepared at the University of Oklahoma (1954). This key was constructed to include pertinent descriptive material with well chosen illustrations. Winter and summer conditions are treated exhaustively with documented references to the trafficability and other conditions important to military operations.

The keys surveyed are tabulated on the following pages. These tabulations detail information relative to geographic areas, film/filter and scale specifications, species or conditions keyed, and condensed comments.

A large number of literature items not published as keys contain excellent descriptions of the photo appearance of vegetation. These can be extracted and used as key-type material helpful in species or vegetation association identification. Without exception, these items include site factors as part of the identifying criteria. The most important are included in the key tabulations.

A few keys prepared for other purposes contain vegetation information of value in trafficability studies. Most useful of these is "Glacial Landforms and Associated Landform Patterns in the Lake Michigan Region and Comparable Areas" (Powers, 1952).

Areally, the majority of keys have been prepared for the more easily keyed vegetation regions. They are more numerous for tropical and arctic areas than elsewhere. Within the United States keys are available for such northern latitude areas as Northern Minnesota, Wisconsin and Maine. Keys to western mountain areas are fewer, and only one was found for southeastern United States.

V DISCUSSION

A significant beginning has been made toward determining the quantitative limits of aerial photographs. There is much yet to be done. The investigations to date point out areas of study where further quantitative research may prove valuable and areas where refinement of interpretation techniques, and/or improvement in photo quality are necessary. The values so far determined have resulted from scattered tests by various persons or agencies with no coordination of methods, procedures, or presentation of data.

Further research in all phases of photo interpretation of vegetation is considered desirable. Some subject areas merit emphasis as they have not been treated thoroughly, if at all. An investigation of time limits for diurnal photography, has not been performed (to our knowledge). An analysis is needed of how much and what kind of information can be obtained from photos taken at various times during the day, and in relation to length of time from the optimum. Testing of photographic papers and emulsions could be profitable in addition to continued research on films and filters. Evaluation of understory conditions is an aspect of vegetation which has been treated primarily in a qualitative manner - quantitative data are needed.

Photo interpretation literature contains many references to vegetation in relation to military problems. Movement of personnel and equipment, protective cover and camouflage, and availability of subsistence and construction resources are treated with varying degrees of thoroughness. However, no direct or specific mention was found relating vegetation to the problems of weapons and missle firing. The character of the forest canopy, the size, shape and density of tree crowns, the size and spacing of tree stems, tree height and understory are all important items to consider in relation to the weapons and missile aspect of military operations. Foresters have been concerned with tree height and crown measurements and species identification for forest management and inventory purposes. Results of their research can be applied to military problems, but additional research must be performed to obtain satisfactory measurements for efficient military interpretation. Determination of tree heights, crown diameter, crown density, and tree count have been considered more thoroughly than diameter and spacing of stems, and crown shape.

Russian literature indicates a recent interest in measurements of height of tree to widest part of the crown and crown height. No mention of such measurements was found elsewhere in the literature review, yet such measurements could add significant information relative to crown shape and depth of canopy. They could also aid in species identification.

The information obtainable from aerial photographs, qualitative and quantitative, depends upon a combination of the factors of photographic quality, geographic location, and the photo interpreter. Of these, the interpreter is probably the most important and the least controllable. The nature of vegetation and its relation to climate, soils, and topography precludes a definitive, systematic classification of air photo techniques and establishment of a set procedure for consistent photo interpretation of vegetation.

The quantitative, qualitative and human aspects of photo interpretation warrant further research, as follows:

1. There is an obvious need for a systematic, planned testing program to determine the limits and accuracy of photographic measurements.

2. There is a need for field and photo study of vegetation in relation to its surroundings to correlate the ground conditions with the photographic representation, and to better identify vegetation species.

3. There is a need for better understanding of the human element in relation to photo interpretation problems.

APPENDIX

TABULATIONS

INFORMATION RELATIVE TO PHOTOGRAPHY TYPES

FILM-FILTER-SCALE

Source: Pope (1957)

Effect of photo scale on accuracy of Forestry Management.

Film-scale-filter:

Panchromatic	1:20,000	USDA Photo
Pan. & Color	1:10,000	24" & 12" lenses
	1:5,000	24" & 12" lenses
	1:2,500	24" & 12" lenses
	1:500	12" & 24" lenses w/motion compensator

Results:

The largest satisfactory scale, using a 12" lens and with 60% overlap, was 1:10,000. When the overlap was increased to 80%, a scale of 1:5,000 was satisfactory. When used in conjunction with a motion compensator, the 12" lens gave excellent results at a scale of 1:500, for areas of short vegetation (brush grasses) where excess parallax is not a problem. With a 24" lens, usable photos were obtained at a scale of 1:2,000. Under these conditions however, image motion is more of a limiting factor than is parallax.

Source: Johnson (1958)

Effect of Photographic scale on precision of Tree Height Measurements.

Film-scale-filter:

Panchromatic	1:20,000	Wratten A25
	1:15,000	" "
	1:10,000	" "
	1:5,000	" "

Used an F56 Fairchild Camera with a FL of 8.25 inches.

Results:

There is no correlation between scale (within this range) and error in tree height measurement.

INFORMATION RELATIVE TO PHOTOGRAPHY TYPES

FILM-FILTER-SCALE

Source: Catholic University (1953)

Film-scale-filter:

(a)	Panchromatic	1:3600	A
		1:3600	G
		1:2400	G
		1:1200	G
(b)	Color	1:3600	
		1:2400	
		1:1200	

Study area:

Woodstock, New York - White Pine Plantation.

Results:

Ability to determine the extent of browning increased as the scale increased reaching a maximum of 50% for pan-emulsions and 95% for color emulsions.

Film-scale-filter:

(a)	Panchromatic	1:15,840	A&G
		1:7920	A&G
		1:4800	A&G

(b) Infrared: same as for pan film.

Study area:

Beaumont, Texas, 1950. Southern Pine, hardwood.

Results:

Infrared emulsions are not suitable for detecting browning of foliage. The panchromatic emulsions with an A filter offer the best combinations.

INFORMATION RELATIVE TO PHOTOGRAPHY TYPES

FILM-FILTER-SCALE

Source: Schulte (1951)

Film-scale-filter

(a)	Panchromatic (Kodak aerographic Super XX)	1:7,200	Wratten No. 12
(b)	Infrared (Kodak Aero Infrared)	1:7,200	Wratten No. 89A
(c)	Color (Kodak Ektachrome Aero)	1:7,200	Special, made for film

Study area:

Val David, Quebec, Canada

Results:

For recognizing plant species infrared is preferable; color and panchromatic about equal; scale should be 1:2,000 or less.

Comments:

The report included no quantitative data and no analysis of the specific photos used for the study.

INFORMATION RELATIVE TO PHOTOGRAPHY TYPES

FILM-FILTER-SCALE

Source: Wear and Dilworth (1955) and Wear and Lauterback (1955)

Film-Filter-Scale:

Color (Aerial Ektachrome) 1:7,200
1:6,000

Study area:

Oregon - Douglas fir forests

Results:

Field and photo counts of dead trees are highly and consistently correlated. Color is superior to panchromatic at the 2 percent level. Twice as many errors were made on panchromatic photos as color. Interpreting color film was twice as fast as panchromatic.

Comments:

These studies were conducted to determine accuracy of color and panchromatic photography for estimating insect damage to timber, and to compare costs of photo method with ground surveys. For this special purpose color photography proved useful and economical.

INFORMATION RELATIVE TO INSTRUMENTS

1. **Source:** Thornton (1954)

   Instrument: Hinged dot template. Used as an overlay to aid in dot counting (area estimates). This report includes details for construction and use.

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2. **Source:** Jensen (1948)

   Instrument: Dot-type scale. Used to measure tree crown diameters in aerial photos.

   Comments: This instrument is recommended in preference to the parallax wedge for crown diameter measurements on small scale photos.

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3. **Source:** Moessner (1949-1)

   Instrument: Crown Density scale. This is a comparison scale to estimate crown densities on photos of 1:20,000 scale. Report includes details for construction and use.

   Comments: No test information

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4. **Source:** Moessner (1956-3)

   Instrument: Parallax Wedge. Can measure a parallax difference to 1.08 inches.

   Comments: This wedge is intended for use on photos of mountainous areas and although designed for vertical coverage, it can be used on low obliques.

INSTRUMENTS

5. **Source:** Moessner (1950-2)

   Instrument: Training Stereogram. Designed for training personnel in the use of the Parallax Wedge.

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6. **Source:** Goodspeed (1949)

   Instrument: Parallax Conversion. Alignment Chart. Used for converting Parallax Wedge readings into tree heights.

   Comments: This chart was designed for Iowa and is limited to areas of level terrain. The errors in chart reading are within the range of erros frequently made in attempting to read the wedge to 0.001".

7. **Source:** Moessner (1957-1)

   Instrument: Frosted template. This template has the effect of spot lighting a study area on an aerial photograph.

   Comments: Instruction for making and using the template included.

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8. **Source:** Hutchison (1948)

   Instrument: Alignment guide. This guide aids in aligning stereo-pairs for optimum viewing and accurate measurements.

   Comments: Instructions for construction and use of the guide are included.

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9. **Source:** Moessner (1949-3)

   Instrument: Slope Scale. This scale permits measurement of slope percent regardless of line of flight. Designed for use with 1:20,000 scale photos. Directions for using are included.

   Comments: Tests using the scale indicated that two thirds of the individual measurements made using the scale should be within $\pm$ 14 percent of the field measurement.

10. Source: Moessner (1953-1)

Instrument: Scale-protractor. Instrument designed to measure distances and areas and to determine scale on air photos ranging from 1:19,500 to 1:22,500. Instructions for use included.

Comments: Accuracy of scale determinations will be low in areas of rough terrain.

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11. Source: Moessner (1956-1)

Instrument: Scale-protractors. Protractor above (Moessner 1953-1) redesigned for use in mountainous country. Three basic scales: 1:10,000, 1:15,000 and 1:20,000 cover elevation differences of 2,000 to 3,000 f-et from that of datum plane. Instructions for use included.

Comments: Accuracy of angles and distances measured will vary with amount of elevation change and distance from center of photo.

INFORMATION RELATED TO PHYSICAL CHARACTERISTICS

CROWN DENSITY

Source: Worley and Meyer (1955)

Scale used:

1:12,000

Film/filter/camera:

Infrared with minus blue filter.

Area/species studied:

Pennsylvania - upland oak.

Crown diameters:

Variation from 10 to 100 ft.

Testing information:

There were 93 plots of 15 acres each. Three interpreters measured each plot twice with dot count scale and crown density scale using lens stereoscope.

Results and accuracy:

Accidental error (standard error of a given interpreter from one measurement to another) was found to be 9.5% by dot grid and 10.4% by density scale. Standard error of averages due to accidental errors of measurement was found to be ±0.73. The crown cover estimates may be affected by systematic error of 5 to 10%. The use of the dot grid method is better suited for developing refined techniques to reduce the systematic errors to a maximum of 5%.

INFORMATION RELATED TO PHYSICAL CHARACTERISTICS

CROWN DIAMETER

Source: Losee (1953)

Scales used:

(a) 1:7200
(b) 1:12,000

Film/filter/camera:

(a) 9 x 9 with 6 inch lens, Panchromatic, April.
(b) 9 x 9 with 24 inch lens, Panchromatic, April.

Area/species studied:

(a) and (b) Boreal forests, softwoods, 120 miles northwest of Port Arthur, 12 types - not listed by name.

Crown diameters in stands:

(a) and (b) vary from 5.3 to 9.8 ft.

Testing information:

(a) and (b) Three age classes - 110, 80, 50 years. Measured crown width on stereo models with parallax bar. Made 30 measurements in each forest type. Error reduced to less than 5% in any type.

Results and accuracy:

(a) 1:1,200 average error - 0.091± 0.33 ft. with probability of 0.95.

(b) 1:7,200 instrumental errors in measurement and personal factors were too great for accurate measurements.

Comments:

Comparison of field and photographic measurement of average crown diameters. See Table 5, p 760.

INFORMATION RELATED TO PHYSICAL CHARACTERISTICS

CROWN DIAMETER

Source: Worley and Meyer (1955)

Scale used:

1:12,000

Film/filter/camera:

Infrared, 8.25 focal length, minus blue filter.

Area/species studied:

Mixed hardwoods (oak), Pennsylvania.

Testing information:

Thirty-six trees were measured twice by three interpreters, each using two devices (wedge and dot-type scale). A total of 432 measurements.

Results and accuracy:

There were no significant errors for differences in forest types (hardwoods or softwoods) or size of crowns. The standard error of visible crown diameters made by single observer is equal to 3 or 4 ft. with either a wedge or a transparency. The wedge is free of systematic errors. The dot scale may lead to systematic errors of 1 to 2 feet. The standard error of averages is ±0.4 ft.

Comments:

Because of more consistency of readings, the wedge is preferable.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

CROWN DIAMETER

Source: Nash (1949)

Scales used:

(a) 1:6,600
(b) 1:7,000

Film/filter/camera:

Trimetrogon obliques and verticals of high quality. February photos with snow on the ground.

Test data:

Test location in Valcartier Forest, Canada. Species included: spruce (white and black), balsam fir, white pine, white cedar, white elm, white birch, yellow birch, cherry, and tamarac. Some telephone poles were measured. A total of 113 measurements were made on verticals and 117 on obliques. The crown widths were measured with Dominion Forest Service Photo Aid No. 69 (special version of pole scale). Hardwood diameters were omitted as not representative without foliage.

Accuracy and results:

On verticals the crown widths were measured by shadow method to a standard error of measurement of ±1.8 feet. On obliques the error was ±2.2 feet. Greater accuracy was obtained on the verticals than on the obliques. Regression line graphs are included in the report. There is no discussion of crown diameter factors as such, however, penumbration of shadows is discussed.

INFORMATION RELATED TO PHYSICAL CHARACTERISTICS

CROWN DIAMETER

Source: Jensen (1948)

Scales used:

(a) 1:18,000
(b) 1:22,000

Film/filter/camera:

No specifications given.

Area/species studied:

Central hardwoods.

Crown diameters studied:

Variations from 4 to 55 ft.

Testing information:

There were 168 saw timber plots. Three interpreters used dot-type scale and tree crown wedge.

Results and accuracy:

Slightly greater consistency for dot-type scale than for wedge.

Comments:

The report covers tests for use of different measuring devices. A conversion table shows actual crown widths for various photo crown widths at various scales.

INFORMATION RELATED TO PHYSICAL CHARACTERISTICS

TREE COUNT - DENSITY

Source: Young (1953)

Scales used:

(a) 1:15,840
(b) 1:12,000
(c) 1:10,000
(d) 1:7,500
(e) 1:5,000
(f) 1:3,500

Film/filter/camera:

Infrared with minus blue and color with proper correction filters. Black and white positive transparencies were made from infrared negatives. Photos obtained during September during noon periods at week intervals.

Testing information:

There were 14 plots of 1/4 acre each. Single flight lines flown. Studies made using light table and binocular mirror stereoscope.

Accuracy and results:

The total height and crown width of individual trees could not be measured because of stand density. As species could not be completely differentiated, they were grouped into forest types which could. There were no significant differences between film/filter combination for accuracy of tree counts by specie groups. As stand density increases, the tree count accuracy decreases. A scale reduction from 1:3500 to 1:15,840 reduced accuracy of count by 20% in both spruce-fir and pine-hemlock groups. The spruce-fir density was based on all trees in the plot because of the shade tolerance of these species. The pine-hemlock density was measured in terms of numbers of these species per plot. They were distinct enough to be separated from other species on the photo.

Comments:

The author concluded that with existing film/filter combinations and air photo scales commonly used, forest measurements* are limited to the forest stand as the unit of measurement. The accuracy of the count may be influenced by species.

*(in area concerned)

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Pope (1957)

Scales used:

(a) 1:20,000
(b) 1:10,000
(c) 1:5,000
(d) 1:2,500
(e) 1:500

Method used:

Parallax

Film/filter/camera:

(a) Panchromatic
(b), (c), (d) 24 inch lens for color and panchromatic
(e) 12 inch lens with image motion control magazine

Test data:

Mature and immature stands in Pacific Northwest, ranging from 50 - 250 ft. high (average 150 ft.). Three interpreters were used.

Accuracy and results:

Standard error of estimate shown in graph form. Error ranged from 8% on color at 1:5,000 to 18% on panchromatic at 20,000 for one interpreter. The most important conclusion stated that no significant overall relationship between height measurement errors and either photo scale and film type. The error magnitude depends on the individual interpreter.

Comments:

Nine possible sources of error were listed as follows:

(1) errors of instrument and interpreter
(2) photo scale determination
(3) altitude differences between camera stations
(4) failure of tree tip resolution
(5) wind motion of tree top
(6) tree crowns obscuring the ground
(7) brush obscuring the ground
(8) false stereo
(9) tip and tilt.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Rogers (1946)

Scales used:

(a) 1:10,000 (variation)
(b) 1:48,000 (variation)

Method used:

Parallax

Film/filter/camera:

Variety of cameras in all seasons for range of scales 10,000 to 48,000.

Test data:

Northern hardwood, oak, spruce, fir, white pine (diversified). There was no specific test program. A wedge was used on all variations of photography.

Accuracy and results:

By using simple conversion, it was found that tree heights (individual) could be measured to within 10 feet, two times out of three on 1:20,000 scale photos and to within 5 feet of the stand average, two out of three times. An important graph showing tree height in feet by photo scale, parallax and parallax change for each 0.001 inch of parallax is contained in the report. Scale ranges cover 1:2,000 to 1:35,000 with parallax from 2.2 to 5.2 inches for 8.25 inch F. L. photos.

Comments:

The report gives lucid instructions for orienting photos and stereoscope, orienting and reading the wedge, and 3 methods of converting readings to tree heights. The 3 methods are:

1 - simple conversion - ignoring corrections
2 - average parallax and average scale
3 - elevation corrections between datum and tree base.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Losee (1953)

Scales used:

(a) 1:1,200
(b) 1:7,200 April, snow on ground.

Method used:

Parallax

Film/filter/camera:

(a) Planning camera with 24 inch lens on 9 x 9 format.
(b) Six inch lens.

Test data:

Study area was in Canada, 120 miles northwest of Port Arthur in boreal forest. Twelve types of softwoods were studied. Measurements involved 64 single trees and 12 stands.

Accuracy and results:

The superiority of large scale was demonstrated by shorter time and lower standard of error. Errors were as follows:

(1) Stand measurements for
1:7,200 ±0.6 ft. ±2.1 (0.95 prob.)
1:1,200 ±2.1 ft. ±0.5 (0.95 prob.)

(2) Individual measurements for
1:1,200 -1.5 ft. to +1.8 ft.
1:7,200 +10 ft. to +16 ft.
The error = -13 ft. small scale and -0.1 ft. large scale.

Comments:

At time of report preparation, individual tree measurements were not completed. They were made to test correction factor to account for snow depth, lack of resolution, and personal equation. It was pointed out that "personal correction for interpreter must be negative."

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Nash (1949)

Scales used:

(a) 1:6,600
(b) 1:7,000

Method used:

Shadow

Film/filter/camera:

Tricamera photography was used (high quality verticals and obliques). Winter (February) photography with snow on the ground was obtained.

Test data:

The area tested was in the Valcartier Forest, Canada. The species included spruce, white and black balsam, pine, tamarac, white cedar, white elm, white and yellow birch and cherry. Some measurements were made on telephone poles. Measurements were made of 113 trees on verticals and 117 trees on obliques. A shadow factor of 4 was used for verticals (1/100 inch tree shadow per 4 feet of tree height). For obliques, the image factors were: 10.8 - background, 11.8 - central portion, 15.0 - foreground. Three interpreters were used (1 for graphs and 2 for comparisons). Statistical computations involved regression analysis methods.

Accuracy and results:

Using shadow heights for verticals, the standard error of estimate was ±2.2 feet for two interpreters and ±2.5 for the other interpreter. The standard error of estimate based on obliques was found to be: ±2.3 ft. for one interpreter, ±2.4, and ±2.6 for the others.

Comments:

There was no discussion on the verticals compared to obliques. However, a series of suggested error sources are listed as follows:

1 - ground slope - field checks resulted in errors of 3 feet on topographic differences on slopes.
2 - snowfall depth necessitated addition of 3 feet to reading.
3 - measuring devices calibrated to 10 feet ~~needed interpolation~~.
4 - interfering crowns obscured the base of trees.
5 - resolving power.
6 - shadow penumbration.
7 - growth time lapse between photo date and check date.
8 - Scale inaccuracies.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Worley and Landis (1954)

Scales used:

1:12,000

Method used:

Parallax

Film/filter/camera:

Infrared with minus blue filter during the summer.

Test data:

Study was an upland oak area in Pennsylvania consisting of 3-size classes of hardwoods and conifers (20-40, 40-60, over 60 ft.). Four interpreters were used (2 -wedge, 2 -bar). Each made two sets of measurements.

Analysis and results:

There was little or no difference in error between open grown and forest grown tree height measurements. The average systematic errors in height measurements were greater for conifers than for hardwoods and greater for large trees than for small trees. The parallax wedge was more accurate than the bar. The standard error of height measurement made by experienced interpreter amounted to about 8 - 10 feet for this type photography.

Comments:

Errors may be explained by lack of resolution of detail in the pointed conifer crowns. The parallax wedge accuracy may be because of the following: (1) sloping line of dots may form a better reference for judging tree top readings than a single dot. (2) Particular bars may have been affected by a systematic error. (3) Error may be due to the interpreter-instrument combination rather than instrument alone.

A Correction Table showing "feet to be added to tree heights for 1:12,000" is shown. Tabulations and derivations are also shown.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Johnson (195[illegible])

Scales used:

(a) 1:20,000 1949 photos
(b) 1:15,000 1949 photos
(c) 1:10,000 1949 photos
(d) 1:5,000 1949 photos

Method used:

Parallax

Film/filter/camera:

All obtained using Panchromatic with Wratten 25 filter in Fairchild F56 camera, 8.25 inch lens, on 6.66 x 6.92 inch format.

Test data:

Tennessee location. The stand consisted of open grown trees - sweet gum, elm, yellow poplar, red maple, sugar maple, white oak, pecan, Virginia pine, sycamore, red oak, and red cedar. Trees ranged from 40 to 70 feet. Fourteen trees were each measured twice by two interpreters on each of 4 scales. Instruments used were Abrams contour finder and USFS wedge.

Results and accuracy:

Both instruments yielded similar results. Error in tree height measurements is not associated with photo scale in the 1:15,000 to 1:20,000 range. The error is associated with some tree characteristic, probably crown shape (species). Error is also associated with the interpreter. It also may be related to the tree height.

Comments:

The report presents a thorough statistical analysis and method of data reduction. Tables of analysis of variance and errors in tree height measurements for parallax bar and wedge are included. There are no simplified standard error of estimate tables.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Sammi (1953)

Scales used:

1:9,600

Method used:

Parallax

Film/filter/camera:

Infrared with No. 25 filter using 12 inch F. L.

Area and species:

Massachusetts

Testing data:

Positive transparencies and semi-matte prints were used. Ten measurements were made on each of 48 trees for both transparencies and semi-matte prints by one interpreter.

Results and Accuracy:

Report presents results graphically. It was found that the mean deviation increased with the tree height on both prints and transparencies using parallax. An increase in coefficient of variation to a maximum of 12% at 1:9,600 scales was noted. The standard deviation and percentage of variation computed indicate height measurement within a consistency of ±24% for positive prints. The variations for transparencies are 2 to 4% less. Transparencies gave better results.

Comments:

One possible explanation of error may be an instrumented error resulting from increased number of micrometer turns for taller trees. The methods are perhaps accurate enough for timber cruise but not for precise work or for volume determination. Since only one interpreter was used, the findings are not conclusive.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Moessner and Rogers (1957-2)

Scales used:

13,500 ft flying altitude
2,000 ft flying altitude

Method used:

Parallax

Film/filter/camera:

Parallaxes of 2 and 4 inches

Test data:

Testing computation of heights by parallax using tabular, graphic and formula techniques. 16 trees - 30 to 280 feet.

Accuracy and results:

Graphic and tabular techniques usable on all trees of all heights when flying height exceeds 4,000 ft. At low flying heights over rough terrain parallax problems should be solved by formula. Reducing flying height from 13,500 to 2,000 ft increased standard error of estimate from 0.7 foot to 1.9 feet for trees less than 100 ft high. Standard error of estimate for all trees when scale not corrected for elevation: 10.6 ft. Corrected scale reduced error to 3-4 feet. Increasing parallax from 2 to 4 inches resulted in standard error of estimate only one-half as large (increased parallax by increasing overlays).

Comments:

Report includes graphs and charts for graphic and tabular techniques, directions for computation by formula, and sample problems. Suggests use of slide rule, and gives savings in time data.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHTS

Source: Rogers (1949)

Scale used:

1:20,000

Method used:

Shadow

Film/filter/camera:

No data.

Test data:

Not given.

Accuracy and results:

Experienced persons can estimate tree heights within 7 feet two times out of three.

Comments:

Article includes directions for converting shadow lengths to tree heights, direction for computing time of photo exposure, aid to date interpolation on graphs, directions for computing scale.

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHT - STANDS

Source: Moessner, Brunson and Jensen (1950)

Scales used:

1:20,000

Method used:

Parallax

Film/filter/camera:

(a) 9 x 9 Summer - 1949
(b) 9 x 9 Winter - 1946
(c) 7 x 9 Summer - 1940

Area and species:

Central hardwoods, Southern Indiana.

Testing data:

Using three interpreters as follows:

(a) 38 stands - 1949
(b) 37 stands - 1946
(c) 18 stands - 1940

Results and accuracy:

The results are shown on standard error bases for all stands as follows:

	Mean Deviation Ft.	Standard Error	Aggregate Deviation %	Mean Coef. of Variance (%)
(a)1949	5.85	±0.95	-1.8	10.28±1.00
(b)1946	9.05	±0.85	-5.5	15.15±1.40
(c)1940	9.17	±1.90	-9.9	14.2 ±2.69

Other important observations include the following. It is important to consider the growth factor between the date of photos and the date of measurements. Summer photos produce better results as the leafless hardwood crowns are nearly invisible in winter photos. A mean deviation of 5 - 7 feet can be expected on good quality summer photos. Considering the 1946 and 1949 photos there was no appreciable difference in mean deviation between saw timber and all stands. For 1940 photos, the mean for saw timber was 6.7 and for all stands 9.2. As parallax readings are angular measurements, longer base will give better results (limited).

INFORMATION RELATIVE TO PHYSICAL CHARACTERISTICS

TREE HEIGHT - STANDS

Source: Moessner (1955)

Scales used: | **Method used:** Parallax

(a) 1:20,000 with 8.25 F.L.
(b) 1:28,000 with 5.25 F.L.
(c) 1:31,500 with 6.00 F.L (enlarged from 1:40,000)

Film/filter/camera:

No data.

Area and species:

Conifer stands in Rocky Mountains (Southern areas of high relief - Idaho). Included Engleman spruce, lodgepole pine, juniper, aspen, non-commercial hardwoods. Study made in areas with 1,500 feet elevation differences. Stands 20 - 90 feet high.

Testing data:

One interpreter studied 19, 15, 24 stands.

Results and accuracy:

The results are shown on standard error bases for all stands:

	Mean Deviation feet	Standard Error	Mean Coef. of Variance %
(a)	7.8	10.7	0.81
(b)	4.0	5.1	0.94
(c)	7.7	10.8	0.74

Stand heights can be estimated about as well from parallax measurements on air photos as from a few Abney level readings in the field. If elevation corrections are made, average stand heights can be estimated on air photos in Rocky Mountains, as accurately as in level areas of the east. The level of dense, flat-topped crowns is easy to determine (hardwood and dense even aged conifers) but difficult to see the ground line. On open conifers, the tip is difficult to resolve but the ground line is easily seen.

INFORMATION RELATIVE TO SPECIES IDENTIFICATION

Source: Pope (1957)

Scales used:

(a) 1:20,000
(b) 1:10,000
(c) 1:5,000
(d) 1:2,500
(e) 1:500

Film/filter/camera:

(a) Panchromatic
(b), (c), (d) Color and panchromatic
(e) 12 inch with image motion control magazine

Area and species:

Pacific Northwest, mature and immature stands.

Procedures:

Used three interpreters, visual comparisons.

Results and accuracy:

The measure of accuracy held to percentage of trees correctly identified. This is shown graphically - not tabular. At 1:20,000 scale it was found that 20% of the species could be identified correctly. At other scales, there was no significant difference in accuracy of species identification between interpreters or films. Between mature and immature stands, there was a significant difference (78-90% - mature and 38-50% - immature). A substantial accuracy increase was noted between 1:20,000 and 1:10,000 to a significant level of 10%; not at the 5% level.

Comments:

The characteristic shape and branching pattern of mature trees as compared to lack of this for immature trees probably accounts for some differences. It may be that species identification discrepancies exist between color and panchromatic emulsions because of the relative image sharpness between the two. Color films are slower, hence larger apertures are required for proper exposure. Further, color rendition at medium to small scales are affected by many more variables than effect larger scales.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Raup and Denny (1950)

Area type and cover:

Alaska and Canada. Forested and non-forested areas were studied. Vegetation types included were: balsam poplar, lodgepole pine, black spruce (bog type), black spruce (slopes), white spruce, alpine fir, dwarf birch and willow, in muskegs, grasslands, sedge, alpine meadow types and alpine tundra.

Key basis:

The report presents a discussion of photo interpretation of the terrain along the Alaska Highway. Special emphasis is given to black and white spruce as indicators. The key includes other aspects such as tone, vegetation borders, and texture of forested and non-forested areas.

Comments:

The report contains stereo-triplet type illustrations which are accompanied by detailed description of terrain, vegetation, soils and trafficability.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Powers (1952)

Area and type cover:

Lake Michigan Region (Illinois, Michigan, Wisconsin). A total of fifteen land forms were keyed.

Photo data:

Photo types vary. Scale studies based primarily on 3.25 inches per mile.

Key basis:

This is a key for the photo identification of glacial land forms of the Lake Michigan Region. The key is primarily based on land forms - vegetation is secondary.

Comments:

The illustrations in this report are excellent. Such items as vegetation and trafficability are mentioned as being pertinent to the particular land forms.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Catholic University (1953)

Area and type cover:

Subarctic mountains in the Nahanni Valley, Canada. The area contained aspen, white spruce, black spruce, scrub birch, alders, willow, reindeer moss, and Tundra complex.

Photo data:

Small scale summer photography.

Key basis:

One key is based primarily on height of vegetation as determined by parallax using stereopairs. Texture is hardly discernible. A second key is concerned with the use of animal trails, streams, and ridges for determining the routes of access to an area by walking.

Comments:

Plates for these two keys and additional information regarding interpretation of vegetation on photos and related trafficability notes are included in Part III of the report. Also included are notes on bed rock. Excellent quality air photo and ground photo illustrations are included. The photos are 1:20,000 RCAF, panchromatic predominately. Some photos are infrared.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Catholic University (1953)

Area and type cover:

Northern Wisconsin. Included were marshlands, lowlands, brush, swamp hardwoods, aspen, white birch, northern hardwood, scrub oak, Jack pine and white pine.

Photo data:

Scales used were 1:17,000 and 1:15,840. The photos were obtained using infrared with minus blue filter.

Key basis:

The report covers a key for identifying the kinds of vegetation from stereo-infrared photographs. The key is based on indicator plants (table presented in the introduction).

Comments:

Individual species were not "keyed out" in the key text. The key refers to illustrations appearing as plates in Part IV. Relationships between tree height and crown diameter to stem size are shown. The keys are well documented. Some work by Edward Stergerwaldt also included.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Catholic University (1953)

Area type and cover:

Chesapeake Bay, Maryland.

Photo data:

Panchromatic air photos at a scale of 1:17,000 were obtained. Some ground photos were also obtained.

Key basis:

The report presents an experimental system of keys for the interpretation of vegetation using aerial photographs. The method is presented in two technical reports. The first study includes keys developed for six seasons based on species identification. The second report stresses land forms and related vegetation.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS-ELEMINATION TYPE

Source: Catholic University (1953)

Area and type cover:

The report covers drainage basins of the Albany and Attawapiskat rivers, James Bay. Included are three general conditions - dry river banks, wet forests and/or swamps, and marshes. Species included black spruce, aspen, cottenwood, white spruce, fireweed, grasses, willow, alder, northern scrubpine, and general muskeg complexes.

Photo data:

This study was performed using 1:40,000 RCAF photos (panchromatic).

Key basis:

The report covers development of a key for recognizing vegetative types on small-scale photos, as applied to low lands in the Sub-arctic.

Comments:

Examples include low altitude obliques. Personal observations are noted. Comments are made about soil moisture and trafficability conditions.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Schultz (1951)

Area and type cover:

Val David, Quebec. White pine, white spruce, balsam fir, alders, white birch, aspen, sugar maple.

Photo data:

1:7,200 scale, June photography, 3000 flying altitude. Panchromatic - Kodak aerographic Super XX film, Wratten No. 12 filter (minus-blue) Infrared - Kodak aero infrared - Wratten 89A filter. Color - Kodak Ektachrome Aero Film.

Key Basis:

Two separate keys, one for Infrared, one for Panchromatic and Color film. Stereograms illustrating seven species include panchromatic and infrared photos side by side for viewing comparatively under one stereoscope set-up. No color film illustrations included. Gray tones, tree shapes and site conditions used as identifying features.

Comments:

Key is limited in scope, but the stereograms are of interest as possible method for preparing more extensive keys.

INFORMATION RELATIVE TO KEYS

DICHOTOMOUS - ELIMINATION TYPE

Source: Yuan (1955)

Area and type cover:

Natural forest and bamboo species in Taiwan. Conifers, Tsuga, Abies, Chamaecyparis, Picia, pines, hardwoods, and 4 species of bamboo.

Photo data:

Modified infrared photography, 1:20,000-1:5,000 scale.

Key basis:

Photo tones, crown shape and texture, tree height and topographic site used to identify species. No illustrations.

INFORMATION RELATIVE TO VEGETATION KEYS

DICHOTOMOUS - ELIMINATION AND DESCRIPTIVE

Source: University of Oklahoma (1954)

Area and type cover:

Boreal fringe areas of marsh and swampland represented by four areas in northern Minnesota: Ely, Hubbard, Koochiching, and Itasca. Jack pine, Norway pine, Aspen-Birch, Oak, upland hardwoods, upland brush, lowland hardwoods, Black spruce, Tamarock, lowland brush, white pine, floating bogs, sedge marsh, agricultural, White spruce, balsam fir, marsh, grass, muskeg cedar.

Photo data:

Summer photos: 1:10,000 and 1:15,840, 1:20,000, panchromatic and infrared. Winter photos 1:7,500, panchromatic. Stereopair air photographs supplemented by ground views.

Key basis:

Keys for Summer (foliage) and Winter (non-foliage) seasons for each of the 4 areas. The elimination key to vegetation is preceded by a descriptive key (ground and photo appearance) of the vegetation types found in the area.

Comments:

A 4 volume publication which includes discussion of physical and biological environments, swamps and bogs, transportation and communication in the area as a whole, plus a detailed discussion of these factors for each of the four areas. It is well organized, informative and contains an excellent selection of illustrations. The best vegetation key reviewed.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Stoeckler (1949)

Area and Type cover:

The study was made in Alaska. Included are major types found in each of the physiographic provinces: white spruce - paper birch; muskegs and swamps; tundra types; high brush; and aspen, balsam, birch.

Photo data:

Variety of verticals (USAF) and low altitude obliques. Many ground photos are also included.

Key basis:

The report presents an analytical method of using photos for identifying vegetation from air-photos. Emphasis is placed on relationships between species, soils, moisture, slope, exposure, aspect, permafrost, and position. Numerous illustrations and diagrams are included.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Powers (1953)

Area and type cover:

Montana. This study was limited to landforms in a dry grassland marginal to glaciated plains and includes such physiographic types as upland and valley plains and erosion remnants.

Photo data:

Aerial photos are at a scale of 2 inches to a mile. The report is also illustrated with stereo-ground photos.

Key basis:

This is primarily a landform key with vegetation included as an indicator of soil type, terrain, moisture, etc.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Catholic University (1953)

Area and type cover:

The study was conducted in Luzerne County, Pennsylvania. Species studied included: white oak, scruboak, hemlock, larch, black spruce and other mixed hardwood stands.

Photo data:

The study was conducted using panchromatic photos at a scale of 1:16,400 (reduced from 15,400).

Key basis:

The key consists of photos accompanied by descriptive notes. Types are not "keyed out." There are notes on trafficability conditions.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Catholic University (1953)

Area and type cover:

The study was conducted in Cambria County, Pennsylvania. Species included oak, hemlock, red maple, and elm.

Photo data:

The study was conducted using oblique and vertical panchromatic photos (USDA photos - PMA - 1952) at a scale of 1:17,000 (reduced from 1:15,800).

Key basis:

The report is concerned with terrain interpretation in oak-temperate forests. The key consists of photo examples accompanied by marginal notes.

Comments:

The use of panchromatic film during the fall if stressed.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Catholic University (1953)

Area and cover type:

The study was conducted in Boulder County, Colorado. Species included ponderosa pine, cottonwood, and mountain mahogany.

Photo data:

Studies were performed on panchromatic photos at a scale of 1:15,600 (enlarged from 1:16,600).

Key basis:

The report covers terrain conditions in mixed pine forests and grasslands. The key consists of photos carrying notations accompanied by short text description. Included were such items as ground conditions, water supply, travel, and concealment.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Catholic University..(1953)

Area and type cover:

Maine. A study of the relationship between soil and vegetation in the northern half of the state which is primarily a spruce-fir region.

Photo data:

Scale of 1:15,840. A panchromatic emulsion with a minus blue filter was the preferred combination.

Key basis:

This key uses vegetation (if identifiable on the photo) as an indicator of site or terrain conditions. For example: pure stands of white pine always indicate a minimum of underbrush. No quantitative information is included. The report does contain a thorough discussion of species and/or association and their role as indicators. Also included are comments regarding soils, moisture, underbrush, road building materials and influence of fire and logging. Information provided by H. E. Young.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE - SELECTIVE TYPE

Source: U. S. Army (1944)

Area and type cover:

Tropical Pacific area. Forest types include rain forest, deciduous forest, bamboo groves, mossy forest, pine forest, savanna, grassland, Mangrove, Nipa, Sago, and Casuarina. Cultivated crops include rubber, coco palms, native gardens, abaca and bananas, tea, coffee, sugar cane, paddy rice and other.

Photo data:

Ground and aerial views included. Scale of aerial photos vary from 1:60,000 to 1:2,000.

Key basis:

Vegetation types characteristic of well-drained areas, swampy areas, and sandy beaches, and cultivated crops are four major breakdowns. Aspects of each forest type or species considered are: Distribution, general description, visibility and concealment, movement, ease of clearing, timber and firewood, topography and ground conditions, and identification on aereal photographs. Ground photos illustrate textural material. Aerial photos follow.

Comments:

Discussion of common terrain conditions in relation to vegetation is brief. Most discussion is in general terms. The U. S. Navy "Pacific Landforms and Vegetation" is probably easier to use.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: Francis and Wood (1955)

Area and type cover:

North Borneo - Sixteen vegetation types in six groups
Salt Water Swamp: Mangrove, Nipa-Palm, mixed coastal forest.
Transitional forest: Casuarina fringe, nibong, coastal padang and other beach vegetation.
Inland forest, drained: Large crowned dipterocarps, mixed (or medium) crown, small crown, montane forest and similar growth.
Inland forest, liable to flood: Large crown, mixed crown, small crown.
Cultivation: Estates and permanent native cultivation, shifting cultivation and associated second growth.
Cleared land: Herbaceous growth and Lalang, drained, and herbaceous growth, liable to flood.

Photo data:

RAF 1:30,000 to 1:25,000 taken over a seven-year period.

Key basis:

Each vegetation type described. Factors included in description are location, site, soil and water conditions, areal extent, and economic uses. Conditions seldom permit good photo flying weather so photos vary in quality. The 16 vegetation types can be detailed only on high quality photos. There is no detailed knowledge of the composition of the mixed coastal forest.

Comments:

Report includes only a few illustrations.

INFORMATION RELATIVE TO VEGETATION KEYS

DESCRIPTIVE

Source: U. S. Naval Photographic Interpretation Center (1950)

Area and type cover:

Alaska - Muskeg and marsh in Taiga areas, and Tundra in true arctic areas.

Photo data:

Not given.

Key basis:

Discussion of vegetation as it indicates or reflects permafrost conditions. Vegetation cover-type table (page 34) is adapted from Stoeckler (1949).

Comments:

Primary purpose of report is analysis of frozen ground. Vegetation is included as one of the factors which can be used to analyze frozen ground conditions from aerial photos.

INFORMATION RELATIVE TO VEGETATION KEYS

STEREOGRAMS

Source: Moessner (1949-4)

Area and type cover:

The study was performed in the Central Hardwood Region (unglaciated) of Illinois, Kentucky, Ohio, and Missouri. Included were upland hardwoods and bottomland hardwoods.

Photo data:

The original photography consisted of 1:20,000 photo scale. Pictures were enlarged to 1:15,800 scale.

Key basis:

The report presents stereo-grams illustrating forest sites. The forest types are based on topographic site and soil factors. Each stereogram is accompanied by such data as forest type, soil, location, date, scale, and parallax. Profiles showing vegetation and topography are included. Certain relationships between soils, vegetation species and drainage are discussed. The quality is good.

INFORMATION RELATIVE TO VEGETATION KEYS

STEREOGRAMS

Source: Moessner (1956-2)

Area type and cover:

The study was conducted in the White River and Arapaho National Forests of Colorado. Included were major commercial species, sizes, and size classes.

Photo data:

Two scales were used:

(a) 1:18,000
(b) 1:23,000

Key basis:

The key is built around combined vertical and horizontal stereo-pairs. The stereo-pairs are arranged such that both air and ground views can be studied from same stereoscope set up. Each Illustration includes photogrammetric data and physical description of the forest. Included are date, elevation, location, scale, FL, and base. Vegetation data includes species, class, height, crown diameter, DBH, crown cover, slope, undergrowth and any other site data.

INFORMATION RELATIVE TO VEGETATION KEYS

STEREOGRAMS

Source: Moessner (1958)

Area and type cover:

(a) Idaho: (Boise Experimental Forest)
(b) Colorado: (San Juan Forest)
(c) South Dakota: (Black Hills)
Ponderosa Pine

Photo data:

(a) 1:20,000 to 1:4,300
(b) & (c) 1:20,000 (variable)

Key basis:

39 combined vertical and horizontal stereograms, each of which includes photo data, location, including elevation, brief description, and indication of soil, site and age class.

Comments:

Similar to Moessner (1956-2).

BIBLIOGRAPHY

Aldrich, R. C. (1953) Accuracy of land-use classification and area estimates using aerial photographs, Journal of Forestry, vol. 51, no. 1, p. 12-15.

_______________ (1955) A method of plotting a dot grid on aerial photographs of mountainous terrain, Journal of Forestry, vol. 53, no. 12, p. 910-913.

American Society of Photogrammetry (1952) Manual of photogrammetry, Washington, D. C., American Society of Photogrammetry, 876 p.

Andrews, G. S. (1940) Notes on interpretation of vertical air photographs, Forestry Chronicle, vol. 16, no. 3, p. 202-215.

_______________ (1948) Air survey and photogrammetry in British Columbia, Photogrammetric Engineering, vol. 14, no. 1, p. 134-153.

Arnold, R. R. Captain (1941) Military uses of aerial photography, Photogrammetric Engineering, vol. 7, no. 1, p. 90-95.

Austin, Robert M. (1948) Aerial war against cereal crop disease, Industrial Photography, August 1958, p. 38-40.

Avery, Gene (1957) Forester's guide to aerial photo interpretation, Southern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Occasional Paper 156, 41 p.

Bateson, Allan R. (1952) A test of aerial photography for forest inventory purposes in the Tennessee Valley, Tennessee Valley Authority, Forest Investigation Branch Report No. 205-52, 34 p.

Benninghoff, W. S. (1950) Use of aerial photographs in mapping vegetation and superficial geology in subarctic regions, Photogrammetric Engineering, vol. 16, no. 3, p. 428-429.

_______________ (1953) Use of aerial photographs for terrain interpretation based on field mapping, Photogrammetric Engineering, vol. 19, no. 3, p. 487-490.

Bickford, C. Allen (1952) The sampling design used in the forest survey of the northeast, Journal of Forestry, vol. 50, p. 290-293.

_______________ (1953) Increasing the efficiency of airphoto forest surveys by better definition of classes, Upper Darby, Pennsylvania, Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Station Paper No. 58, 9 p.

——— (1953) Use of aerial photographs in estimating forest drain, Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Upper Darby, Pennsylvania, Station Paper No. 59, 10 p.

Billings, W. D., and Morris, R. J. (1951) Reflection of visible and infrared radiation from leaves of different ecological groups, American Journal of Botany, vol. 38, p. 327-331.

Black, Lloyd D. (1955) Regional keys are valid geographical generalizations, Photogrammetric Engineering, vol. 21, no. 5, p. 706-708.

Black, R. F. (1952) Polygonal patterns and ground conditions from aerial photographs, Photogrammetric Engineering, vol. 18, no. 2, p. 123-234.

Bradshaw, K. E. (1955) Engineering uses of soil-vegetation survey data, California Forest and Range Experiment Station, Forest Service U. S. Department of Agriculture, Berkeley, California, 1955 Station Investigative Meeting, 3 p.

Broadview Research and Development (1957) Quantitative evaluation of photo interpretation keys. Appendices, Broadview Research and Development, Burlingame, California, Final Report, N.P.

Brunnschweiler, Dieter H. (1957) Seasonal changes of the agricultural pattern: A study in comparative airphoto interpretation, Photogrammetric Engineering, vol. 23, no. 1, p. 131-139.

Brunson, F. Dean, and Jensen, Chester E. (1951) Controlled sampling for aerial photo timber cruises, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Station Notes No. 66, 3 p.

Burks, G. F. and Wilson, R. C. (1939) A vegetation inventory from aerial photographs, Photogrammetric Engineering, vol. 5, no. 1, p. 30-42.

Burwell, Robert W. (1942) Application of photogrammetry to forestry, Photogrammetric Engineering, vol. 8, no. 1, p. 18-21.

California Forest and Range Experiment Station (1956) Kinds of maps, legends, and reports, California cooperative soil-vegetation survey, Forest Service, U. S. Department of Agriculture, Berkeley, California, 6 p.

Carow, John (1955) The use of aerial photographs in Lake States forestry. Forest Photo Interpretation, Portland, Oregon, K. R. Wood & Associates, Inc., p. 79-83.

Catholic University of America (1953) Investigation of methods of determining terrain conditions by interpretation of vegetation from aerial photography, Prepared at the Arctic Institute of Catholic University, Washington, D. C. under the direction of Dr. Hugh T. O'Neill, Office of Naval Research Contract No. N6-onr-23504, V.F., Technical Report Number 6 in four (4) parts as follows: Part I - General Principles of Interpretation of Vegetation from Air Photographs and Their Incorporation into Keys. Part II - Interpretation of Vegetation from Air Photographs of the Chesapeake Bay, A Type of Inland Shores. Part III - Interpretation of Vegetation from Air Photographs of the Arctic and Subarctic Regions. Part IV - Terrain Conditions Deducible from Air Photographs of the "Near Subarctic": Maine, Wisconsin, Colorado and Pennsylvania.

Chapman, V. J. (1947) The application of aerial photography to ecology as exemplified by the natural vegetation of Ceylon, Indian Forester, vol. 73, no. 7, p. 287-314.

Chase, Clarence D., and Spurr, Stephen H. (1955) Photo-interpretation aids, Lake States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, St. Paul, Minnesota, Miscellaneous Report No. 38, 13 p.

Choate, Grover A. (1957) A selected annotated bibliography of aerial photo interpretation keys to forests and other natural vegetation, Journal of Forestry, vol. 55, no. 7, p. 513-515.

Clark, Walter (1946) Photographic materials for aerial photography, Photogrammetric Engineering, vol. 12, no. 2, p. 151-161.

Clark, Walter (1946) Photography by infrared. New York: John Wiley and Sons, Inc.

Cochran, Patrick C. K. (1931) Aerial reconnaissance mapping in northern Rhodesia, Geographical Review, vol. 21, no. 2, p. 213-220.

Colwell, Robert N. (1946) The estimation of ground conditions from aerial photographic interpretation of vegetation types, Photogrammetric Engineering, vol. 12, p. 151-161.

__________ (1948) Aerial photographic interpretation of vegetation for military purposes, Photogrammetric Engineering, vol. 14, p. 472-481.

__________ (1950) New techniques for interpreting aerial color photography, Journal of Forestry, vol. 48, p. 204-205.

__________ (1952) Relationships between military and forest photo interpretation, Journal of Forestry, vol. 50, p. 271-276.

__________ (1953) Aerial photographic interpretation of vegetation as an aid to the estimation of terrain conditions, Committee on Geophysics and Geography, Research and Development Board, Washington, D. C., Selected Papers on Photogeology and Photo Interpretation, p. 109-135.

__________ (1953) Procedure for the construction of photo interpretation keys, Committee on Geophysics and Geography, Research and Development Board, Washington, D. C., Selected Papers on Photogeology and Photo Interpretation, p. 135-154.

__________ (1954) A systematic analysis of some factors affecting photographic interpretation, Photogrammetric Engineering, vol. 20, p. 433-454.

__________ (1955) The P I picture in 1955, Photogrammetric Engineering, vol. 21, no. 5, p. 720-724.

__________ (1955) Some basic considerations in forest photogrammetry and photo interpretation, Forest Photo Interpretation, Portland, Oregon, K. B. Wood and Associates, Inc., p. 18-32.

__________ (1955) Some uses of three dimensional models for illustrating photogrammetric principles, Photogrammetric Engineering, vol. 21, no. 4, p. 491-510.

__________ (1956) Determining the prevalence of certain cereal crop diseases by means of aerial photography, California Agricultural Experiment Station, Berkeley, California, Hilgardia, vol. 26, no. 5, p. 223-286.

Cromer, D. A. N., and Aitken, J. D. (1948) An aerial inventory of Norfolk Island pine, Forestry Abstract, vol. 11, p. 15-30.

De Laubenfels, David J. (1957) The status of "Conifers" in vegetation classifications, Annals of the Association of American Geographers, vol. 47, no. 2, p. 145-149.

Department of the Army (1954) Photographic interpretation handbook, Washington, D. C: Government Printing Office, Technical Manual 30-245, 303 p.

Dodge, H. E. (1954) Compilation procedure for mapping evergreen timber areas of the Northwestern United States by multiplex plotting equipment, Photogrammetric Engineering, vol. 20, p. 796-802.

Elias, M. M. (1953) The use of air photos for terrain interpretation at long range, Photogrammetric Engineering, vol. 19, no. 3, p. 474-477.

Ferree, M. J. (1953) A method of estimating timber volumes from aerial photographs, College of Forestry, Syracuse State University of New York, Technical Publication 75, 50 p.

535th Engineer Detachment, Corps of Engineers, U. S. Army (1956) Terrain study of Hunter Liggett Military Reservation, Camp Roberts, and Hearst Estate, Army Map Service, Washington 25, D. C., Text & Map.

Forest Service (N.D.) Field instructions for forest inventory, Intermountain Forest & Range Experiment Station, U. S. Department of Agriculture, Rocky Mountain Area, Ogden, Utah, 120 p.

Francis, E. C. and Wood C. H. S. (1955) Classification of vegetation in North Borneo from aerial photographs, Malayan Forester, vol. 18, no. 1, p. 38-44 (Kuala Lumpur, Malaya)

Frost, Robert E. (1953) Factors limiting the use of aerial photographs for analysis of soil and terrain, Photogrammetric Engineering, vol. 19, no. 3, p. 427-436.

Gardner, Robert A. (1955) Interpretation of soil-vegetation survey data, California Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Berkeley, California, 1955 Investigative Meeting, 6 p.

Gardner, Robert A. and Wieslander, A. E. (1957) The soil - vegetation survey in California, Soil Science Society of America Procedings, vol. 21, no. 1, p. 103-105.

Garrard, C. William (1951) An annotated bibliography of aerial photographic applications to forestry, Syracuse State University of New York, College of Forestry Bulletin No. 26, 88 p.

Garver, Raymond D. (1953) Aerial photo interpretation by the Forest Service, Photogrammetric Engineering, vol. 19, no. 1, p. 117-120.

____________ (1949) Picturing forest from the air, Trees, Yearbook of Agriculture, U. S. Department of Agriculture, Washington, D. C., p. 679-682.

Garver, R. D., and Moessner K. E. (1949) Forest Service use of aerial photographs, Photogrammetric Engineering, vol. 15, no. 4, p. 504-517.

Gates, D. M., and Tantraporn, W. (1952) The reflectivity of deciduous trees and herbaceous plants to the infrared to 25 microns, Science vol. 115, p. 2297.

Ghani, Z. (1955) Estimating timber volumes from aerial photographs, The Pakistan Journal of Forestry, vol. 5, p. 74-83.

Gingrich, S. F., and Meyer, H. A. (1955) Construction of an aerial stand volume table for Upland Oaks, Forest Science, vol. 1, p. 140-147.

Goodfellow, M. J. (1955) Seasonality as a factor in the use of aerial photographs for geographic purposes, Clark University, Worcester, Massachusetts, Unpublished MA Thesis.

Goodman, M. S. (1954) The aerial identification of farm crops in northern Illinois, Northwestern University, Evanston, Illinois, PhD Dissertation, p. 210.

Goodspeed, Allen W. (1949) Tree height determination from aerial photographs in Iowa, Ames Forester, 1949, p. 23-30.

Gorrie, R. M. (1953) Aerial photography as an aid in planning improved land use and flood control, World Crops, vol. 5, no. 10, p. 405-408.

Gutkind, E. A. (1952) Our world from the air. Garden City, New York: Doubleday and Company, Inc., photos.

Guyer, Joseph A., and Waldron, Vincent G. (1956) Photo interpretation techniques, a bibliography, Washington, D. C., Library of Congress, Technical Information Division, 162 p.

Halliday, W. E. D. (1937) A forest classification of Canada, Canada Department of Mines and Resources, Forest Service Bulletin No. 89.

Hardy, W. C. (1956) Air photo overlays, Forestry Branch, Department of Northern Affairs and National Resources, Canada, Forest Research Division Technical Note No. 46, 9 p. and figures.

Hartman, Fred J. (1947) A simplified method for locating sample plots on aerial photographs, Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Station Note No. 3, 3 p.

Heath, Gordon R. (1953) Simple devices aid use of aerial photographs, Journal of Forestry, vol. 51, p. 125-127.

__________ (1955) An associative method of regional photo-interpretation, Photogrammetric Engineering, vol. 21, p. 589-598.

__________ (1957) Correlations between man's activity and his environment which may be analyzed by photo interpretation, Photogrammetric Engineering, vol. 23, no. 1, p. 108-114.

Heinsdijk, D. (1955) Forest type mapping with the help of aerial photographs in the tropics, Tropical Woods, no. 102, p. 27-46.

Hesselmann, H. (1939) A map of Swedens beech forest distribution based on aerial reconnaissance, Geografiska Annaler, vol. 21, p. 77-87.

Hixon, H. J. (1950) The use of aerial photographs in timber cruising on the National Forests, Photogrammetric Engineering, vol. 16, p. 317-321.

Hollerwager, F. (1954) Is there a correlation in the Teak forests between crown diameter and the height of the trees with regard to the diameter at breast height, Journal of Scientific Research, Djakarta, Indonesia, vol. 3, no. 1, p. 3-20.

Howlett, L. E., and Carman, P. D. (1949) Photography for forestry purposes, Division of Physics, National Research Council of Canada, Ottawa, Canada, NRC No. 1907, 5 p.

Hutchison, O. Keith (1948) Aerial photo alignment guide, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Station Notes No. 50, 2 p.

Ives, R. L. (1939) Infrared photography as an aid in ecological surveys, Ecology, vol. 20, p. 433-439.

Jenkins, D. W. (1945) Use of the airplane in vegetation surveys, Ecology, vol. 26, p. 413-414.

Jensen, Chester, E. (1948) Dot-type scale for measuring tree-crown diameters on aerial photographs, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Station Notes No. 48, 1 p.

Jensen, H. A., and Colwell, R. N. (1947) A system for classifying vegetation in California, California Fish and Game, vol. 33, p. 199-266.

__________ (1949) Panchromatic versus infrared minus-blue aerial photography for forestry purposes in California, Photogrammetric Engineering, vol. 15, no. 2, p. 201-223.

Johnson, Evert W. (1958) Effect of photographic scale on precision of individual tree height measurement, Photogrammetric Engineering, vol. 14, no. 1, p. 142-152.

__________ (1954) "Shadow-Height" computations made easier, Journal of Forestry, vol. 52, no. 6, p. 438-442.

Johnson, Floyd A. (1949) Sampling for estimates of timber volume on large areas, Timberman, vol. 50, no. 8, p. 60 & f.

__________ (1949) Statistical aspects of timber volume sampling in the Pacific Northwest, Journal of Forestry, vol. 47, p. 292-295.

__________ (1952) Aerial photographs - an efficient tool in management plan surveys, Journal of Forestry, vol. 48, p. 340-342.

Kelsh, Harry T. (1943) Hunting rubber from the air, Photogrammetric Engineering, vol. 9, no. 4, p. 202-210.

King, J. E. (1953) Forest Service procedure of utilizing high and low altitude photography in its companion-instrument photogrammetric procedure, Photogrammetric Engineering, vol. 19, no. 1, p. 88-97.

Kummer, Ray (1955) Growth and yield study methods of immature timber, Forest Photo Interpretation, Portland, Oregon, K. B. Wood and Associates, Inc., p. 113-115.

Landis, Glenn (1955) Concept and validity of association photographic interpretation keys in regional analysis, Photogrammetric Engineering, vol, 21, no. 5, p. 705-706.

Landis, G. H., and Meyer, H. A. (1954) The accuracy of scale determination on aerial photographs, Journal of Forestry, vol. 52, p. 863-864.

Lindskog, L. (1953) Airphotos as aids in certain civilian activities, Svensk Lantmateridskrift. Sweden.

Losee, S. T. B. (1949) Some aspects of inventory surveys from aerial photographs, Forest Chronicle, vol. 25, p. 250-256.

____________ (1951) Photographic tones in forest interpretation, Photogrammetric Engineering, vol. 17, p. 785-799.

____________ (1952) Application of photogrammetry to forestry, in Canada, Photogrammetric Engineering, vol. 18, p. 742-762.

____________ (1953) Timber estimates from large scale photographs, Photogrammetric Engineering, vol. 19, p. 752-762.

____________ (1955) Forest inventory in Eastern Canada, Forest Photo Interpretation, Portland, Oregon, K. B. Wood & Associates, Inc., p. 53-72.

Lueder, D. R., and Huntor, Keeneth E. (1958) Aerial photos in color: Two views of their worth, Engineering News-Record, vol. 160, no. 15, p. 34-35.

MacAndrews, F. D. (1955) Average height weighted by volume in airphoto interpretation, Forestry Branch, Department of Northern Affairs and National Resources, Ottawa, Canada, Forest Research Division Technical Note No. 17, p. 11.

McCurdy, P. G. (1947) Manual of coastal delineation from aerial photographs, Hydrographic Office, U. S. Navy, Washington, D. C., Publication No. 592, 143 p.

McLarran, James H. (1954) Soil-materials interpretation from airphotos in the Northwest, State College of Washington, Pullman, Washington, Number 224, Bulletin of the Washington State Institute of Technology, 9 p.

Mason, Bartell, Jr. (1955) A resource survey in tropical hardwoods, Forest Photo Interpretation, Portland, Oregon, K. B. Wood and Associates, Inc., p. 104-112.

Massie, E. S. (1940) Forest Service planimetric maps, Photogrammetric Engineering, vol. 6, no. 4, p. 151-155.

Maynard, Paul (1955) Validity of PI keys in the interpretation of industry, Photogrammetric Engineering, vol. 21, no. 5, p. 714-716.

Meyer, Merle P. (1955) Photogrammetric training for the technical forester, Photogrammetric Engineering, vol. 21, no. 5, p. 746-750.

__________ (1957) A preliminary study of the influence of photo paper characteristics upon stereo image perception, Photogrammetric Engineering, vol. 23, no. 1, p. 149-155.

Meyer, Merle P., and Trantow, Louis H. (1957) Some observed effects of variations in photo paper emulsion and tone upon stereo perception of tree crowns, Photogrammetric Engineering, vol. 23, no. 5, p. 896-899.

Meyer, H. A., and Worley, D. P. (1957) Volume determinations from aerial stand volume tables and their accuracy, Journal of Forestry, vol. 55, no. 5, p. 368-372.

Mignery, Arnold L. (1951) Use of low-altitude continuous-strip aerial photography in forestry, Southern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Occasional Paper 118, 19 p.

Minor, C. O. (1951) Stem-crown diameter relations in Southern Pine, Journal of Forestry, vol. 49, p. 490-493.

__________ (1953) Preliminary volume tables for use with aerial photographs, Forestry Farmer, vol. 12, no. 10, p. 9-11.

Moessner, Karl E. (1948) Photo classification of forest sites, Proceedings - Society of American Foresters, 1948, p. 278-291.

__________ (1949) A crown density scale for photo interpreters, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 52, 1 p.

__________ (1949) An improved mounting for field stereoscopes, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 54, 1 p.

_______________ (1949) A percent slope scale for photo interpreters, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 53, 1 p.

_______________ (1949) Stereograms illustrating forest sites, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Miscellaneous Release No. 4.

_______________ (1950) Principle uses of air photos by the Forest Service, Photogrammetric Engineering, vol. 16, p. 301-304.

_______________ (1950) A stereogram for training in the use of parallax wedge, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 60, 2 p.

_______________ (1953) An aerial photo scale - protractor, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 74, 2 p.

_______________ (1953) Photo interpretation in forest inventories, Photogrammetric Engineering, vol. 19, p. 496-507.

_______________ (1954) A simple test for stereoscopic percipation, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Technical Paper No. 114, 14 p. (Also Photogrammetric Engineering, vol. 21, no. 3, p. 331-339).

_______________ (1955) The accuracy of stand-height measurements on aerial photos in the rocky mountains, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Odged, Utah, Research Note No. 25, 5 p.

_______________ (1956) Aerial photo scale protractors for mountainous areas, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Research Note No. 40, 7 p.

_______________ (1956) Combined vertical and horizontal stereograms, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Note No. 36, 3 p.

_______________ (1956) A parallax wedge for mountainous areas, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Note No. 39, 1 p.

_______ (1957) Frosted templates aid the photo interpreter, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Note No. 41, 2 p.

_______ (1957) How important is relief in area estimates from dot sampling on aerial photos? Forest Service, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Paper No. 42, 16 p.

_______ (1957) Preliminary aerial volume tables for conifer stands in the Rocky Mountains, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Research Paper 41, 17 p.

_______ (1957) Relation of minimum area standards to proportions obtained by dot samples of aerial photos, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Research Paper No. 44, 13 p.

Moessner, Karl E., and Rogers, Earl J. (1957) Timber cruising on aerial photos, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Technical Paper No. 126, 27 p.

_______ (1957) Parallax wedge procedures in forest surveys, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Miscellaneous Publication No. 15, 22 p.

Moessner, Karl E., Brunson, Forrest D, and Jensen, Chester E. (1950) The accuracy of stand-height measurements on air photos, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Station Notes No. 59, 2 p.

_______ (1951) Aerial volume tables for hardwood stands in the Central States, Central States Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbus, Ohio, Technical Paper No. 122, 15 p.

Moiseev, V. S. (1955) Aerial photo interpretation and aerial appraisal of forests, Forest Service, U. S. Department of Agriculture, Washington, D. C., translated from Lesnoe Khoziaistvo No. 8, 20-27 p., 10 p. (mimeographed).

Nash, A. J. (1948) The Nash scale for measuring tree crown widths, Forestry Chronicle, vol. 24, p. 117-120.

_______ (1948) A photoelectric planimeter, Surveying and Mapping, vol. 8, no. 2, p. 64-69.

_______ (1948) Some volume tables for use in air survey, Forestry Chronicle, vol. 24, p. 4-14.

_______ (1949) Some tests on the determination of tree heights from air photographs, Forests and Scientific Services Branch, Department of Mines and Resources, Dominion Forest Services, Ottawa, Canada, Forest Air Survey Publication No. 5, 9 p., bibliography.

Nelson, Robert E., and Bradshaw, Kenneth E. (1954) Photo interpretation of vegetation and soils in California, Paper presented at Annual Meeting of Northern California Section, American Society of Photogrammetry, San Francisco, California, 6 p., mimeographed.

Nelson, R. E., Bradshaw, K. E., and Wieslander, A. E. (1957) Photo interpretation of vegetation and soils in wild land areas of California, Soil Science Society of America Proceedings, vol. 21, no. 1, p. 106-108.

Neumann, Christoph (1933-1934) Beitrag zur Vorratsermittlung aus Luftmesserbildern (The contribution made by aerial photography in estimating the volume of standing timber) Zeitschrift fur Weltforstwirtschaft, Band 1, Heft 2/3, 1933 p. 147-158 and Band 1, Heft 4/5, 1934, p. 195-233. Translated by Bernard Feyer, California Forest and Range Experiment Station, Berkeley, California, 1935, 69 p. (Typewritten, unpublished translation)

O'Neill, Hugh T. (1953) Keys for interpreting vegetation from air photographs, Photogrammetric Engineering, vol. 19, p. 422-424.

O'Neill, Hugh T., and Nagel, William (1952) The O'Neill-Nagel non-glare adjustable illumination for stereoscopy, Sub title: Instrumental aids in photo interpretation II, Photogrammetric Engineering, vol. 18, p. 699-701.

Palley, M. N. (1953) The Saskatchewan forest inventory, Forestry Chronicle, vol. 29, p. 251-256.

Parsons, H. E. (1945) Mapping and identifying timber stands by aerial observations, Canadian Lumberman, vol. 65, no. 2, p. 16-18.

Paterson, S. S. (1956) The forest area of the world and its potential productivity, Department of Geography, Royal University of Goteburg, Sweden, 216 p. (Distributed by the author)

Pippin, R. E. (1957) Survey to determine use of and need for photo interpretation keys in the Armed Forces, Confidential - Final Report, Contract AF 30 (602) -1503, Broadview Research and Development, Burlingame, California, Prepared for Rome Air Development Center, Grifiss Air Force Base, Rome, New York, 101 p., Appendix.

Pope, Robert B. (1950) Aerial photo volume tables, Photogrammetric Engineering, vol. 16, p. 325-327.

_______________ (1957) The effect of photo scale on accuracy of forestry measurements, Photogrammetric Engineering, vol. XXIII, no. 5, p. 869-873.

Powers, William E. (1951, revised 1952) A key for the photo identification of glacial landforms and associated landform patterns in the Lake Michigan region and comparable areas, Contract No. N7 onr 45-005, Geography Branch, Earth Science Division, Office of Naval Research, Navy Department, Department of Geography, Northwestern University, Evanston, Illinois, Technical Report No. 2, 84 p. illustrations.

Raup, H. M., and Denney, C. S. (1950) Photo interpretation of the terrain along the southern part of the Alaskan Highway, Department of the Interior, Washington, D. C., U. S. Geological Survey Bulletin 963-D, p. 95-133, maps and photos.

Rayton, W. B. (1938) Future possibilities in aerial photography, Photogrammetric Engineering, vol. 4, no. 4, p. 209-211.

Reed, John C., Jr. (1957) Vegetation studies for military purposes, The Military Engineer, vol. XLIX, no. 332, p. 415-419.

Robinson, J. M. (1947) Air photography and its application to forest inventory, Canadian Lumberman, vol. 67, no. 19, p. 42-44.

_______________ (1948) Tri-camera winter photography cuts forest inventory, Journal of Forestry, vol. 46, p. 643-645.

_______________ (1952) The dot reading overlay for the measurement of map areas, Forestry Branch, Department of Mines and Resources, Ottawa, Canada, Forest Inventories Publication No. 8.

Robinson, M. W. (1947) An instrument to measure forest crown cover, Forestry Chronicle, vol. 23, no. 3, p. 222-223.

Rogers, Earl J. (1942) Aerial photographs in timber estimating, Journal of Forestry, vol. 40, no. 5, p. 430-432.

_______________ (1946) Use of the parallax wedge in measuring tree heights on vertical aerial photographs, Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Forest Survey Note No. 1, 17 p.

_______________ (1949) Estimating tree heights from shadows on vertical aerial photographs, Journal of Forestry, vol. 47, no. 3, p. 182-191. Also - Northeast Forest Experiment Station Station Paper No. 12, December 1947, 16 p.

________ (1949) A short cut for scaling aerial photos, Journal of Forestry, vol. 47, no. 10, p. 819-822.

________ (1952) Large scale airphotos tested in forest survey, prove unsatisfactory, Northeastern Forest Experiment Station, Forest Service, Department of Agriculture, Upper Darby, Pennsylvania, Northeastern Research Notes No. 12, p. 1-3.

________ (1953) A plan for research in fields of aerial photo interpretation, Photogrammetric Engineering, vol. 19, no. 5, p. 801-805.

Ryker, H. C. (1933) Aerial photography: Method of determining timber species, Timberman, vol. 24, no. 5, p. 11-17.

Sammi, J. C. (1953) Limitations on tree height measurements by parallax, Photogrammetric Engineering, vol. 19, p. 617-619.

Samoilovich, G. G. (1955) Identification of trees by aerial photographs and measurement of their dimensions, Forest Service, U. S. Department of Agriculture, Washington, D. C., Translated from Geog. Obshch. Soiuza SSR Geog. Sborn. vol. 5, no. 86103, p. 176-206, 20 p. (mimeographed).

________ (1955) Method of forest inventory by means of interpretation of aerial photographs with reduction of ground appraisal, Forest Service, U. S. Department of Agriculture, Washington, D. C., translated from Geograficheskiy Sbornik, vol. 5, p. 144-154, 14 p. (mimeographed).

________ (1956) Appraisal and interpretation training in forest management, Forest Service, U. S. Department of Agriculture, Washington, D. C., translated from Lesnoe Khozyaistvo, No. 2, 6 p.

Sanders, Revere G. (1941) Military cameras for high speed airplanes, Photogrammetric Engineering, vol. 7, no. 1, p. 60-76.

Savage, Myron B. (1955) Some sampling techniques used in inventory of mature forest stands in the Northwest, Forest Photo Interpretation Portland, Oregon, K. B. Wood and Associates, Inc., p. 36-46. (A collection of Papers Compiled for use of Interpretation Committee of American Society of Photogrammetry)

Schulte, O. W. (1951) The use of panchromatic, infrared and color photography in the study of plant distribution, Photogrammetric Engineering, vol. 17, p. 698-714.

Seely, H. E. (1941) The duoscope - portable mapping instrument, Photogrammetric Engineering, vol. 7, no. 1, p. 18-21.

__________ (1942) Determination of tree heights from shadows in air photographs, Lands, Parks and Forests Branch, Department of Mines and Resources, Dominion Forest Service, Ottawa, Canada, Aerial Forest Survey Research Note No. 1, 10 p.

__________ (1947) Some developments in the use of air photographs for forest surveys, Photogrammetric Engineering, vol. 13, no. 3, p. 443-452.

__________ (1949) Air photography and its application to forestry, Forests and Scientific Services Branch, Department of Mines and Resources, Dominion Forest Service, Ottawa, Canada, Forest Air Survey Publication No. 6, 10 p.

__________ (1955) A forest survey method, Forestry Branch, Forest Research Division, Department of Northern Affairs and National Resources, Canada, Technical Note No. 8, 15 p.

__________ (1957) Forest inventories in Canada, (Report presented to the Seventh British Commonwealth Forestry Conference, held in Australia and New Zealand, 1957), Forestry Branch, Department of Northern Affairs and National Resources, Forest Research Division, Canada, Miscellaneous Publication No. 8, 11 p.

Seymour, Thomas D. (1957) The interpretation of unidentified information: a basic concept, Photogrammetric Engineering, vol. 23, no. 1, p. 115-121.

Sheppard, A. C. T. (1938) What Canada is doing with the aid of camera and aeroplane, Photogrammetric Engineering, vol. IV, no. 1,

Simontacchi, A. A., Choate, G. A., and Bernstein, D. A. (1955) Considerations in the preparation of keys to natural vegetation, Photogrammetric Engineering, vol. 21, p. 582-587.

Sisam, J. W. B. (1947) The use of aerial surveys in forestry and agriculture, Imperial Bureau of Pastures and Field Crops, Imperial Forestry Bureau, Oxford, England, Joint Publication No. 9.

Sloan, Ivan I. (1954) Theory and application of image motion compensation to photogrammetry, Photogrammetric Engineering, vol. 20, no. 5, p. 831-835.

Smith, H. T. U. (1942) Aerial photographs in geomorphic studies, Photogrammetric Engineering, vol. 8, no. 2, p. 129-155.

__________ (1943) Aerial photographs and their applications, New York: D. Appleton - Century Company, 372 p.

__________ (1953) Photo interpretation of terrain, in Selected Papers on Photogeology and Photo Interpretation, Committee on Geophysics and Geography, Research and Development Board, Washington, D. C., p. 7-31 plus 20 figures.

Smith J. Harry G., and Hindley, Earle (1957) Spectrophotometric analysis of foliage of some British Columbia conifers, Photogrammetric Engineering, vol. 23, no. 5, p. 894-895.

Smithers, L. A., and Summers, J. W. (1950) Control of contrast in forest stand photography, Forestry Branch, Department of Resources and Development, Forest Research Division, Canada, Silvicultural Leaflet No. 41, 2 p.

Society of American Foresters (1956) Forestry handbook. New York: The Ronald Press, p. 19-1 - 19-27.

Sonley, G. R. (1946) Interim report on experimental air photography for forest - cover classification, Forestry Chronicle, vol. 22, p. 157-158.

Southern, H. N., and Lewis, W. A. S. (1938) Infrared photograph of Arctic birch forests and fells, Journal of Ecology, vol. 26, p. 328-331.

Spurr, Stephen H. (1945) Parallax wedge measuring devices, Photogrammetric Engineering, vol. 11, no. 2, p. 85-89.

__________ (1946) Volume tables for use with aerial photographs - from a paper presented to the U. S. Forest Service Survey - Timber Management Meeting, Harvard Forest, Petersham, Massachusetts

__________ (1948) Aerial photography, Unasylva, vol. 2, no. 4, p. 183-194.

__________ (1948) Estimating timber from aerial photographs, Sylva, vol. 3, no. 2, p. 3-16.

__________ (1949) Films and filters for forest aerial photography, Photogrammetric Engineering, vol. 15, p. 473-481.

__________ (1952) Forest inventory. New York: The Ronald Press, 442 p.

__________ (1954) History of forest photogrammetry and aerial mapping, Photogrammetric Engineering, vol. 20, no. 3, p. 551-560.

__________ (1954) The Multiscope in retrospect, Photogrammetric Engineering, vol. 20, no. 4, p. 698-99

__________ (1955) History of forest photogrammetry and aerial mapping, Forest Photo Interpretation, Portland, Oregon, K. B. Woods and Associates, Inc., p. 7-17.

__________ (1956) Forest photogrammetry and aerial mapping: A bibliography, Ann Arbor School of Natural Resources, University of Michigan, 60 p.

Spurr, S. H., and Brown, C. T. Jr. (1946) Specifications for aerial photographs used in forest management, Photogrammetric Engineering, vol. 12, no. 2, p. 131-141.

_______________ (1946) Tree height measurements from aerial photographs, Journal of Forestry, vol. 44, no. 10, p. 716-721.

Stanton, Bruce T. (1953) Photogrammetry for practicing foresters and woodland managers, Photogrammetric Engineering, vol. 19, no. 5, p. 805-808.

Steigerwaldt, E. E. (1950) Stereotypes for aerial photo interpreters, Journal of Forestry, vol. 48, p. 693-696.

Stoeckeler, E. G. (1949) Identification and evaluation of Alaskan vegetation from airphotos with reference to soil, moisture, and permafrost conditions, U. S. Army, Corps of Engineers, St. Paul District, A Preliminary Paper, 103 p.

_______________ (1952) Trees of interior Alaska, their significance as soil and permafrost indicators, U. S. Army, Corps of Engineers, St. Paul District, 25 p.

Stoeckler, E. G., and Young, H. E. (1957) Application of airphoto techniques in planning logging road networks, Forestry Department, University of Maine, Orono, Maine, Technical Note No. 44, 4 p.

Stone, Kirk (1948) Aerial photographic interpretation of natural vegetation in the Anchorage area, Alaska, Geographic Review, vol. 38, no. 3, p. 465-474.

Tarkington, R. G. (1953) An aspect of color photography and interpretation, Photogrammetric Engineering, vol. 19, no. 3, p. 418-420.

Thornton, Philip L. (1954) An aid for stereo dot counting on aerial photos, Central States Forest Experiment Station, Forest Service, Department of Agriculture, Columbus, Ohio, Station Notes No. 84, 2 p.

Throbity, H. K. (1950) Use of aerial photographs in the inventory phase of the forest management job, Photogrammetric Engineering, vol. 16, p. 321-324.

Trorey, L. G. (1952) Aerial surveys in forest management in the Pacific Coast Forest Region, Empire Forestry Review, vol. 31, no. 2, p. 99-102.

Truesdell, Page E. (1953) Report of unclassified military terrain studies section, Photogrammetric Engineer, vol. 19, no. 3, p. 468-472.

Tryon, T. C., Hale, G. A., and Young, H. E. (1955) Dot griding airphotos and maps, Photogrammetric Engineering, vol. 21, no. 5, p. 737.

U. S. Air Force, Directorate of Intelligence (1949) Aerial photographic interpretation of Alaskan soils, Headquarters, U. S. Air Force, Washington, D. C., p. 144.

U. S. Air Force Directorate of Intelligence (1950) Review and evaluation of aerial photographic interpretation of vegetation types to military intelligence of arctic and subarctic areas, (Secret) Headquarters, United States Air Force, Washington, D. C., 34 p. Appendices (This publication can be downgraded to Restricted if the appendices are removed.

U. S. Army, Office, Chief of Engineers, Military Intelligence Division, (1944) Photo interpretation of vegetation in the tropical Pacific area and its use as an indicator of kind of ground, Prepared by the U. S. Geological Survey, Military Geology Unit, Washington, D. C., Engineering Notes No. 20, 115 p.

U. S. Naval Photographic Interpretation Center (1950) Aerial photo analysis of permanently frozen ground, Published by Direction of the Chief of the Bureau of Aeronautics, NAVAER 10 - 35 - 362, 71 p.

University of Oklahoma (1954) Boreal fringe areas of marsh and swampland, Office of Naval Research Contract No. Nonr-982(01), Research Institute, University of Oklahoma, Norman, Oklahoma

Technical Report No. 1, A general background study, by Morris, John W., 256 p.

Technical Report No. 2, A photo identification key for the summer (foliage) season, by Meyer, Merle P., 100 p.

Technical Report No. 3, A photo-identification key for the winter (non-foliage) season, by Meyer, Merle P., 87 p.

Technical Report No. 4, Final and summary report, by Morris, John W., 33 p.

Vanatta, G. R. (1936) Filters for separation of living and dead leaves in monochromatic photographs, Journal of Biological Photographers Association, vol. 4, p. 177-191.

Wear, John (1955) Aerial photography in forest insect investigations, Forest Photo Interpretation, Portland, Oregon, K. W. Wood and Associates, Inc., p. 116.

Wear, J. F., and Dilworth, J. R. (1955) Color photos aid salvage of beetle - killed douglas-fir timber as mapping technique is developed, The Lumberman 3 p. (Reprint).

Wear, J. F., and Lauterbach, P. G. (1955) Color photographs useful in evaluating mortality of Douglas-fir, Proceedings, Society of American Foresters Meetings, p. 169-171.

Wainer, Hank (1955) The mechanical aspect of photo interpretation keys, Photogrammetric Engineering, vol. 21, no. 5, p. 708-711.

Whitmore, Frank C. (1955) Manpower for military photo interpretation of terrain, Photogrammetric Engineering, vol. 21, no. 5, p. 717-719.

Wieslander, A. E., and Wilson, R. C. (1942) Classifying forest and other vegetation from air photographs, Photogrammetric Engineering, vol. 8, no. 3, p. 203-215.

Wilcox, F. R. (1940) Possibilities of stratosphere and substratosphere photography in the administration of forest lands, Photogrammetric Engineering, vol. 6, no. 4, p. 156-159.

__________ (1940) The use of aerial photographs and aircraft in woods operations, Photogrammetric Engineering, vol. 6, no. 3, p. 138-143.

Wilde, S. A. (1956) Forest soils and forest growth. Waltham, Massachusetts: Chronica Botanica Company.

Willingham, J. W. (1957) The indirect determination of forest stand variables from vertical aerial photographs, Photogrammetric Engineering, vol. 23, no. 5, p. 892-893.

Wilson, A. K. (1954) Delineating Ponderosa Pine volume and site quality classes from aerial photographs, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Paper No. 34, 10 p.

Wilson, R. C. (1948) Photo-interpretation aids for timber surveys, Journal of Forestry, vol. 46, p. 41-44.

__________ (1950) Controlled forest inventory by aerial photography, The Timberman, vol. LI, no. 4, 3 p.

Wood, K. B. (1953) Photo interpretation in forestry, Photogrammetric Engineering, vol. 19, no. 3, p. 477-481.

__________ (1954) Forest engineering and photo interpretation, Photogrammetric Engineering, vol. 20, no. 1, p. 134-138.

__________ (1955) A commercial forest survey in Western Yellow Pine, Forest Photo Interpretation, Portland, Oregon, K. B. Wood and Associates, Inc., p. 95-99.

__________ (1955) Forest photo-interpretation. Portland, Oregon: K. B. Wood and Associates, Inc., 116 p.

Worley, David P., and Landis, G. H. (1954) The accuracy of height measurement with parallax instruments on 1:12,000 photos, Photogrammetric Engineering, vol. 20, p. 823-829.

Worley, D. P., and H. A. Meyer (1955) Measurements of crown diameter and crown density (cover) and their accuracy for 1:12,000 photographs, Photogrammetric Engineering, vol. 21, p. 372-375.

Young, Harold E. (1953) Tree counts on air photos in Maine, Photogrammetric Engineering, vol. 19, p. 111-116.

_______________ (1954) Photogrammetric volume determination of huge pulpwood piles, Photogrammetric Engineering, vol. 20, no. 5, p. 808-813.

_______________ (1955) The need for quantitative evaluation of photo interpretation systems, Photogrammetric Engineering, vol. 21, no. 5, p. 712-713.

_______________ (1955) Timberland inventories based on air photos in the Northeast, Forest Photo Interpretation, Portland, Oregon, K. B. Wood & Associates, Inc., p. 73-78.

Young, Harold E., and Wing, Lawrence A. (1953) Use of air photos for location of truck roads and road building materials in Maine, Department of Forestry, University of Maine, Technical Note No. 20, 2 p.

Yuan, H. C. (1955) Key for the photo indentification of natural forest types and bamboo species in Taiwan, Taiwan Land Use and Forest Resource Survey, 2 p. (mimeographed)

Zonnereld, J. I. S., Cohen, A., Eijk, J. J., and Beltman, B. J. (1952) The use of aerial photographs in a tropical country (Surinam), Photogrammetric Engineering, vol. 18, p. 144-168.

ADDITIONS TO BIBLIOGRAPHY

Axelson, Hans (1956) Effect of photo scale on the use of aerial photographs in Swedis forestry, Norlands Skogsvardsforbunds Tidskrift, Stockholm, For AF, p. 255-

Boesch, Hans (1958) Interpretation of aerial photographs, Contract No. DA-91-508-EOC-240, U. S. Army, Office, Chief of Research and Development, Final Technical Report No. 1, 21 p.

Johnson, Evert W. (1957) The limit of parallax perception, Photogrammetric Engineering, vol. 23, no. 5, p. 933-934.

Moessner, Karl E. (1958) Stereograms in Ponderosa pine, Forest Service, U. S. Department of Agriculture, Ogden, Utah, Intermountain Forest and Range Experiment Station Research Note No. 60, 3 p. (39 stereograms available).

Powers, William E. (1953) Photo interpretation of landforms in a dry grassland marginal to glaciated plains, ONR Contract No. N7 onr 45-005, Department of Geography, Northwestern University, Evanston, Illinois, Technical Report No. 5, 88 p.

Spurr, S. H. (1948) Aerial photographs in forestry. New York: Ronald Press Co., 333 p.