EVALUATION OF HIGH-ALTITUDE COLOR INFRARED PHOTOGRAPHY FOR FOREST INVENTORY

by

THOMAS H. KELLEY

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Dr. James F. Lahey

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EVALUATION OF HIGH-ALTITUDE COLOR INFRARED PHOTOGRAPHY FOR FOREST INVENTORY

ABSTRACT. High-altitude color infrared photography is found to be an effective tool for forest inventory in the Umpqua National Forest of southwestern Oregon. Intelligent resource management requires the rapid, accurate, and economical inventory results that can be supplied by remote sensing. Color infrared film is shown to possess properties that make it well suited to high-altitude vegetation studies. U-2 color infrared imagery is used to simulate LANDSAT satellite data preceding its application in the study area. When compared to the U. S. Forest Service timber mapping product obtained from conventional black and white photography in the early 1960s, small scale color infrared displayed results superior or equal in nearly all aspects. However, extensive ground surveys are still required for accurate assessment of stand species composition.

INTRODUCTION

The forested lands of the earth are unquestionably one of man's most vital resources. Worldwide demand for wood products will necessarily rise throughout the remainder of this century. In the United States, Forest Service projections based on rising relative prices for wood products envision a thirty-five percent increase in domestic roundwood apparent consumption between 1972 and 2000.[1] To meet future demands it is imperative that maximum efficiency be implemented in managing forest resources.

Remote Sensing in Forestry

Intelligent resource management involves three phases: inventory, analysis, and operation. Development of fast, accurate, and economical inventory procedures is the logical first step in management intensification. It is here that remote sensing is proving to be most useful by providing essential data on the location of timber species, stand-size classes, stocking densities, and general condition of timber stands to the land manager. If one considers the magnitude of data required to assess the resource potential of a large forested region it becomes apparent that conventional on the ground observations create overwhelming manpower, logistic, and financial problems. Rarely would such an analysis not benefit by the use of vertical aerial photographs.

Foresters were among the first to see the potentialities of black and white aerial photographs to land management applications. Most aerial inventories of forest resources in the U. S. have employed large scale (1:20,000 or larger) panchromatic photography viewed in stereo by the interpreter. Timber stands are stratified directly on the photographs on the basis of size class, crown density, and broad vegetation type, whereas information on volume by species for representative sample plots is most often obtained on the ground by experienced field crews. However, the limited number of distinct tone signatures that can be discerned on black and white photos often restrict their usefulness.

Recent advances in image quality and reduction in costs have made the use of color aerial films more attractive. Numerous studies have demonstrated that color photography can be more effective than black and white for forestry purposes, as features and conditions are represented in a wide range of colors distinct in hue, saturation, and brightness.[2] A newer type of color film gaining acceptance in forestry includes an emulsion layer sensitive to near infrared energy in the 700-900 nanometer spectral range. This color infrared (CIR) film is also referred to as false-color film.

Much has been written in the last decade on forestry applications of large scale color infrared photography; dealing in large part with its advantages for damage detection and evaluation, resulting from forest insects, disease, and air pollution.[3] However, the literature is sadly deficient on the use of small scale color infrared photography for forest inventories. Most of the work accomplished on this topic was conducted during the late 1960s by members of Berkeley's Forestry Remote Sensing Laboratory.[4] These studies analyzed imagery of California forest lands at scales ranging from 1:28,000 to 1:100,000, with findings in accord as to the superiority of color infrared photos over other films. More recent projects have demonstrated the usefulness of ultra small scale (1:120,000-1:160,000) color infrared photography for broad forest classification in Canada and California.[5]

Research Objectives

Conflicting results from remote sensing research throughout the world has revealed the danger in generalizing findings of one region or environment to another. Thus, this paper presents results on the applicability of small scale color infrared photography for mapping timber type classes in the Oregon Cascades. This project was also designed to assess the accuracy of earlier Forest Service classification methods within the study area.

It is envisioned that the timber mapping done here will form a "ground truth" basis for a future LANDSAT classification of the area. Color infrared photography was chosen for this inventory effort as its spectral sensitivity most closely resembles that of the four LANDSAT detector bands. From the final timber map and considerable ground surveying, it will be possible to select training sites for the various surface cover classes. Locating appropriate training sites is essential to establishing the spectral signatures from which a supervised LANDSAT computer classification can be generated.

COLOR INFRARED FILM

Before proceeding to the research methodology and findings, a brief review of the operational characteristics of color infrared film will be presented. This film is composed of three emulsion layers. The top layer is sensitive to the near infrared and visible blue spectral regions and forms a cyan positive image; the middle layer is green-sensitive and forms a yellow positive image; the bottom is red-sensitive and forms a magenta image when processed (Fig. 1).

A normal color film also has three layers, one which is sensitive to blue light, one to green, and one to red. Because of reversal processing during film development, the dye of an emulsion layer does not form if the layer was exposed to radiation to which it is sensitive. Thus for normal color film, objects reflecting only blue radiation will expose the yellow dye layer, leaving the magenta and cyan dyes to combine in a subtractive mixture to form a blue image (Table 1).

With color infrared film, a yellow filter is always used to absorb the blue light before it reaches the film. The same three dyes are used as in normal color film, but for successively longer wavelength regions. Once

Fig. 1. Arrangement of layers and filter for color infrared film.

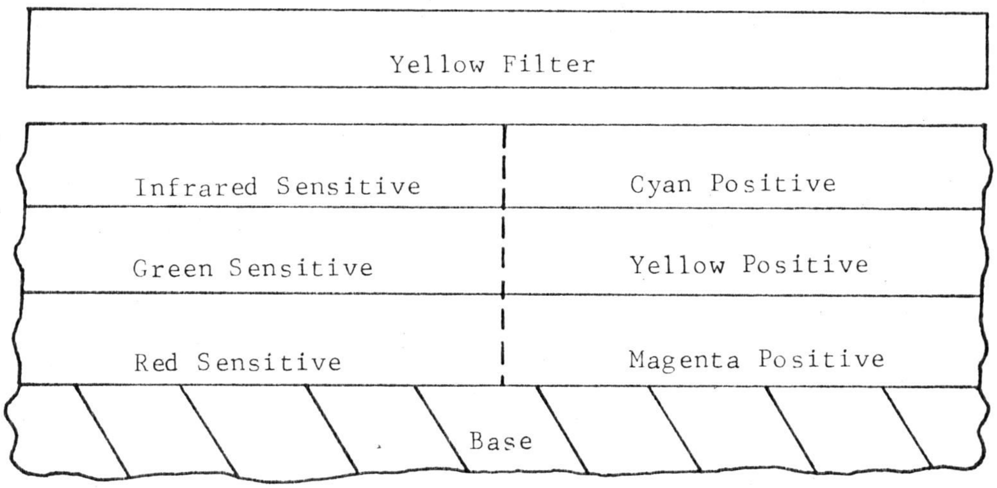

TABLE 1.--PRINCIPLES OF OPERATION OF NORMAL COLOR FILM AND OF KODAK EKTACHROME INFRARED AERO FILM.

spectral region	UV	Blue	Green	Red	IR
color film sensitivity		blue	green	red	
color of dye layer		yellow	magenta	cyan	
resulting color		blue	green	red	
color IR sensitivity		blue	green	red	IR
sensitivity with filter			green	red	IR
color of dye layer			yellow	magenta	cyan
resulting color			blue	green	red

Source: N. L. Fritz, "Optimum Methods for Using Infrared-sensitive Color Films," Photogrammetric Engineering, v.33 (1967), pp.1129.

again processing brings out the colors blue, green, and red, however the blue has resulted from green exposure, green from red wavelengths, and red from infrared exposure (Table 1).

The features of plant leaves which are responsible for the usefulness of this film are their relatively low levels of visible reflectance and high levels of infrared reflectance. Plant leaves reflect a significant amount of green energy and partially expose the yellow layer in addition to near complete exposure of the cyan layer by near infrared reflectance. In this way the magenta and part of the yellow dyes are left intact after film development so that vegetation color varies from magenta to red on the positive image. Most foliage types are not very different from one another in reflectance in the visible region. The high reflectance and great differences between reflectance of foliage in the longer wavelengths explain the value of film sensitive in this range for detecting dissimilarity in foliage condition and species composition (Fig. 2).

Although this high infrared reflectance is a function of internal leaf structure, it has sometimes erroneously been attributed to chlorophyll. In the visible portion of the spectrum, chlorophyll is responsible for high absorption. However, in the near infrared there is no absorption by chlorophyll. As the level of reflectance here is roughly equal for both white and green parts of the leaf, it can be concluded that neither the absence nor the presence of chlorophyll accounts for infrared reflectance.[6]

Most of the incident infrared energy penetrates the leaf cuticle and epidermis and is diffused and scattered within the leaf. This occurs primarily at the cell walls where refractive index differences between air and hydrated cellulose are found.[7] Generally about forty to sixty percent of the near infrared radiation is scattered upward through the leaf surface

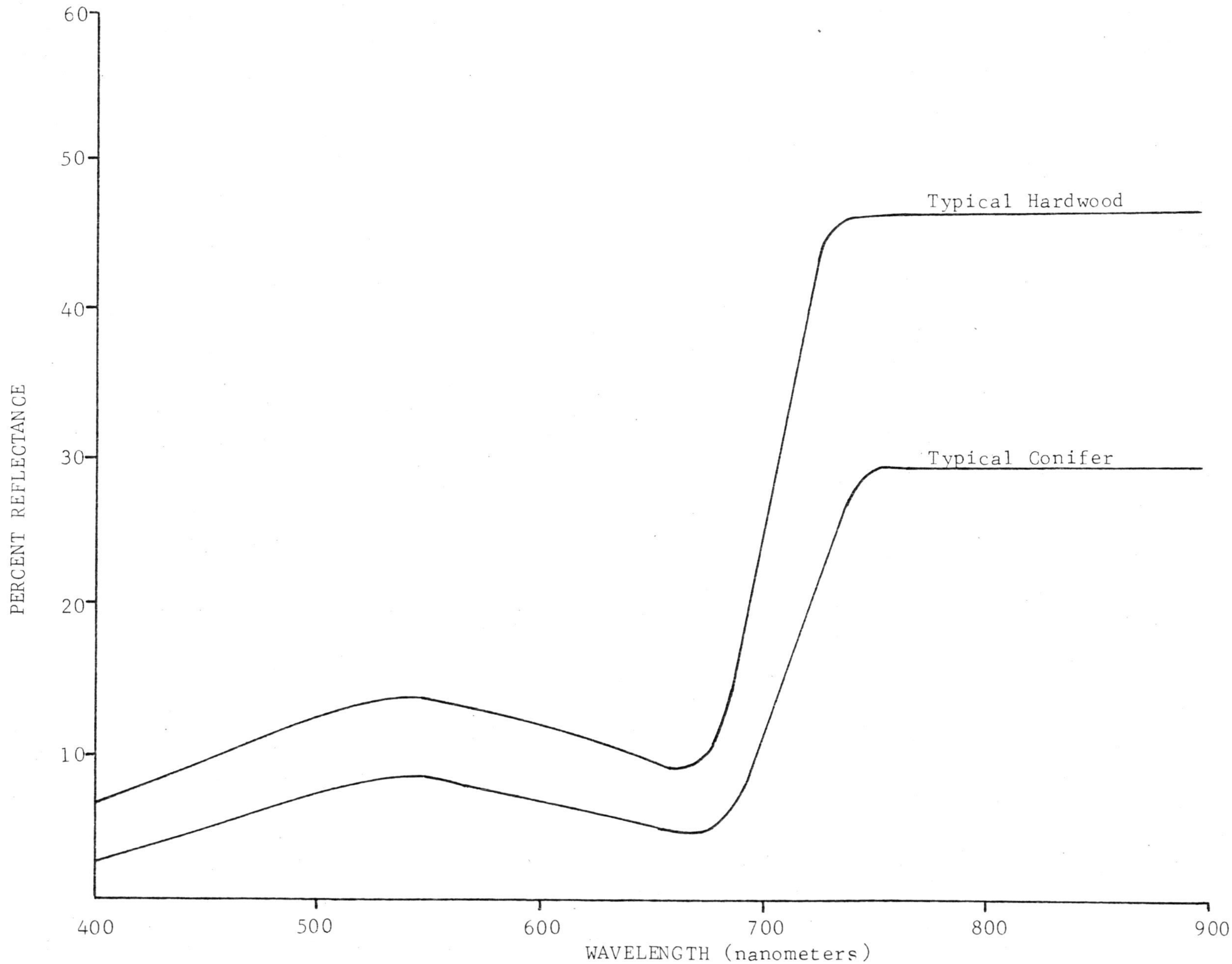

Fig. 2. Generalized spectral reflectance curves indicating higher reflectance and wider range of reflectance in the infrared.

and constitutes what is referred to as reflected infrared radiation.[8]

When compared to black and white or normal color films, three advantages of color infrared film can be noted that render it a most useful medium for high-altitude photointerpretation. First, increased haze penetration as the longer infrared wavelengths are less subject to atmospheric scattering. Second, greater total brightness of vegetation is achieved by the high infrared return from living plants. Third, greater target to background contrast is caused by the higher total percentage of reflectance of foliage within the infrared range.

Although color infrared film appears to combine many of the best features of color and panchromatic media, results from high-alitude aircraft have not always been totally successful. At times the image is predominantly blue or cyan with the infrared reflection barely discernable as dark purplish-brown.[9] From high altitudes, two external factors work against an interpretable red record on color infrared photographs. Water vapor in one atmospheric mass can attenuate penetrating wavelengths between 700 and 900 nanometers as much as twenty percent.[10] In addition, the effect of Rayleigh scattering is still present for wavelengths longer than the 520 nanometer threshold of the film system. The potential of the film for high altitude use can be realized, however, by the use of a system of filters auxiliary to the basic sharp-cutting filters (Wrattens 12 and 15) recommended by the manufacturer.[11]

THE STUDY AREA

The study area for this research consisted of approximately 24,000 hectares of forested land within the Diamond Lake Ranger District of the Umpqua National Forest of southwestern Oregon (Fig. 3). Streams in the

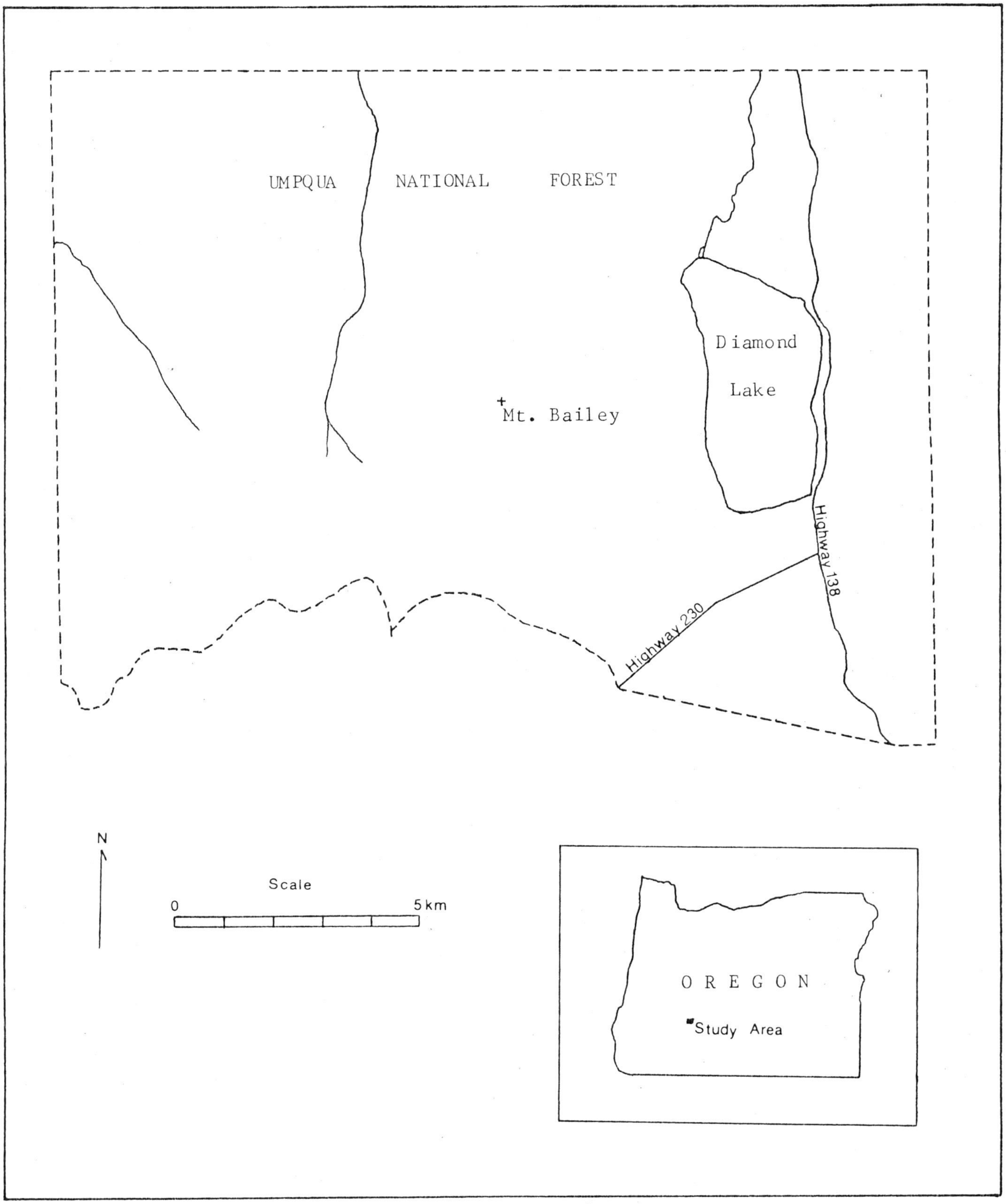

Fig. 3. The study area in Umpqua National Forest.

vicinity form the southeast extension of the North Umpqua River drainage basin.

The terrain within the area falls into two major recognized provinces. The eastern two-thirds representing the High Cascades physiographic region, is generally characterized by rolling terrain interrupted at intervals by glaciated channels and dotted by volcanic peaks and cones. Mount Bailey (2549 meters) represents this type of feature within the study area. The High Cascade Province is geologically young; the most extensive depositions were extruded from volcanic vents during the late Pliocene and Pleistocene epochs. Scattered over the region are younger flows and cones from the upper Pleistocene and Holocene.

The western third of the study area occupies the older and more dissected Western Cascade Province, with its lower elevations but more rugged relief. Here are found volcanic flows and pyroclastics laid down during the Oligocene and Miocene epochs.

This district is marked by the interface of three dominant forest types. The central portion of the study area is dominated by the true fir-mountain hemlock timber complex representing upper elevation species and composed primarily of noble fir (*Abies procera*) and mountain hemlock (*Tsuga mertensiana*) (Table 2). In the east, the principal species is lodgepole pine (*Pinus contorta*), especially south of Diamond Lake. In the extreme north and west, Douglas-fir (*Pseudotsuga menziesii*) is the predominant timber type.

METHODOLOGY

The project began with the acquisition of high-altitude color infrared coverage of the study area. An original print was taken in July, 1974 by

TABLE 2.--TIMBER TYPES AND TREE SPECIES RECOGNIZED WITHIN THE STUDY AREA

Timberland Types	Species Composition
True Fir-Mountain Hemlock	Noble Fir
	Mountain Hemlock
	Pacific Silver Fir
	Alpine Fir
Lodgepole Pine	Lodgepole Pine
Douglas-fir	Douglas-fir
White Fir	White Fir
	Grand Fir
White Pines	Western White Pine
	Whitebark Pine

a U-2 aircraft from an altitude of approximately 20,000 meters at a scale of 1:130,000. From this, an enlargement to roughly 1:30,000 was produced.

A 1961 timber type map of the Diamond Lake Ranger District, Umpqua National Forest at a scale of 1:63,360 was received from the U. S. Forest Service. This map was compiled from black and white 1:12,000 photographs interpreted under a stereoscope. The extent of field checking associated with this mapping effort is uncertain, but those areas adjacent to roads were to be well documented and low flying aircraft were apparently employed to spot check in inaccessible country. For a complete description of type mapping procedures used by the Forest Service, see Appendix.

It should be noted that at the time of this writing the Umpqua National Forest was engaged in a new timber inventory based upon a computer compatible ecoclass system.[12] Under this system, climax ecosystems as well as successional vegetation currently occupying a site will be mapped directly onto 1:15,840 black and white photographs. Each basic mapping designation, or cell, is to be entered in the TRI (Total Resource Information) computer system along with information on elevation, slope, soil type, and past management activities. Forest Service plans call for this data to be readily available for use in management decisions.

The color infrared photointerpretation began with the delineation of forest classes onto an acetate overlay over the 1:30,000 enlargement. Progress was made by marking out the easiest areas and working toward the more difficult. The Forest Service timber type map was used as ground truth to correlate vegetation classes, particularly species identification, to photo characteristics. The entire study area was visually stratified into homogeneous plots on the basis of timberland type, stand-size class, stocking density, and species composition according to a standard commercial forest land classification system (see Appendix). A further component of the analysis involved a more intensive stratification of a several hundred hectare plot in order to assess the full potential of this imagery for detailed forest delineation (Fig. 4).

The completed overlay was then compared with the Forest Service map so that an analysis of the effectiveness of both could be undertaken. A limited number of field checks assisted this portion of the project.

RESULTS

The Photointerpretation

Stratification began on the 1:30,000 color infrared enlargement with the discrimination between forest and nonforest lands. This separation was accomplished very rapidly for the three Forest Service designated noncommercial forest classes recognized within the study area: 1) noncommercial-rocky zones; 2) grass or brush; and 3) nonvegetated lands, here consisting of lakes and urban uses.

The noncommercial-rocky class was characterized primarily as high elevation lands, totally white under a deep snowpack. A further noncommercial class, the subalpine nonmerchantable stands, was generally included within the noncommercial-rocky as unusually heavy snows obliterated most traces of this class on the slopes of Mount Bailey. Below the snowzone, rocky areas were identified by their light blue hue (Fig. 4).

Above the snowline but within the commercial forest, areas of grass and brush were characterized by a white tone, and were distinguished from clearcuts by their more irregular shape. At lower elevations, grass appeared as an even textured bright pink and was easily interpreted as lying below the surrounding forest. Certain plots of grass or brush responded with a grayish-pink hue, apparently due in some degree to a lack of vigor in the vegetation. Any confusion with clearcut land was again resolved on the basis of shape.

Lack of reflection in wavelengths to which this film is sensitive resulted in a distinctive black tone from areas of standing water. Lakes were also characterized by their extremely smooth texture (Fig. 4). The only land classified as urban within the study area was the village of Diamond Lake. It was characterized by bright tones and regular, recognizable patterns.

Within the commercial forest zone, it was necessary to stratify plots on the basis of stand condition, stocking density, stand-size class, and species composition. Condition classes identified were recent clearcuts and residual stands after partial cutting. Clearcut plots were clearly distinguished as rectangular, sharply defined openings in the forest canopy,

Fig. 4. Color infrared photograph showing area of study and smaller section of intensive mapping at 1:130,000. Examples of features described in the text: Noncommercial-rocky (A); Grass or brush (B); Diamond Lake (C); Clearcut (D); Residual stand (E); Well stocked lodgepole pine pole timber (F); True fir-mountain hemlock small sawtimber (G); Douglas-fir large sawtimber (H).

marked by gray to pinkish-gray hues. Unlike grassy fields, individual clear-cuts generally displayed uneven tones and were clearly associated with road location. Residual stands, on the other hand, were largely distinguishable by texture. These plots exhibited a mottled or spotted appearance of numerous unevenly spaced openings in the forest canopy (Fig. 4).

Commercial forest stocking densities as designated by the U. S. Forest Service were divided into three classes: 1) poorly stocked (10-40 percent); 2) medium stocked (40-70 percent); and 3) well stocked (70-100 percent). Color infrared photo determination was based on degree of crown closure--the proportion of area covered by tree crowns. Below the snowzone, textural variation caused by tree crown to ground surface contrast proved quite effective for making this assessment. Shallow snow cover assisted density delineations by intensifying contrast, whereas deep snowpack buried smaller timber in some locations.

Stand-size, as designated by the U. S. Forest Service, was divided into the following four classes by breast high diameters: 1) seedlings and saplings (0-5 inches d.b.h.); 2) pole timber (5-11 inches d.b.h.); 3) small sawtimber (11-21 inches d.b.h.); and 4) large sawtimber (21 inches or larger d.b.h.). Color infrared photo determination was based on crown diameters, assuming trees with the largest crowns have the biggest trunk diameters. Unfortunately, at this scale individual crown diameters were impossible to distinguish for seedlings, saplings, and pole timber. Individual tree crowns were generally visible for the sawtimber classes.

Of prime importance to a forest inventory is identification of timber species. For this study, color infrared hue, in its variety of shades or tones proved to be the principal indicator of species composition. Several earlier studies concluded that spectral reflectance of tree foliage varied more within a particular species than between species.[13] Spectral variation was found to be more a function of a tree's vigor, topographic site, and soil moisture conditions than of its species. Here, it was envisioned that during the interpretation of large timber stands on small scale photographs, stand tone would respond as a composite of individual tree variation with a greater likelihood that this composite tone would be unique for particular species.

At this point, the photo characteristics for each major timber species within the study area will be analyzed. By far the most readily identifiable species encountered was lodgepole pine. This tree occurred primarily in large homogeneous stands as well as in mixtures with the true firs and mountain hemlock. Lodgepole pine was recognized on the color infrared imagery by its distinctive light to dark gray and purplish-gray hues, identifying it where found alone or as an understory (Fig. 4). The western white pine (Pinus monticola), encountered sporadically within the area, exhibited nearly identical tonal characteristics but was separated from lodgepole by its larger crown.

Noble fir and mountain hemlock were found to be the primary constituents of the upper elevation, true fir-mountain hemlock complex. Rarely found in pure stands, these species usually occurred in mixed stands with each other, lodgepole pine, Douglas-fir, and other firs. Both species were characterized by bright red hues in the central portion of the photograph, fading to somewhat duller reds and gray-reds near the edges (Fig. 4). Distinguishing between the two species was based primarily on crown size, as mountain hemlock is a smaller tree with a more narrow, pyramidal crown. In addition, the large sawtimber firs often appeared as a slightly darker purplish-red than did the younger firs and mountain hemlock. To a lesser degree, elevation and exposure were considered, as mountain hemlock is more likely to be found at elevations above 2000 meters and on north exposures.

Two additional fir species were recognized under the true fir-mountain hemlock timberland type. Pacific silver fir (Abies amabilis) and alpine fir (Abies lasiocarpa) were encountered in limited extent within mixed stands. The silver fir was generally associated with noble fir and exhibited a rather bright red hue. The alpine fir was found at higher elevations and was virtually indistinguishable from mountain hemlock with which it associated. The distinctive spirelike crown of this species did not prove helpful for identification on the high-altitude imagery.

Another prominent species, Douglas-fir, was found in homogeneous stands as well as in mixtures with noble fir, mountain hemlock, lodgepole pine, and white fir. It was characterized by hues varying from bright red to purplish-red (Fig. 4). In some situations this tree's broad crown was helpful to identification. In addition its preference to sheltered slopes, canyons, and benches was a factor.

The white fir timberland type is composed of white fir (Abies concolor) and grand fir (Abies grandis). These species were present only in heterogeneous stands, primarily with noble fir and Douglas-fir. This timber type responded on the color infrared with red to dull red hues, similar to noble fir.

Evaluation of the Inventories

It is now desirable to render an assessment of the color infrared photography and of the Forest Service mapping procedures examined. Before continuing it must be pointed out that an objective evaluation of stratification boundaries in a forest environment is often impossible. Few abrupt boundaries exist between one class and another. Instead, a boundary is most often comprised of a continuum in which one forest type gradually blends into another. Thus, more often than not, there are no ground truth boundary lines to work with and evaluations are somewhat subjective. In any event, an investigator who keeps these facts in mind and proceeds with care is capable of a meaningful assessment.

As indicated earlier, this color infrared photography proved excellent for the forest-nonforest discrimination. Results suggest that photographic scales considerably smaller than 1:130,000 as well as satellite data would be effective for such broad delineations. The 1961 Forest Service timber type map was also highly successful for this division, however probability suggests that the addition of hue to the analysis by color infrared film permitted this forest-nonforest stratification to be performed in less time.

Of major importance to this inventory and to a future LANDSAT classification are stand density determinations. Much of the color infrared stratification was based on this feature which was represented by degree of crown closure. Only in the deep snow where numerous trees were partially or totally obscured, was this determination made with low levels of accuracy. General agreement was observed between the color infrared overlay and the Forest Service map on boundary placement between stocking classes. However, areas of marked nonconformity were encountered. For example, a large plot classified by the Forest Service as poorly stocked noble fir sawtimber over an understory of mountain hemlock pole timber, appeared as two distinct plots of obvious density difference on the color infrared enlargement. Several similar examples of clear density changes overlooked in the earlier inventory tend to support the superiority of the smaller scale color infrared.

The practicality of the Forest Service stocking classification system in which ninety percent has arbitrarily been divided into three density classes should be considered. Crown closure is a crude indicator of timber volume; most of these data are generally acquired through on the ground sampling methods. What is required of the aerial survey is information that will directly assist the land manager in decision making. It might be more meaningful for the interpreter to indicate whether stands are overstocked or understocked to a degree that they create special management situations. For example, overstocking would imply that timber density exceeds maximum and is a management problem due to stagnation. Such an approach is currently being adopted by the Forest Service in the Pacific Northwest as part of the aforementioned new ecoclass classification system.

The color infrared proved favorable for distinguishing pine, principally lodgepole, from all other species. Identification was based on the distinctive gray tone and narrow crown. Numerous plots recognized as primarily lodgepole pine on this imagery were classified otherwise on the timber type map. Several of these sites were visited, with the presence of lodgepole confirmed. Even as an understory, the existence of lodgepole pine was quite evident. The distinctiveness of lodgepole often made possible stratification to a much greater level of detail than found on the Forest Service map (Fig. 5). For example, within several sections that had been classified as having no lodgepole pine, a small percentage or an understory of this species was noted on the color infrared. In addition, within large sections categorized on the timber type map as mixed stands of lodgepole and associated species, small plots of pure lodgepole were separable on the color infrared enlargement.

Certainly the level of detail extracted from an aerial photograph is

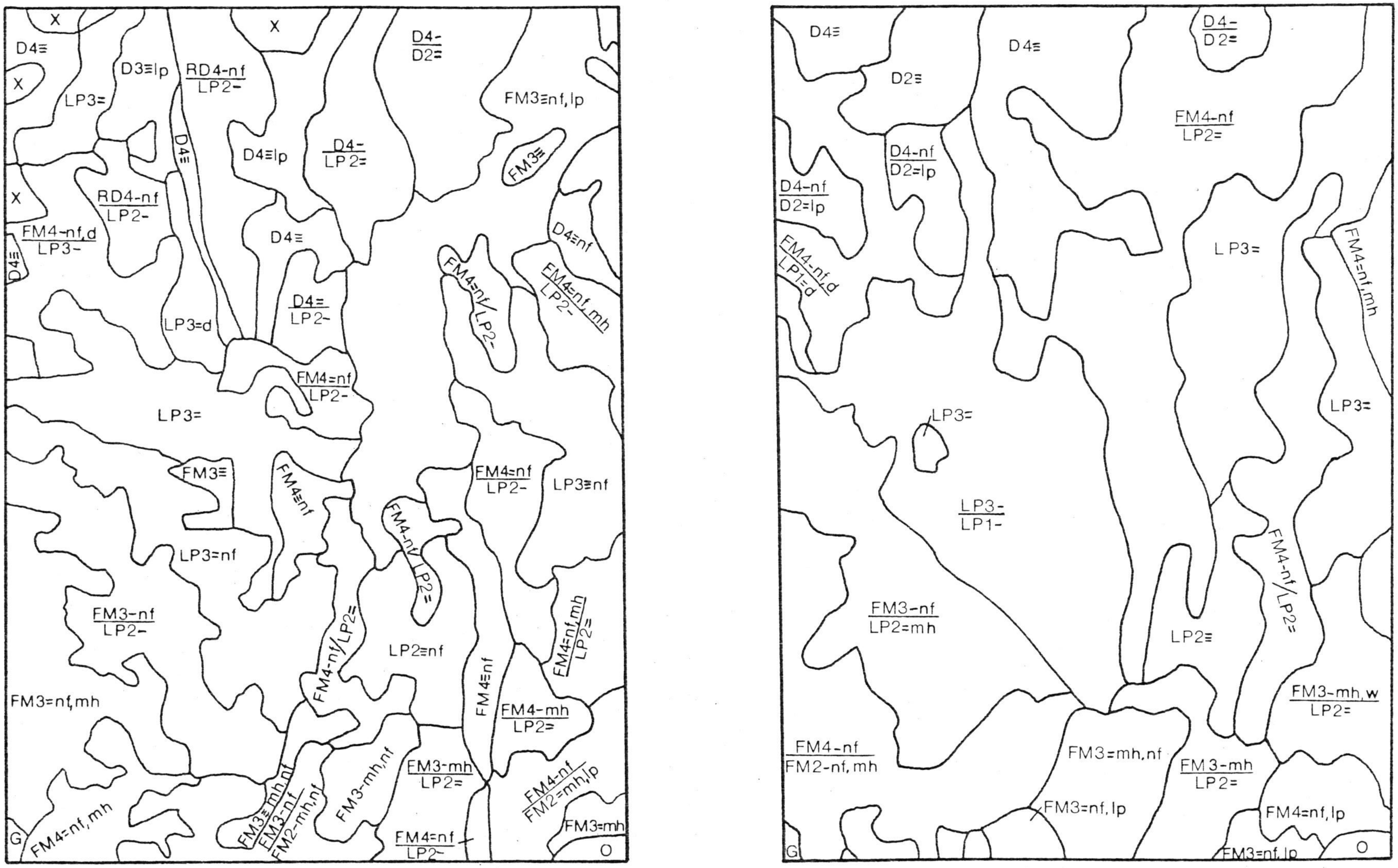

Fig. 5. Comparison of a section of the study area at approximately 1:30,000; on the left is that done with the high-altitude color infrared, on the right is that area as it appears on the 1961 Forest Service timber type map. Note the significantly greater detail of the color infrared, particularly resulting from recognition of lodgepole pine boundaries and stand density changes.

one of degrees, depending on the image quality and final project objectives. Within the section of the study area reserved for intensive analysis, mapping units were broken down much further in order to assess the full potential of this high-altitude photography. Thus, a small heterogeneous portion of the region was divided to the limits of visual interpretability--a level of rigor impractical for large-area forest mapping.

Results from the complex forest environment so analyzed were most impressive. No attempt was made to descriptively classify each subcategory, and in fact, it was not always clear what surface factors accounted for each small division. In certain locations, the color infrared interpretation, based primarily on minor tonal and textural variation, stopped just short of separating one tree from the next. This high degree of stratification was largely the result of recognition of small area stocking density changes and minor hue variations from slight changes in species composition, size classes, or understory composition. Tree size was an influential element in sections of large sawtimber of poor to medium stocking. In such cases, the individual widely spaced crowns were clearly visible and the tendency was to encircle each tree. Although separation of individual trees is impractical as a forest mapping procedure, it provides the reader with some feeling for the detail evident on this high-altitude photography.

Timber size class differentiations from this color infrared imagery were often uncertain at the four size class levels of the Forest Service classification scheme. Although stand size differences between adjoining plots were often apparent, the designation of one as pole timber and the other as small sawtimber was highly conjectural. However, the color infrared photograph did supply sufficient information for a reasonable degree of relative size determination. Thus, saplings and pole timber were usually separable from the larger sawtimber on the basis of crown diameter and stand texture. Presumedly the Forest Service mapping effort was somewhat more successful for size class distinctions as stereo viewing added tree height data to the interpretation.

The usefulness of the four-tiered timber size classification developed by the Forest Service may be questioned. Even at extremely large scales, estimates of stem diameters from aerial photographs are very crude. Expensive and time consuming ground surveys are necessary to accurately place stands within these classes. More meaningful for commercial inventories would be a system designed for use in aerial surveys in which large, and therefore merchantable timber was distinguished from immature trees.

Related to, and based upon much the same data as stand size determination was the recognition of forest understories. As suggested earlier, lodgepole pine was readily recognized on the 1:30,000 color infrared imagery where it occurred below other species. However, hue was not an effective indicator of understories among the other species. In these cases, a mottled, uneven stand texture often identified areas of understories. For example, two layered stands within the true fir-mountain hemlock type were identified in this manner. In other plots, scattered old growth timber, often Douglas-fir, was evident by its large crown diameters standing over even textured saplings or pole timber.

The major distracting feature of the high-altitude color infrared photography was its inability to clearly distinguish between species, other than lodgepole pine. Hue was the primary identification characteristic, but most species appeared as shades of red too similar to neighboring species to be separated by hue alone. Variation in hue was usually more evident between differing sites, age classes, and locations on the photograph than between species. For example, a stand of small Douglas-fir sawtimber could not be distinguished from an adjacent group of noble fir small sawtimber, but displayed highly different hue characteristics than a Douglas-fir stand found elsewhere in the study area.

Placement of highly accurate boundaries was accomplished throughout most of the region, but description of each plot by species composition on the basis of photo characteristics was not possible. In lieu of extensive ground work, the Forest Service map was relied upon to assist with species identification. In addition, factors such as crown diameter, elevation, exposure, and location within the study area aided species recognition.

Species identification apparently met with only limited success on the 1:12,000 Forest Service photographs, although individual tree crown texture as well as crown shape and branching pattern were visible--species recognition aids not apparent on the 1:30,000 color infrared imagery. Ground checking was necessary for most positive stand identifications in this earlier effort. Much of the overall species composition accuracy of the Forest Service map must be questioned because of the several plots found to be classified incorrectly.

CONCLUSIONS AND RECOMMENDATIONS

This study has presented the strengths and weaknesses of two types of aerial imagery for forest inventory in southwestern Oregon. Serious doubts have been raised concerning the accuracy of the Forest Service mapping effort of the early 1960s and the usefulness of portions of the timber classification system employed.

The operational characteristics as well as the factors making color infrared film an effective medium for high-altitude vegetation studies have been explored. It should be noted that high-altitude small scale photography offers several other advantages. Small scale photographs have the benefit of presenting a synoptic, or large area view of forest lands. Where usable, they give a greater cost effectiveness on a per-hectare basis in data acquisition than large scale coverage. Because smaller scale photography permits a plane to cover more area per unit time, the higher operating costs of high-altitude aircraft may be offset. This is especially true of regional scope surveys where thousands of square kilometers may be covered. In addition, smaller scale can mean lower photo development and printing costs as fewer photographs are required for each project.

The high-altitude color infrared photography examined here proved valuable for delineating between broad ground condition classes, variations in timber stocking densities, and large and small timber classes. For these reasons the completed timber type overlay should prove beneficial to the training site selection process of a LANDSAT classification. Results from the section of detailed mapping suggest that this type of photographic product may prove valuable for the exacting applications generally reserved to much larger scale imagery.

With the exception of lodgepole pine, species recognition was not accomplished with high levels of accuracy. As with the earlier large scale black and white photography, precise identification of species composition requires considerable ground surveying. For this reason it is felt that high-altitude color infrared at the scales examined is appropriate for detailed timber species mapping only where extensive ground work will accompany the photointerpretation, or for correcting and updating earlier inventories.

FOOTNOTES

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10 R. J. List, Smithsonian Meteorological Tables (Washington: Smithsonian Institution Miscellaneous Collections 114, 1958), pp. 425-426.

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APPENDIX

Forest Type Mapping in the Pacific Northwest Region

FOREST TYPE SYMBOLS AND DEFINITIONS. The job of managing the timber resource of a National Forest requires a detailed knowledge of the condition classes that make up the forest. A forest manager must know the volume of timber, condition, and where it is located. Under present inventory procedures, area totals for the various condition classes, volume, rate of growth, defect, species, and other items are obtained from inventory plots. These figures show the condition of the forest and form the basis for many management decisions. Information on the location of the various condition classes or types, as they are commonly called, is obtained from the type map made at the same time, but independent of the forest inventory. The type map provides the forest manager with a working tool for timber resource management planning.

Present type mapping practices rely heavily on the use of aerial photographs. Type designations may be determined from the photographic appearance of the stand. Some items, such as crown density, are determined entirely from aerial photos. However, other items like species composition are largely determined on the ground. These instructions for type mapping give not only definitions of the symbols used but also the techniques of using aerial photos for mapping.

In classifying forest types, the first major breakdown is between forest and nonforest land. This is generally the easiest of the photo

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Source: U.S.D.A. Forest Service, "Timber Management Plan Inventory Handbook", (Portland: Region 6, 1965).

forest classification tasks. Nonforest lands are those lands that have never supported forest growth and lands once forested but now developed for nonforest use. These include water, rock, urban areas, agricultural lands, and range lands. Forest lands include lands having ten percent or more of growing space occupied by forest trees of any size, or lands which have been deforested but not put to some nonforest use.

Forest lands are divided into noncommercial and commercial groupings. Noncommercial forest lands are defined as forest lands incapable of yielding usable crops of industrial wood because of adverse site conditions or so physically inaccessible as to be unavailable economically in the foreseeable future. Commercial forest land is susceptible of management for continuous crops of timber, while noncommercial forest land is not. Commercial forest lands, which include the bulk of our forest lands, are classified either into forest types identified by a three-component type designation consisting of species type, size class, and density of stocking; or into one of several deforested condition classes. Rules for determining species type, size class, and density--and the symbols used--are found in the following section.

Commercial Timberland Types. Type names will be derived from the species or group of species with the plurality of basal area in sawtimber stands and number of stems in all other stands.

Type Name	Symbol
Douglas-fir	D
Ponderosa pine	P
Western hemlock	H
Sitka spruce	S
Engelmann spruce	ES
Western larch	WL (includes alpine larch)
White fir	WF (includes grand fir)
White pine	W (includes whitebark pine)

Commercial Timberland Types. (con't.)

Sugar pine	SP
Lodgepole pine	LP (includes knobcone pine)
True fir-mountain hemlock	FM (includes all true firs with the exception of white fir)
Cedars	C
Hardwoods	HD

In addition to the main type symbol, species composition of the type is indicated by standard symbols (lowercase letters) in every commercial forest type unit according to the following rules: no species will be recognized unless it comprises at least twenty percent of the type unit by basal area (or number of stems). Symbols will be listed in decreasing order of abundance. No more than three species will be recognized in any type unit. Whenever the main type symbol clearly indicates the specific key species, this species symbol will be omitted. For combination types, the main type symbol does not indicate the specific key species and it will be necessary to list the recognized species.

Species Composition. (conifers only)

Common and Scientific Name	Symbol
Douglas-fir (*Pseudotsuga menziesii*)	d
Engelmann spruce (*Picea engelmannii*)	es
Sitka spruce (*Picea sitchensis*)	s
Mountain hemlock (*Tsuga mertensiana*)	mh
Western hemlock (*Tsuga heterophylla*)	h
Alaska-cedar (*Chamaecyparis nootkatensis*)	yc
Incense-cedar (*Libocedrus decurrens*)	ic
Port-Orford-cedar (*Chamaecyparis lawsoniana*)	pc
Western redcedar (*Thuja plicata*)	c
Lodgepole pine (*Pinus contorta*)	lp
Shore pine (*Pinus contorta*)	ln
Knobcone pine (*Pinus attenuata*)	kp
Ponderosa pine (*Pinus ponderosa*)	p
Jeffery pine(*Pinus jeffreyi*)	p
Sugar pine (*Pinus lambertiana*)	sp

Species Composition. (con't.)

Western white pine (Pinus monticola)	w
Whitebark pine (Pinus albicaulis)	wb
Subalpine fir (Abies lasiocarpa)	af
Noble fir (Abies procera)	nf
Pacific silver fir (Abies amabilis)	a
Shasta red fir (Abies magnifica shastensis)	srf
White fir (Abies concolor)	wf
Grand fir (Abies grandis)	wf
Western larch (Larix occidentalis)	wl
Subalpine larch (Larix lyallii)	wl
Redwood (Sequoia sempervirens)	r
Western juniper (Juniperus occidentalis)	j

Species identification is one of the most difficult tasks of the photo interpreter. Most species cannot be identified with complete certainty on aerial photos. Among the criteria used in interpretation of forest lands are tone, texture, size and shape of crowns, branching, pattern, shadows, and topographic position. Knowledge of the geographic and altidudinal range of a species helps in identification.

Size Class. In the field, forest stands are divided into size classes based on tree diameters. Their designations are: seedlings and saplings, pole timber, small sawtimber, and large sawtimber. These broad diameter classes can be fairly well recognized on aerial photos from the texture of the stand, height of the trees, and diameter and shape of crowns. Symbols and definitions for the size classes follow:

Symbol	Stand Size Class	Description
1	Seedlings and samplings	0 to 5 inches d.b.h.
2	Pole timber	5 to 11 inches d.b.h.
3	Small sawtimber	11 to 21 inches d.b.h.
4	Large sawtimber	21 inches and larger d.b.h.
5	Large old-growth Douglas-fir sawtimber	21 inches and larger d.b.h., usually over 180 years old.

Density. Density of stocking is expressed as the percentage of crown closure seen on the aerial photo. Where density is less than ten percent, the area is classified as nonstocked. Various interpretation aids such as Timber Survey Aid No. 5 are available to assist in the judgment of density. In order to get a true appreciation of density, photos should be viewed stereoscopically.

Symbol	Description	Density
-	10 to 40 percent of full crown closure	Poorly stocked
=	40 to 70 percent of full crown closure	Medium stocked
≡	70 to 100 percent of full crown closure	Well stocked

Nonstocked Areas. Forest lands not qualifying as sawtimber, pole timber, or seedlings and saplings stands are called nonstocked. They should be designated by one of the following condition class symbols:

Symbol	Condition Class
X	Recent clearcut area (cutover during last five years)
XO	Old clearcut areas (cutover prior to last five years)
F	Area deforested by fire
I	Area deforested by insects
WT	Area deforested by wind

Noncommercial Forest Types.

Symbol	Description
J	Juniper
OM	Oak-madrone (scrub stands)
SA	Subalpine (nonmerchantable stands above commercial forest zone)
NR	Noncommercial-rocky (area within commercial forest zone; too rocky, steep, or sterile to produce a merchantable stand; but containing at least ten percent stocking)

Nonforest Types.

Symbol	Description
A	Agricultural land (cultivated and pasture)
G	Vegetative land (grass or brush)

Nonforest Types. (con't.)

O	Nonvegetative land (including barrens and cities)
W	Water (including streams, lakes, and tideflats)

TYPE MAPPING PROCEDURES. Type mapping is a combination of field and office work. Efficient type mapping gets most out of photography by a maximum of office interpretation and a minimum of field work. The balance between field and office work depends on the skill and experience of the type mapper, the complexity of types, the quality of the photography, and the accessibility of the area.

Several days of familiarization are necessary before actual type mapping begins. A reconnaissance is made along main travel routes, and forest types which are encountered along the way are noted on the photos. Frequent stops are made to compare the ground appearance of representative stands with the appearance of their images in stereoscopic view. This enables the type mapper to acquire a background of mental images of ground views to fit with their corresponding vertical views. Stereoscopic pairs of photos containing typical examples of forest types may be selected as examples and used throughout the mapping project for reference. Stereograms of this kind aid in the identification of types in areas that cannot be field checked.

After the familiarization period described above, the regular mapping job may be started. One way to conduct mapping is by a process called pretyping. This consists essentially of mapping photos in the office and then checking them in the field. Initially it is best to map out only a few photos of accessible areas in the office before making a field check. Gradually as confidence is gained and technique is improved, more photos can be mapped before making a field trip--including inaccessible areas which will not be reached by a field check. Pretyping is best practiced by mappers who are well acquainted with an area. An alternative to pre-typing is post-typing. By this method, all available field checking routes are covered first and extensive notes are made on the photos. Type lines are mapped out in the office after field travel.

Delineation Procedure. All type mapping should be done under a stereoscope. While certain broad classes can be recognized on a single photo, the stereoscope view aids immeasurably in identifying species and size classes. In delineating types, it is generally best to begin by marking out the easiest areas and working toward the more difficult. Generally, broad forest and nonforest types can be recognized easily. It is possible also to delineate typical stand-size classes and density-of-stocking classes in pole and sawtimber without much trouble. However, sometimes type delineations based on differences in species composition, seedling and sapling stocking, and borderline cases in size classes can be difficult. The placement of type lines where types blend with no clearcut boundary depends on the decision of the mapper.

The type mapper must keep scale variations, shadow relations, and viewing angle in mind when naming forest types. Differences in date of photography, time of day of photography, and photo lab printing processes within the same photo project will give identical types different appearances.

The natural shape as well as the size of a type unit should be traced. The ins and outs of the type boundaries should be traced rather than generalizing into round, oval, or rectangular patches. Type stringers less than two chains in width should be ignored. Mapping will be done to a ten acre minimum.

Any type unit should be included which is smaller than the minimum specified with the surrounding type or the nearest related adjoining type. Where smaller types are included with larger types, the effect of such inclusions upon average composition of the type as finally included within one boundary should be considered. The symbols for species composition, size class, or density of the type as outlined should indicate the average of those factors over the whole area outlined. For example, a number of small meadows scattered throughout a large area of well-stocked timber may lower the average stocking of the timber area as outlined from well stocked to medium stocked.

If the photography being used is not fairly recent, a check of the records should be made of recent cuts and burns. Clearcut units not recorded on photos should be transfered directly from the sale area map to the base map on which the type map is to be placed. Fire-caused type changes should be marked on the photos in their appropriate places. Planting records will indicate area of seedlings and saplings when this size class is not apparent on the photos.

Previous survey type maps can provide useful clues in the determination of species composition and serve as a basis for judging size class. The type mapper should be mindful of the possible changes in size class that may have occurred since the last mapping. Types should be outlined within effective areas only. It is good practice to first carry over the type lines and type symbols from adjoining photos onto a photo to be typed before any other work is done on it.

Checking. Field checking should be confined to those areas adjacent to the road with occasional side trips to vantage points. An occasional lengthy foot trip along a trail that reaches several major types in isolated areas may be advisable. Usually, extensive foot travel to check out distant types is not warranted for the caliber of map being produced. When planning cross-country travel, the mapper should consider the value of the types in doubt and the amount of time necessary to check them. For example, cross-country travel to determine if a stand of lodgepole pine is in size class two or size class three is probably not warranted.

Notes on types along the route of travel to a plot taken by inventory crews are a valuable source of information for the type mapper.

Airplanes have been successfully used in the past to check types in remote areas. The use of aircraft should be considered when mapping projects contain a considerable amount of inaccessible country.

Field checking enables the mapper to refine type lines, identify questionable areas, and pick up any errors in mapping. If misidentifications of species and size class are discovered in field checking, not only should he correct the visited area but also all the surrounding types of the same classification which will not be seen in the field check should be reassessed for possible changes.

Two-Story Type Mapping. Two-storied stands are stands which have two distinctive height classes of considerable difference called the overstory and the understory. Often the overstory and the the understory are each even-aged. Therefore, the two-storied stand consists of two independent parts and often should be managed as such. The two-story type map calls attention to such management opportunities.

There are a few general rules to be observed in two-story type mapping. The same type symbols and rules used in single-story type mapping are used in two-story mapping. In applying densities, the total density of the two stories cannot exceed 100 percent. The overstory and the understory should be at least two size classes removed. A closed overstory canopy usually means that the understory cannot be seen on aerial photos. No understory should be recorded even if it is apparent from ground examination. In all two-story mapping the management implications should be carefully considered. A logical management reason should be served or else the type map may become unnecessarily cluttered.