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Aerial Photo Guide to New England Forest Cover Types

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Abstract

Presents color infrared photos in stereo pairs for identification of the New England forest cover types. Depicts range maps, ecological relations, and range of composition for each forest cover type described. The guide is designed to assist the needs of interpreters of color infrared photography.

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Guide to forest cover types of New England

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Black Spruce--Tamarack ... BS/T
Red Spruce ... RS
Red Spruce--Balsam Fir ... RS/BF
Red Pine ... RP
Eastern White Pine ... WP
Eastern Hemlock ... H
White Pine--Hemlock ... WP/H
Pitch Pine ... PP
Atlantic White-Cedar ... AWC
Aspen ... Asp
White Birch ... WB
Sugar Maple ... SM
Red Maple ... RM
Northern Red Oak ... RO
Beech--Sugar Maple ... B/SM
Sugar Maple--Beech--Yellow Birch ... SM/B/YB
White Oak--Black Oak--Northern Red Oak ... WO/BO/RO
White Pine--Red Oak--Red Maple ... WP/RO/RM
Red Spruce--Sugar Maple--Beech ... RS/SM/B
White Birch--Red Spruce--Balsam Fir ... WB/RS/BF

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Aerial Photo Guide to New England Forest Cover Types

Rachel Riemann Hershey
William A. Befort

Introduction

This illustrated guide will aid interpreters of color infrared (CIR) aerial photography in identifying New England forest cover types. Forest cover types in this guide are those defined for the New England area by the Society of American Foresters (SAF) (Eyre 1980). Table 1 lists the SAF cover types, the SAF type groups to which they belong, and the USDA Forest Service Renewable Resources Evaluation (RRE) type groups (Waddell et al. 1989) to which they correspond.

Guide Organization

The guide is designed as a selection key. It presents detailed illustrations and descriptions for each forest cover type. The interpreter applies this information to decide which types best match the stands under study. The large number of forest cover types in New England and the variability within each in species composition and spatial arrangement, make them unsuited to the dichotomous distinctions required by an elimination key.

Each cover type is presented in a uniform format on two sides of a loose-leaf page. This arrangement allows interpreters to regroup the types to suit the needs of any project, and it simplifies revision and updating. On the front of each page are two aerial stereograms depicting the cover type, together with a summary of the identifying features. On the reverse side there is a map of the type's geographic range, a diagram illustrating its range of species composition, silhouette sketches of its main tree components, and a graphic representation of the ecological requirements of the principal tree species. In addition, several short paragraphs further describe the type and comparisons between it and other easily confused types. The user is assumed to have a 2-power lens stereoscope and an understanding of aerial photography principles. Those who require an introduction to aerial photo fundamentals are referred to Crisco (1988) or Rasher and Weaver (1990).

To avoid constantly repeating the word "type", as in "the Black Spruce type", a naming convention is used for distinguishing the species from the type. Lower case letters (black spruce) are used when referring to the species, and upper case letters (Black Spruce or BS) are used when referring to the type. Multiple-species types additionally feature a hyphen or slash in the name (Beech--Sugar Maple or B/SM).

Aerial Photographs

No aerial photo guide can offer more than a limited selection from the available range of photo scales and film emulsions. We chose two film/scale combinations to make this guide as broadly useful as possible for interpreters working with large- to medium-scale color infrared (CIR) imagery. The first exhibit on each page is a large-scale CIR stereogram, in the scale range 1:6000 to 1:8000. The second is a medium-scale panchromatic stereogram, in the scale range 1:20000 to 1:24000. The same site appears on both sets of photos. Type boundaries are shown on the large-scale stereograms, and the types are identified by the abbreviations given in the Contents and Table 1. The location of each large-scale stereogram is indicated on the corresponding medium-scale stereogram, which can be used to gain a broader perspective of the terrain in which the example stand was found. The CIR photos were taken from about 6500 feet above ground level with a hand-held Nikon F2A 35mm camera, 150mm

Table 1.--The SAF type groups and forest cover types presented in this guide, and the corresponding Renewable Resources Evaluation type groups

SAF type group	SAF type (abbr.)	RRE type group (Eastern)
Boreal Forest Region		
Boreal conifers	Balsam Fir (BF)	Spruce--fir
	Black Spruce (BS)	"
	Black Spruce--Tamarack (BS/T)	"
Boreal hardwoods	Aspen (Asp)	Aspen--birch
	White Birch (WB)	"
Northern Forest Region		
Spruce-fir types	Red Spruce (RS)	Spruce--fir
	Red Spruce--Balsam Fir (RS/BF)	"
	Red Spruce--Sugar Maple--Beech (RS/SM/B)	"
	White Birch--Red Spruce--Balsam Fir (WB/RS/BF)	"
Pine and hemlock types	Red Pine (RP)	White--red--jack pine
	Eastern White Pine (WP)	"
	White Pine--Hemlock (WP/H)	"
	Eastern Hemlock (H)	"
	White Pine--Red Oak--Red Maple (WP/RO/RM)	"
Northern hardwoods	Sugar Maple (SM)	Maple--beech--birch
	Sugar Maple--Beech--Yellow Birch (SM/B/YB)	"
	Beech--Sugar Maple (B/SM)	"
	Red Maple (RM)	"
Central Forest Region		
Upland oaks	White Oak--Black Oak--Red Oak (WO/BO/RO)	Oak--hickory
	Northern Red Oak (RO)	"
Other	Pitch Pine (PP)	Loblolly--shortleaf pine
Southern Forest Region		
Other	Atlantic White-Cedar (AWC)	Oak--gum--cypress

Nikkor f/3.5 lens, Wratten 12 (deep yellow) filter, and Kodak Ektachrome Infrared Film 2236.[1] They are enlarged approximately twice from original scale. Most of the CIR photography was taken during the summer of 1986. The medium-scale panchromatic stereograms were taken from standard USDA Agricultural Stabilization and Conservation Service (ASCS) 9-inch photo coverage, most of it acquired in the early 1970's with Fairchild aerial cameras, 8.25-inch lenses, Wratten 12 filters, and Kodak Plus-X Aerographic Film 2402. These are at contact scale.

[1]This film is identical to Kodak Aerochrome Infrared Film 2443. The number only designates the packaged 35mm format. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Range Maps

Knowing the geographic range of cover types can help an interpreter eliminate unlikely types from consideration. Little systematic information is available on the geographic distribution of particular tree species combinations. Maps used in this guide show the shared ranges of the individual species comprised in the types. Range information was drawn from published sources, in particular Little (1971) and Fowells (1975). Figure 1 exemplifies the range maps in this guide.

Environmental Indices

Ecological information about the vegetation types under study is frequently useful to photo interpreters. The system of synecological coordinates developed by Bakuzis (1959) in Minnesota was adopted for this guide because it provides significant information about site requirements of species in an easily understood form suitable for graphic presentation. Bakuzis derived index values expressing the site preferences of species in terms of demands for moisture, nutrients, heat, and light (see also Bakuzis and Kurmis 1978; Bakuzis and Hansen 1959). These preferences are ranked on a scale from 1 to 5, in which 1 represents a low requirement and 5 a high requirement. A species with a moisture value of 5 favors wet sites; a species with a light value of 1 is shade-tolerant. Data from 301 field plots were used to adjust Lake States values to New England conditions following the methodology of Brand (1985). Figure 2 is an example of the environmental indices as presented in the guide. Each species component of a cover type is treated individually. See Appendix I for a full description of the method used for determining these values, and a discussion of the difficulties encountered when a single species frequently occupies a wide range of sites.

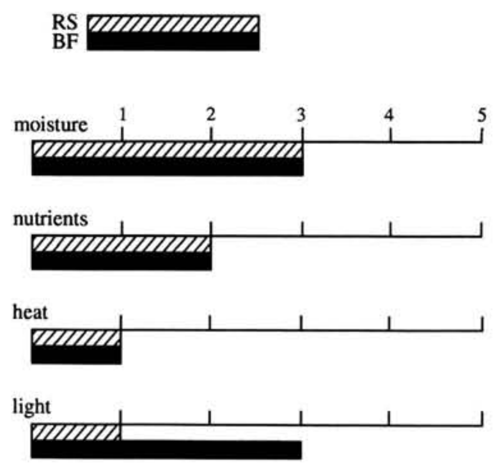


Figure 2.--Example of an environmental index showing the ecological relations of the Red Spruce--Balsam Fir type in New England. Diagram shows that RS and BF are alike in their requirements for moisture, nutrients and heat, and that RS is somewhat more shade-tolerant than BF.

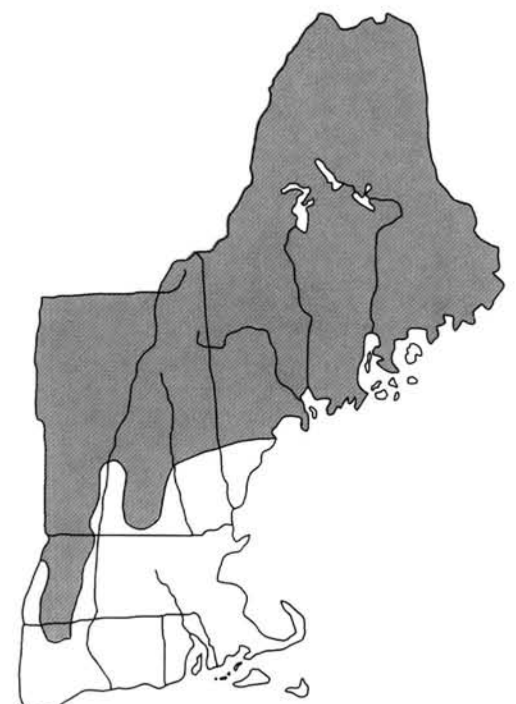


Figure 1.--Example of a range map showing the geographic distribution of the Red Spruce--Balsam Fir type in New England.

Composition Diagrams

Composition diagrams, a graphical method of representing SAF type composition rules, illustrate the variation in species composition (or "range of composition") possible within each type. The diagrams also help interpreters visualize the illustrated stand's relation to other possible compositions included in the type. Figure 3 shows three kinds of composition diagrams used in the guide. It depicts idealized types defined by a single species, two species, and three species.

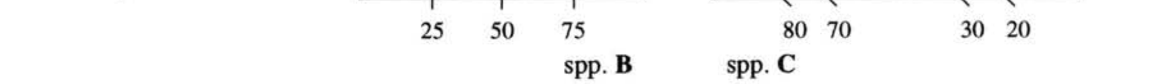
These diagrams, just as the verbal definitions they attempt to encapsulate, embody some ambiguities. First, they do not take into account species other than those mentioned in type definitions. Where "other" species make up more than 50 percent of a stand, the stand cannot be assigned to a type in the guide. Second, as the triangular composition diagram of three-species cover types does not permit consideration of other species, the percentages given in such diagrams do not refer to total stand composition, but to the portion of the stand formed by the defining species; that is, the percentages are the proportions that the defining species bear to each other (for example, sugar maple, beech, and yellow birch in the SM/B/YB type). The three-species diagram is probably the hardest to read. In this example, the **x** in the above three-species diagram can be read as 29 percent spp. A (the horizontal guide lines), 47 percent spp. B (the right-angled guide lines) and 24 percent spp. C (the left-angled guide lines). As mentioned above, these values represent the percentage of these three species relative to each other. The percent composition of the three-species types does not appear in the range of composition diagram, but is given in the caption under the CIR stereogram. See Appendix II for a full description of the design and creation of these diagrams.

Additional Information

The reverse side of each page in the guide also contains additional textual information about each type which can be used for reference. Data concerning the common situation, typical boundaries, and associate species is provided. This information was taken primarily from *Forest cover types of the United States and Canada* (Eyre 1980) and *Silvicultural systems for the major forest types of the United States* (Burns 1983). A final paragraph of comparisons identifies other similar types and describes how these can best be distinguished from one another. The tree silhouettes, provided in part simply for quick page reference, are taken primarily from Sayn-Wittgenstein (1960).

Ground Truth and Testing

Each of the sites depicted in this guide was visited on the ground. Point-sample data were collected at five plots within each stand to ensure correct type designation. After the guide was



Single-species type

Two-species type

Three-species type

Figure 3.--Example of composition diagrams. Shading shows the range of composition, in percent, for a type. General rules:

- The component species must comprise ≥ 50 percent of the stand.
- In two-species types, if the species combination comprises a majority while one species also comprises a majority, then 25 percent is the lower limit for the other species (or else the stand falls into the single-species types).
- In three-species types, in the similar situation where there is ≥ 50 percent of one of the component species, 20 percent is the lower limit for a single species and 30 percent is the lower limit for both other species combined (or else the stand falls into one of the single- or two-species types).

These rules are somewhat modified in practice, as the SAF classification does not recognize all possible two- and three-species combinations as types (see Appendix II). Superimposed on the diagrams is an X to demonstrate where within that range the example stand in the CIR stereogram occurs.

assembled, a test was conducted in which five interpreters classified 95 other New England forest sites as to cover type with and without use of the guide. Photographs used in this test were all CIR, ranging in scale from 1:6000 to 1:15840. Results showed an increase in type identification accuracy, significant at the 99 percent confidence level, when the guide was used. For further discussion of the accuracy test and results, see Hershey (1990) or Riemann (1987).

Significance and Variability of Color and Texture

Color

Differences in reflectance create differences in color and tone on the photographic image that allow discrimination of plant species and vegetation types. The characteristic surface, thickness, internal structure and pigment content of leaves, and the characteristic structure and geometry of the canopy, as determined by the orientation of the plants and their leaves, all affect the amount of radiation reflected. Infrared reflectance in particular offers broad potential for type discrimination. Vegetation reflects much more near-infrared (and mid-infrared) than visible light, and subtle differences between species in crown characteristics can show up as large differences in infrared reflectance (color/tone). For example, the needle foliage of conifers creates internal shadows. This, in combination with the fact that the leaves themselves reflect less infrared radiation, gives them a darker appearance than hardwoods in the infrared. Typical CIR imagery combines this reflectance information from the near-infrared with information from the green and red visible bands in a "false-color" display. Once the interpreter becomes accustomed to this display, it is a highly useful tool for identifying tree species and forest cover types, especially in areas where topography and other physical features are not strong indicators, as in New England.

Color must be dealt with in relative terms. Color infrared photography is not consistent enough to allow a species or type to be described in precise hue, chroma, and value terms. Factors such as shadow, season, printing process, film batch, and exposure can all affect the appearance of color photography, and CIR, in particular, is extremely sensitive to some of these. Intensity of tones and shades can vary considerably between missions, film batches, and formats (and somewhat even within a frame as well as between frames) as a result of changes in sun angle, light intensity, exposure, and/or variations in the film and processing (Enslin and Sulivan 1974; Nielson and Wightman 1971). Much information about a type can be gathered from its color, but the interpreter of CIR must assess image color carefully.

However, although absolute color may change, relative colors remain consistent and can be relied upon. Tables 2 and 3 were developed from the study of the New England species on many different photographs. Species were observed to differ independently in both color and color intensity. In the tables, the species are ranked as to where they fall relative to each other within an observed range. With respect to color, conifers (with the exception of hemlock) range from a grey-brown to a green in CIR, and hardwoods (including hemlock) range from a pink to an orange. Color intensity is an attempt to capture the strength/concentration/saturation of the color and is expressed simply as ranging from soft to intense color.

Texture

Texture is the second significant clue in species and forest type identification. The texture of a single tree on an image is determined primarily by its crown shape, branch structure, crown size, and at very large scales, its foliage type and orientation. Typical descriptions of texture refer to the impressions this creates, such as: needle-like, feathery, well-defined, indistinct, billowy, upright tufts, fine, lacy, clumped (for example, Ciesla and Hoppus 1989; Sayn-Wittgenstein 1960). The texture of a stand is determined by the size class of the trees in the stand, crown diameter, crown closure, and to a certain extent, texture of the individual crowns. For example, an even canopy will produce a much softer texture than a more open or broken and uneven canopy with many emergent trees. Similarly, a type of primarily small-crowned species will exhibit a much finer texture than large crowns. Some example descriptors of stand texture are: finely-textured, carpet-like texture, fuzzy, honeycomb, pincushion, smooth, even, uniform, popcornball, pockmarked, lumpy, and rough.

Texture is a much more consistent feature than color, but the impression of texture changes with photo scale. Table 4 presents a comparison of the relative textures of New England tree species on photography at scales of approximately 1:6000. It was developed to accompany the two previous tables on relative color. Both softwood and hardwood crowns are ranked in texture from soft to well-defined.

Table 2.--The relative color of species on CIR photography. Softwoods (excluding hemlock) are ranked from grey-brown to green; hardwoods (including hemlock) are ranked from pink to orange

Color range	Species	Color range	Species
grey-brown		pink	
	White pine		Hemlock
	Red pine		Beech
	Pitch pine		White oak
	Balsam fir		Sugar maple
	Red spruce		Red maple
	Black spruce		Aspen
	Tamarack		White birch
	dead stem		Red oak
green		orange	

Table 3.--The relative color intensity of species on CIR photography

Softwoods	Color intensity	Hardwoods
	soft color	
Hemlock		White birch
White pine		Yellow birch
Balsam fir		Beech
Pitch pine		Aspen
Tamarack		Sugar maple
Black spruce		Red maple
Red pine		White oak
Red spruce		Red oak
Atlantic white cedar		
	intense color	

Table 4.--The relative texture of species' crowns on photography near the scale of 1:6000

Softwoods	Texture	Hardwoods
	soft	
Hemlock		White birch
White pine		Beech
Pitch pine		Aspen
Red pine		Yellow birch
Tamarack		Red maple
Balsam fir		White oak
Black spruce		Sugar maple
Red spruce		Red oak
Atlantic white cedar		
	well-defined	

Reference Stereograms

These CIR photographs and stereograms, preceding the body of the guide itself, provide context, amplify the necessarily limited number of photographic exhibits that a modular guide can contain, and accustom inexperienced interpreters to the range of color representation that can be expected from CIR products. These figures are designated by letters from A to W. Figures A-M are primarily examples of varying color qualities. Figures N-W provide further illustrations of the various forest types in the guide. The latter are referenced on the guide pages, and the types that appear on them are cross-referenced in the index that follows this section.

Color infrared film is highly sensitive to handling, processing and exposure. Figures A, B, and C, which show the same Red Oak (RO) site, illustrate the color shifts that may occur because of old or improperly stored CIR film, or because of overexposure. For users acquiring their own photography, two of the most significant variables that can be controlled in CIR photography are flight altitude and the speed difference between the infrared-sensitive and red/green sensitive emulsion layers, termed IR-balance. Fleming (1979) presents methods of corrective filtration to adjust for these factors.

Figure A. The effect of old film on color. RO type has a much greyer appearance. Bear Brook State Park, NH. 8/21/86. 1:6000.

Figure B. "Normal" CIR color of RO: Bear Brook State Park, NH. 8/26/86. 1:6000.

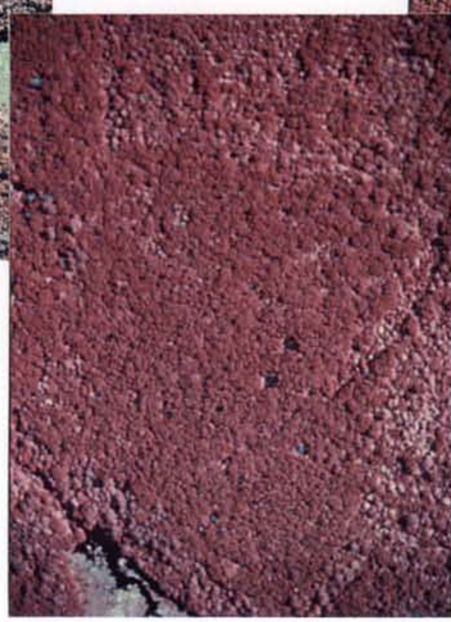


Figure C. The effect of exposure on color: 1 stop overexposed. Note loss of detail and some loss of color distinction. Bear Brook State Park, NH. 8/26/86. 1:6000.

Even more striking color discrepancies may arise in the printing process. CIR film is a reversal film, normally processed to a positive transparency. Making a positive print from a CIR transparency and making one from a normal color transparency are identical processes, but the "unusual" color combinations in CIR photos often give trouble to the automatic color analyzers that now control much of photo printing. Figures D and E were made from the same transparency.

Differential illumination and camera optical characteristics can cause color variations within single photographs. Topographic slope and aspect, which alter the angle of the canopy to incident light, are a source of differential illumination. The effects are subtle, but can be misleading. Figure F contains a fairly even distribution of SM/B/YB, yet sections of the stand are slightly different shades as a result of the hilly topography underneath.

Figure D. The effect of printing on color. RS/BF type; first printing. Twin Mountain, NH. 8/31/86. 1:6000.

Figure E. The effect of printing on color. Second printing of the same transparency. Twin Mountain, NH. 8/31/86. 1:6000.

Figure F. The effect of slope on the appearance of stand color. As a result of being on the shady side of the slope, stand **a** appears slightly darker than stand **b**, which has a very similar species composition. Franconia, NH. 8/4/86. 1:8500.

Despite the variability of CIR color, relative colors remain consistent. WP and RP occur together often and demonstrate this feature well. Where RP is a deep rust, WP is a grey pink (Figure G); where RP is a dark blue-magenta, WP is a light blue-grey purple (Figure H); and where RP is a dark rust magenta, WP is a grey magenta (Figure I). In short, WP is just a lighter, slightly greyer version of the color of RP.

Figure G. Consistency of relative color. Pawtuckaway State Park, NH. 8/21/86. 1:6000.

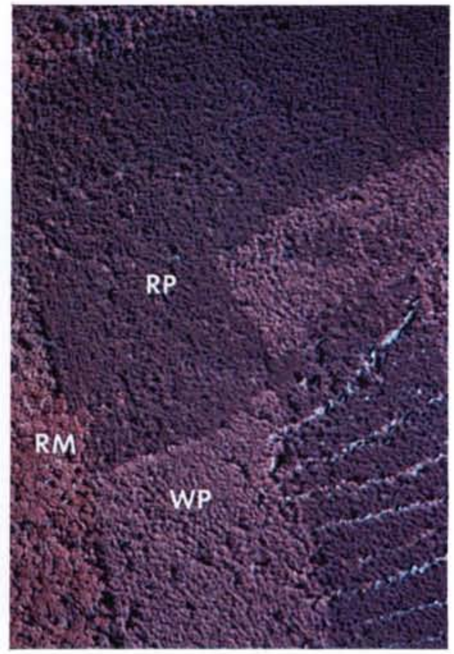


Figure H. Consistency of relative color. Wolfboro, NH. 8/31/86. 1:6000.

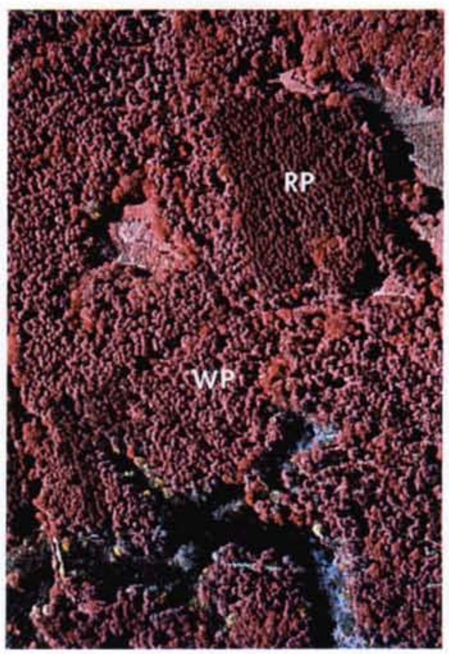


Figure I. Consistency of relative color. Pawtuckaway State Park, NH. 9/8/86. 1:6000.

Sapling stands of any forest type do not have the developed crowns, stand density and thus the texture that is typical of a mature stand. Even-aged sapling stands, in particular, often have a very uniform and finely textured appearance as a result of their consistently small crowns. Figure J is an example of an old clearcut that is now very densely occupied with saplings 8 to 12 feet in height. In this example, there are quite a few tree species involved, but the only change visible to the interpreter across the expanse of saplings is the color, which varies from lighter pink to darker purple.

Midsummer is a season of relative stability in the appearance of tree species on aerial photographs. Individual species will display different color characteristics on photography taken early or late in the summer season. Figure K is an example of the effect of red maple beginning to take on its fall colors--in CIR, this translates to yellow and gives a mottled appearance to the cover type as a whole.

Figure J. Usefulness of color to determine species when there are no texture clues. The stand delineated is an old clearcut. Notice the consistent texture of the even-aged saplings within the clearcut area, but also the shifts in color with respect to the shifts in species composition. Unfortunately, the predominance of "other" species (for example, pin cherry) in this sample means that these stands cannot be assigned to one of the types in this guide. Franconia, NH. 8/4/86. 1:8500.

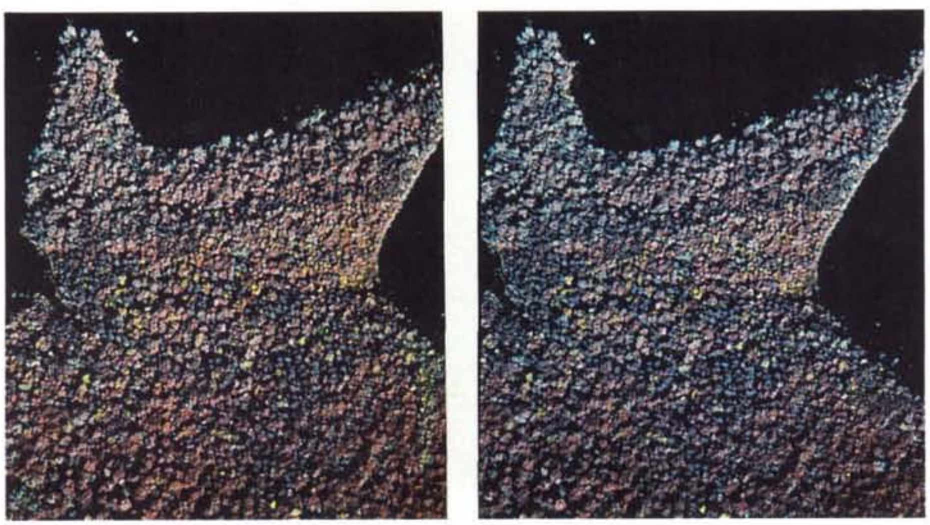


Figure K. Effect of changing autumn colors in CIR photography. The yellow crowns of red maple give this RS stand a variegated appearance in a photo taken in late summer. Pillsbury State Park, NH. 9/8/86. 1:6000.

A dead and leafless stem has a distinctive, almost bright turquoise color in CIR. A large proportion of dead stems in any stand can change the overall impression of color of the stand. In general, dead stems scattered evenly throughout a stand add a lighter, more turquoise quality to the entire stand. Figure L contains an open RS stand with both large mature individuals and large dead red spruce stems.

Where the canopy is less dense or patchy, the understory species and/or ground conditions (for example, dry vs. swampy) are visible from the air and will affect the visual impression of stand color in an aerial photograph. Figure M illustrates this with the WB type. Stands **a** and **c** are WB with an understory of red spruce, and stand **b** is WB with a beech understory.

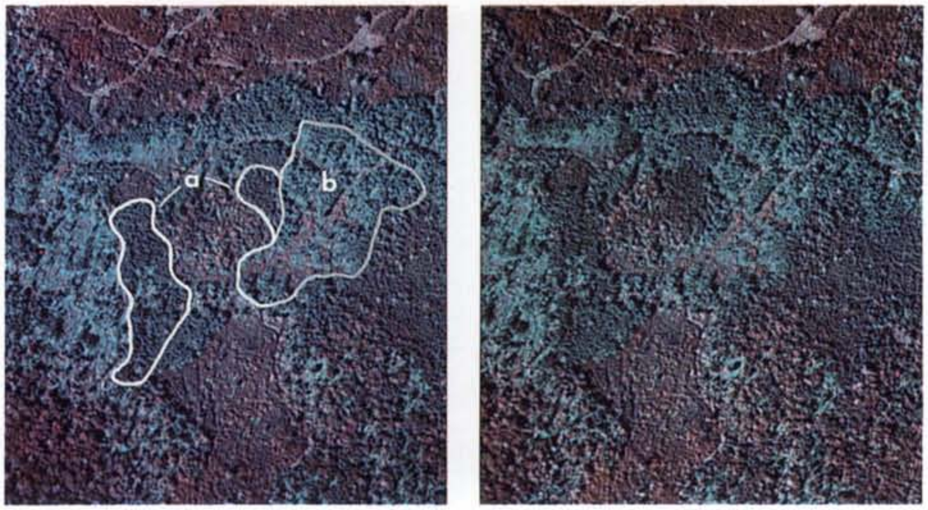


Figure L. Effect of a high proportion of dead stems on color. Stands **a** and **b** are both mature RS stands. but stand **b** has a high proportion of large dead stems and as a result a lighter more turquoise color. Franconia, NH. 8/4/86. 1:8500.

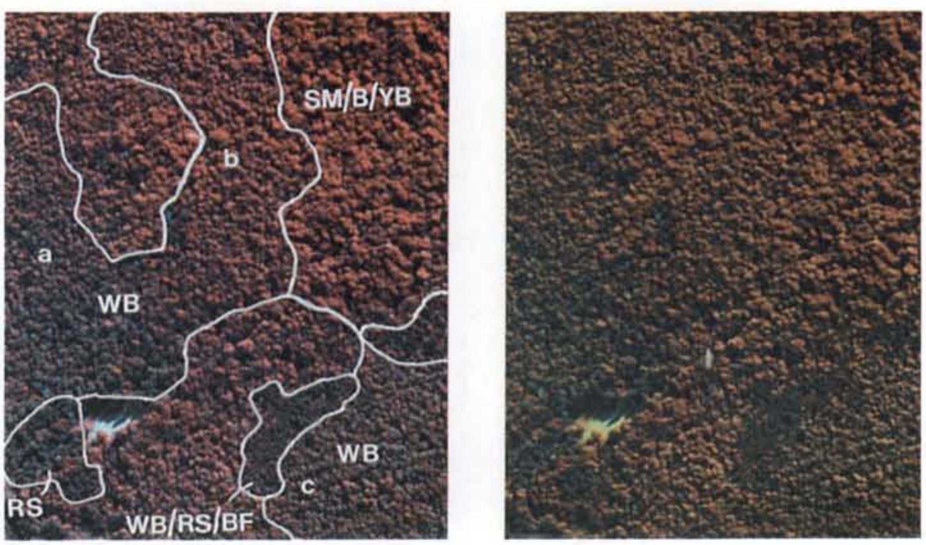


Figure M. Effect of understory species on stand color. In this example, a WB stand with an understory of red spruce (stand **a**) appears much darker than a similar stand with a beech understory (stand **b**). Even with a relatively pure and dense canopy of WB (stand **c**), red spruce in the understory can still affect stand color. Cardigan State Park, NH. 8/31/86. 1:6000.

The following stereo pairs demonstrate variations of the types that an interpreter may come across, and help the interpreter distinguish between similar or potentially confusing species and types.

PP can quickly be distinguished from RP and WP by its color. Figure N contains stands of all three types for easy direct comparison. Describing again in relative terms, WP is the lightest and most grey (stand **a**), RP is a darker, more intense version of the same color (stand **b**), and PP, while also a dark color, is much more green than either of the other two (stand **c**).

Two stands with the same species composition may appear slightly different because of different spatial distributions of those species. Figure O is a more evenly distributed (less patchy) version of the WP/RO/RM type. The smaller stands are non-plantation examples of the RP type.

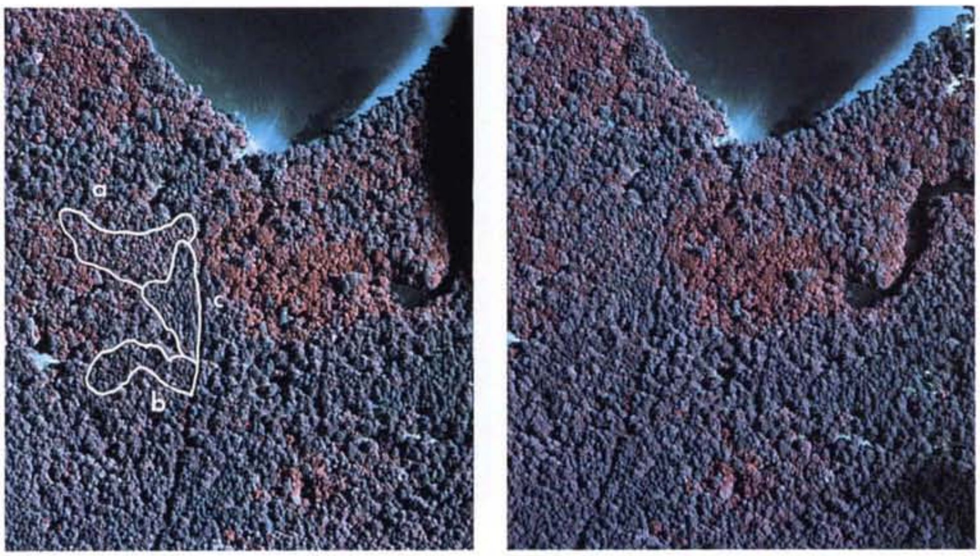


Figure N. A comparison of the relative colors of PP, RP, and WP. White Lake State Park, NH. 8/4/86. 1:6000.

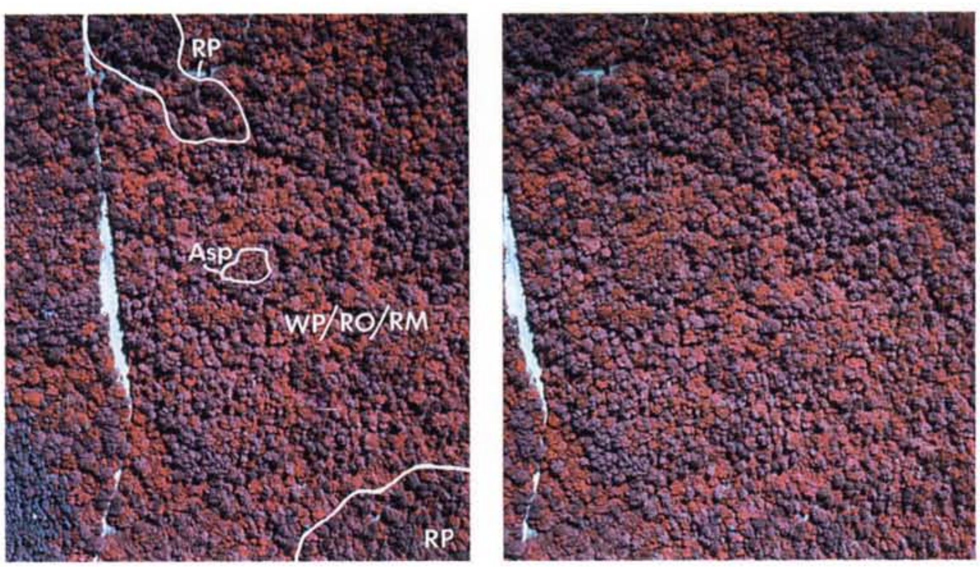


Figure O. Effect of patchiness on overall stand appearance. The examples here can be compared to the examples of each type provided on the WP/RO/RM and RP pages in the body of the guide. For reference, also labeled is a clump of aspen, identifiable by its smaller crowns and slightly sandier color. Near Wolfboro, NH. 8/12/86. 1:6000.

Usually, the distinction between hardwoods and softwoods on CIR airphotos is easy to make. Eastern Hemlock, however, has a broad fuzzy crown and pink color that can easily be mistaken for a hardwood. In Figure P, the high proportion of hemlock could easily be missed. With careful examination, however, the hemlock crowns can be distinguished from the red oak by their softer, less well-defined crowns and slightly more pink and less orange color. Of the hardwoods, beech crowns in particular are very similar to hemlock.

Any cover type definition will include a certain range of species composition, each of which can appear slightly different. For example, in three-species types, there are instances where one of the species may be hardly present or missing altogether. A stand of white pine and red maple (Figure Q) is such an example of a variation of the type WP/RO/RM.

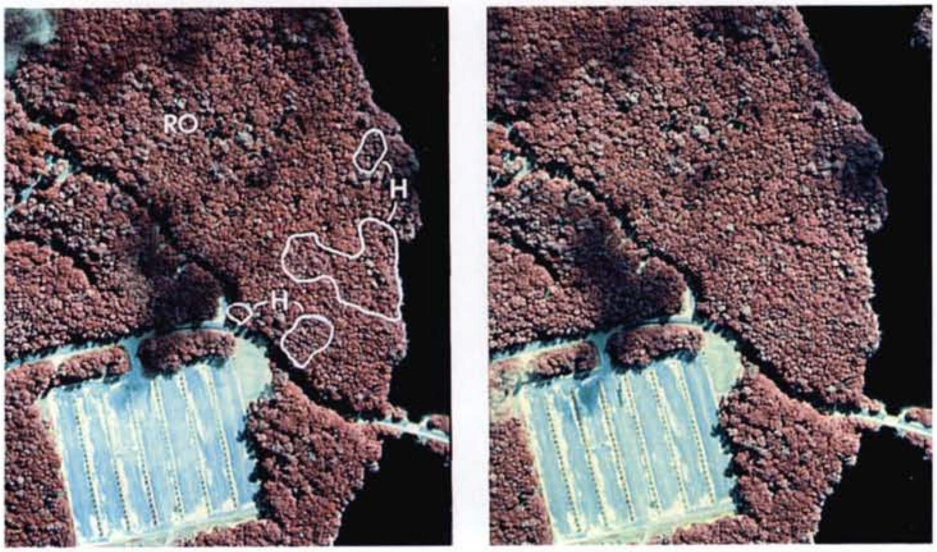


Figure P. Differentiating Hemlock from Red Oak. Most of the forested area in this photo is RO. The smaller areas delineated, however, identify local concentrations of hemlock. Note the slightly softer and less well-defined crowns of the hemlock. The large dark splotches are shadows from patchy cloud cover. Pawtuckaway State Park, NH. 8/21/86. 1:6000.

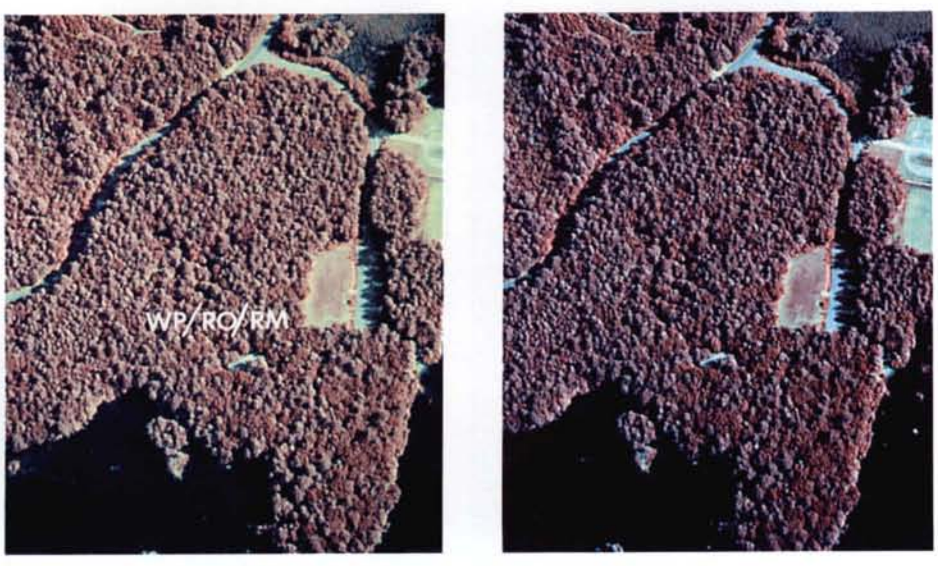


Figure Q. Appearance of a three-species type when one species is hardly present. In this example of a WP/RO/RM type, red oak is hardly present. Bear Brook State Park, NH. 8/21/86. 1:6000.

Overmature stands typically contain a broad mixture of tree ages and species associates, as some of the older, very large trees have begun to die and create gaps for new growth. From an aerial photograph, the type will have a very rough, uneven canopy, a wide mixture of colors and crown textures, and a high percentage of dead stems. Stand **a** in Figure R is an example of an overmature RS type.

The WB type, typically small-crowned, slightly orange and very soft in both texture and color intensity on CIR photography, was on one occasion found to appear much more deeply colored and textured (Figure S). As this was clearly not a simple developing or exposure error, while being significantly different from the typical, it has been included as another example of how the WB type may appear.

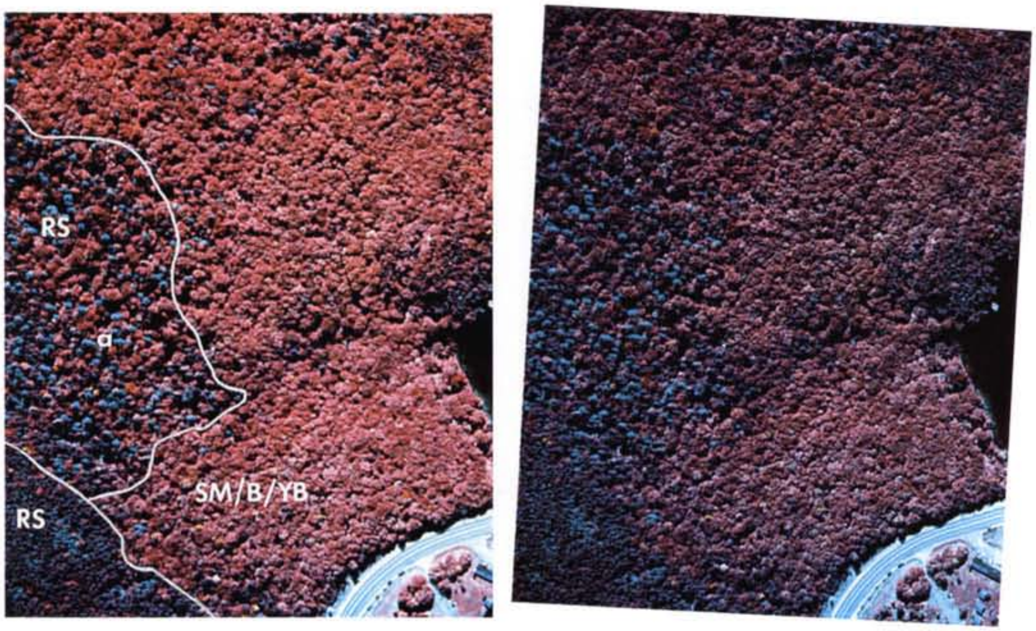


Figure R. Appearance of an overmature stand (RS example)--stand a. Near Crawford Notch, NH. 8/31/86. 1:6000.

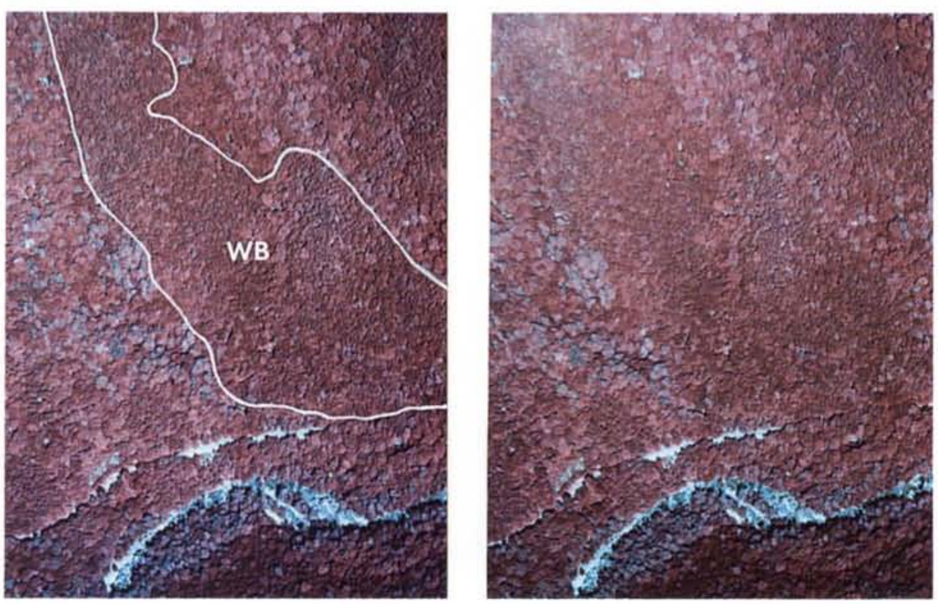


Figure S. A distinctly different example of WB. Near Bartlett, NH. 8/4/86. 1:6000.

RM and RO, both often intensely colored and well-defined types, can be distinguished. In direct comparison, red maple has a slightly softer and more pink crown than does red oak (Figure T).

The scrub variety of WO/BO/RO will take on a finer stand texture because of the smaller average crown size (Figure U).

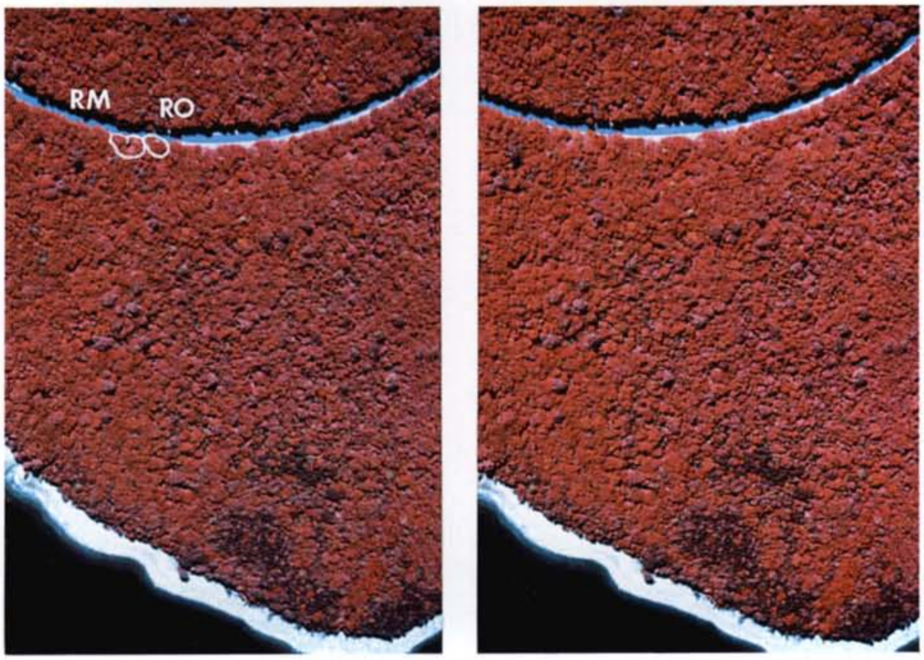


Figure T. Differentiating red maple from red oak. Particularly along the road, the orange-red red oak and the more lightly colored red maple are easily discernible. Quabbin Reservoir, MA. 8/31/86. 1:6000.

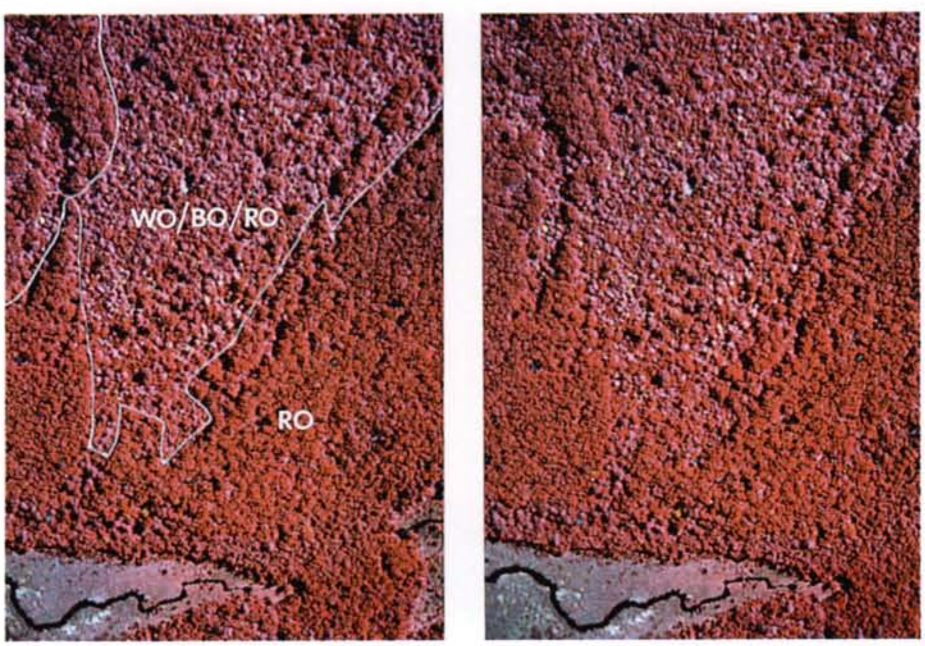


Figure U. Scrub version of WO/BO/RO. Bear Brook State Park, NH. 8/26/86. 1:6000.

Krummholz, that high altitude variety of RS/BF (or WB/RS/BF), also has a fine texture as a result of the small trees and small crowns. The type color is patchy and has a tendency to run much more toward the pink, even when there is no white birch component in the stand (Figure V).

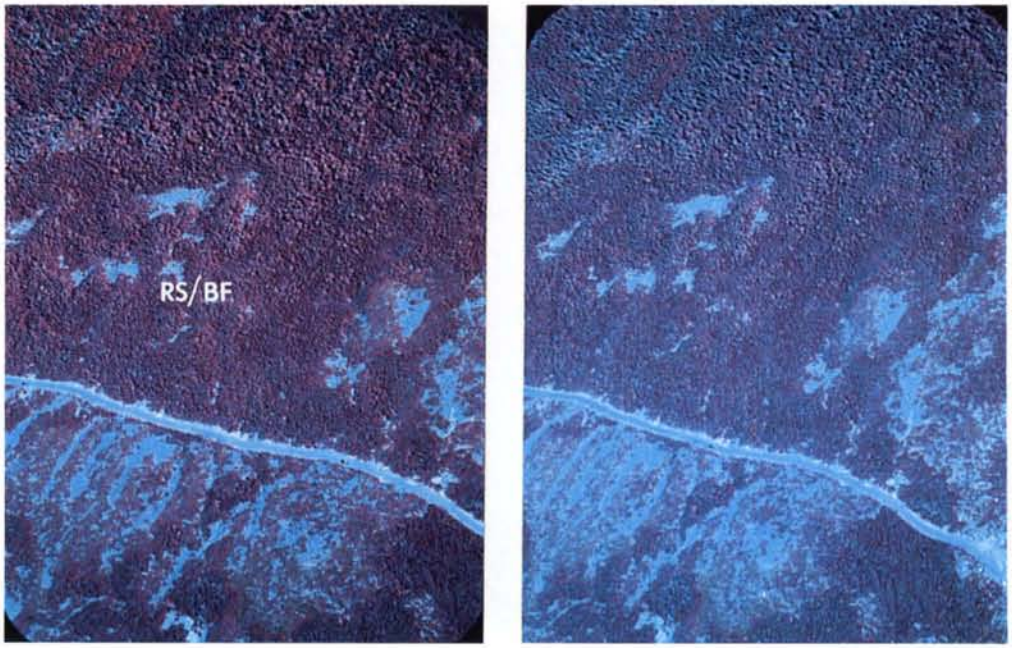


Figure V. Appearance of a krummholz version of RS/BF. Mt. Washington, NH. 8/31/86.

Forest Cover Type Index

Forest Cover Type

Key pages (designated by type abbreviation)

Reference pages (numbered)

Aspen
Asp, SM
12

Atlantic White-Cedar
AWC

Beech--Sugar Maple
B/SM, RS/SM/B

Black Spruce
BS, BS/T

Black Spruce--Tamarack
BS/T

Hemlock
H
13

Pitch Pine
BS/T, PP
12

Red Maple
RS/BF, AWC, Asp, RM
9, 15

Red Oak
RO, WO/BO/RO
7, 13, 15

Red Pine
RP, RS/SM/B
9, 12

Red Spruce
RS, RS/BF,WB, RM
10, 11, 15

Red Spruce--Balsam Fir
RS, RS/BF, H, WB/RS/BF
8, 16

Red Spruce--Sugar Maple--Beech
RS/SM/B

Sugar Maple
SM

Sugar Maple--Beech--Yellow Birch
WB, SM/B/YB
8, 11, 14

White Birch
RS, Asp, WB
11, 14

White Birch--Red Spruce--Balsam Fir
WB, WB/RS/BF
11, 16

White Oak--Black Oak--Red Oak
WO/BO/RO
15

White Pine
RP, WP, PP, RO, WO/BO/RO
9, 12

White Pine--Hemlock
WP/H

White Pine--Red Oak--Red Maple
BS/T, PP, WO/BO/RO, WP/RO/RM
12, 13

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Appendix I

Development of the Ecological Relations Diagrams

It is often useful to know a species' requirements and tolerances to climatic and edaphic conditions. Once a plant community has been labeled as a particular forest cover type, information regarding each species' moisture, nutrient, heat, and light requirements further describes the community. Such information may also be part of the classification system. The forest cover types in the 1954 edition of *Forest cover types of North America* (Society of American Foresters 1954), for example, are listed according to their moisture requirements, and the 1980 edition (Eyre 1980) divides the sections roughly along the lines of heat requirements (boreal, northern, central, southern and tropical).

In a guide to forest cover types, such information should be valid, complete, and brief--that is, reduce the information to a few words or graphic representation. Species requirements in the literature, however, are usually presented in broad qualitative classes, and any quantitative data are scattered and necessarily refer to conditions of limited range (as species can vary greatly in their requirements over their entire range) (Lindeman 1942). Thus, other methods had to be investigated. Synecological coordinates--a method of combining the qualitative and quantitative data available into a scale of relative values--were chosen for this purpose. Developed by Bakuzis (1959) for Minnesota, synecological coordinates express, on a scale from 1 to 5, each species' requirements for "essential environmental factors ... within a certain plant-geographical region." The term "synecology," meaning "community ecology," emphasizes the fact that the values indicate a species' environmental requirements *when competing with other plants* and not under ideal circumstances such as the absence of competition. The four essential factors used to describe species site preferences are moisture, nutrients, heat, and light requirements.

In general, synecological coordinates, or environmental indices, are established for a particular region by evaluating previously published information and adjusting it to the local geographic region on the basis of field observations of community (stand) species composition. The original values can be either estimates from species descriptions in the literature or a set of values already calculated from another similar region. The plot data recorded during the field analysis for the guide supplied the community composition information used for adjusting Minnesota values to New England conditions. Following the methods used by Bakuzis (1959) in Minnesota and again by Brand (1985) in Michigan, the indices were adjusted in six stages for each of the four factors. Tables 5A and 5B demonstrate this procedure.

Step 1) Original relative values for each of the 4 factors--moisture, nutrients, heat, light--were assigned to each species. All numbers used for the original values were taken from the Minnesota set (Bakuzis 1959) where possible. A few species were not present in the Minnesota study and required new original values. Red spruce, Atlantic white-cedar, pitch pine, grey birch, and black birch were all assigned new values estimated from the literature and from personal experience. All species encountered in the field data were necessarily included in the calculations, even though only those species appearing in types in the key were finally included on the pages of the guide.

Step 2) Stand (community) synecological values were calculated simply as averages of the values of all species present. No regard was given to the relative importance (percent composition) of species unless they were considered rare--observed less than five times in the entire survey. In that situation, they were not part of the average.

Step 3) For each species, an "average-community" value was figured as an average of all the stands in which it occurred.

Step 4) All those species were grouped according to their original relative synecological values of 1, 2, 3, 4, and 5, respectively (with values taken from Step 1). (In table 5B, their newly calculated average community values are carried along with each species in parentheses).

Step 5) The average of the species' average-community values was calculated for each group, creating a new value.

Step 6) Each species was reassigned to a category by matching its average community value (obtained in Step 3) with the closest mean value for the new group (obtained in Step 5). The new relative values were derived by reading back across the table.

Table 5A.--A sample tabulation of moisture values, illustrating the first three steps in adjusting synecological coordinates to local circumstances. (1) Species abbreviations and corresponding Minnesota moisture values appear in the first two rows. The left column lists photo and plot numbers. Checkmarks indicate which species were encountered on a given plot. (2) The right column contains "community values." (3) In the bottom row, new values appear for each species representing the average of all the community values of all the plots on which that species occurred.

Step 2 ▼

	Species	GB	WB	YB	Asp	BC	BF	H	RM	SM	BO	RO	WO	PP	RP	WP	RS	Community values
Step 1➤	Original value	2	3	4	2	2	4	4	2	3	2	1	2	1	1	2	3	
	Photo and Plot (√'s incidate species occurrence on that plot)																	
	O14B 1								√	√	√	√	√			√		2.0
	2								√	√		√	√			√		2.0
	O14A 1								√		√	√	√			√		1.8
	2	√	√					√	√	√		√	√			√		2.4
	O12B 1		√			√						√	√			√		2.0
	2								√			√	√					1.7
	P62 1													√				1.0
	P63 1											√		√		√		1.3
	2	√	√						√					√		√		2.0
	B14W 1			√		√	√		√									3.0
	2		√	√	√		√		√								√	3.0
	3		√		√	√	√		√								√	2.7
	4	√	√			√	√		√								√	2.7
	5		√		√		√		√								√	2.8
	P44 1													√	√	√		1.3
	2								√					√		√		1.5
	3								√		√	√		√	√	√		1.4
	M18 1													√		√	√	2.0
Step 3➤	Average of community values	2.37	2.51	3.00	2.83	2.60	2.84	2.40	2.21	2.13	1.73	1.83	1.98	1.50	1.35	1.79	2.64	

Table 5B.--The last three steps in calculating synecological coordinates are: (4) grouping each species according to its original assigned value, (5) averaging community values of each of the species in the group to get a mean average community value for each of those groups, and (6) regrouping each species by matching their average community values to the closest mean average community value. The new relative values designation is found by reading back across the table to the left from each species. This example is a section from the New England calculations for moisture.

Relative values	Preliminary index groups (species average community value)	Mean avg. community values	Reassign according to new values
1	RO (1.83), PP (1.5), RP (1.35)	1.56	RO, PP, RP, BO, WP
2	GB (2.37), Asp (2.83), BC (2.60), RM (2.21), BO (1.73), WO (1.98), WP (1.79)	2.22	RM, SM, WO
3	WB (2.51), SM (2.13), RS (2.64)	2.43	GB, WB, H
4	YB (3.00), BF (2.84), H (2.40)	2.75	RS, Asp, BC, YB, BF
5	none		
	▲ **Step 4**	▲ **Step 5**	▲ **Step 6**

The method was first tested using only a portion of the field analysis data to investigate some of the possible parameters, such as whether to include intermediate and understory species in the calculations, or how much difference using different original values made. Nineteen species from 37 stands were involved. Only the values for moisture were calculated, but that was considered enough to evaluate the tendencies. In the first test, some difference in relative values was evident between the calculations using only canopy species and those including the understory and intermediate species. However, although some values were noticeably different in mid-calculation, the difference in final values was not substantial. The biggest difference occurred in beech, which showed up in the understory of many stands in which it was not present in the canopy. This tended to decrease the moisture values for beech dramatically and increase moisture values for those stands in which it was found in the understory. In the final calculation, only canopy species were used.

One important assumption in this method is that the stands sampled and used in the adjustment of environmental indices include the maximum diversity of stands in the region--coming from the entire range of possible communities. The test run, in which this assumption was not met, clearly illustrated this effect. In the test primarily pine, oak, and beech-birch-maple stands were used. These stands included hemlock, and it was thus included in the calculations, but the sample only captured the more xeric side of hemlock's range. As a result, the final synecological value for moisture for hemlock was skewed in the drier direction. In the final calculations, however, the condition of maximum diversity should be amply filled by the data collected during the field analysis for this guide, as the emphasis of the guide has been to represent all of the forest cover types of New England.

It is difficult to calculate synecological coordinates for those species that handle a wide range of conditions. If a species is frequently encountered on two different types of sites, such as wet and dry, and with correspondingly different associate species, the resulting synecological value will be a moderation of both extremes--often around the value 3--even if that species is rarely found on moderate sites. A similar problem occurs if a shade-intolerant species persists in stands after other shade-tolerant species have grown in, as often occurs with birch. In this situation, the light values for that shade intolerant species will be averaged with both its light and dark associates, resulting again in a single moderate value that does not tell the entire story. In these and similar situations, the final ecological values were adjusted to better reflect that species' establishment preferences.

Table 6 lists field adjusted values for New England, along with the relative values used as the original in calculating the New England coordinates, and the number of plots in which it occurred in the field data.

Table 6.--Relative values for moisture (M), nutrients (N), heat (H), and light (L) used in the ecological relations section of the guide. Values of 1 for M, N, H, and L represent dry, poor, cool, and dark, respectively.

Original values					Adjusted New England[a] values						
M	N	H	L	No. of stands	M	N	H	L	No. of stands	Common name	Scientific name
4	2	1	2	163	3	2	1	3	82	Balsam fir	*Abies balsamea*
3	4	4	2	est[b]	4	5	4	1	14	Striped maple	*Acer pensylvanicum*
2	2	3	3	70	2	2	2	3	215	Red maple	*Acer rubrum*
3	5	3	1	46	3	5	4	1	73	Sugar maple	*Acer saccharum*
4	5	2	2	13	4	4	3	1	86	Yellow birch	*Betula alleghaniensis*
3	2	2	2	new[c]	2	3	3	3	16	Black birch	*Betula lenta*
3	2	2	5	149	3	3	3	3	140	White birch	*Betula papyrifera*
2	2	3	5	new	2	2	2	5	43	Grey birch	*Betula populifolia*
4	2	2	1	new	4	2	1	1	11	Atlantic white-cedar	*Chameacyparis thyoides*
3	4	4	1	est	3	5	4	1	69	Beech	*Fagus grandifolia*
3	4	5	3	est	3	5	5	2	51	White ash	*Fraxinus americana*
5	1	1	5	33	5	1	1	5	8	Tamarack	*Larix laricina*
4	1	1	3	86	4	1	1	4	13	Black spruce	*Picea mariana*
3	2	1	2	new	3	2	1	2	106	Red spruce	*Picea rubens*
1	2	2	4	70	1	2	2	5	35	Red pine	*Pinus resinosa*
1	2	2	4	new	1	2	2	5	32	Pitch pine	*Pinus rigida*
2	2	2	3	106	2	2	2	3	139	Eastern white pine	*Pinus strobus*
2	2	2	4	129	3	2	2	4	59	Quaking aspen	*Populus tremuloides*
1	2	3	5	23	2	2	3	5	12	Pin cherry	*Prunus pensylvanica*
2	3	4	3	<5	2	3	3	3	36	Black cherry	*Prunus serotina*
2	5	5	2	8	1	4	5	3	43	White oak	*Quercus alba*
1	4	3	3	70	1	3	4	3	85	Northern red oak	*Quercus rubra*
2	3	4	4	est	1	3	5	4	25	Black oak	*Quercus velutina*
4	3	1	1	<5	3	3	2	1	62	Eastern hemlock	*Tsuga canadensis*

[a] When a species' value was thought to be unduly influenced in one direction or another by the associate species captured in the sample, adjustment of those values by one place was considered allowable. There were two exceptions: WB and YB were considered to be dramatically affected by their shade-tolerant associates and their light values were correspondingly adjusted by 2. The following values were shifted up (+) or down (-) on the key pages as a result of corrections that were deemed necessary to better reflect that species' establishment preferences in New England.

Species	Factor	From	To
Yellow birch	light	1	3
White birch	light	3	5
Beech	nutrients	5	4
Red spruce	light	2	1
Red pine	light	5	4
Pitch pine	nutrients	2	1
Aspen	light	4	5
White oak	nutrients	4	3
Red oak	moisture	1	2
Red oak	nutrients	3	4

[b] Estimated by Bakuzis and Kurmis (1978)

[c] New for New England

Appendix II

Development of the Composition Diagrams

Any cover type label necessarily includes a certain range of species composition. To properly apply the type classification, an interpreter should know the limits of this range. The example photos in a photographic key can represent only a fraction of the possible variation. To give the interpreter some perspective, a diagram has been included for each type in the guide to describe the range in species composition possible under its definition, and to depict where within that range the example stand occurs. Superimposed on the range of composition diagrams is an 'X' to demonstrate where within that range the example stand in the CIR stereogram occurs.

Ideally, the categories in any classification system should be distinct, mutually exclusive, and as exhaustive as possible, and to be depicted graphically, they must be. To do so, the inherently vague definitions presented in the SAF guide (Eyre 1980) were simply formalized. Using any and all of the cues given in the SAF guide, we established several rules to remain consistent across the types and to ensure that they are mutually exclusive.

First, the simple majority rule given in the SAF guide ("x/x/x comprise the majority") was applied to situations in which both a single species **and** a recognized combination of species compose a majority of the stocking. For example, a stand of 55 percent WP, 20 percent RO, and 25 percent RM would represent a majority of both WP and WP/RO/RM, each of which are recognized as forest cover types. In this instance of deciding between the single-species and the three-species type, a 30 percent cutoff was used. In other words, where that single species composed 50 percent or more of the stand (basal area), that stand was classified as the single-species type *unless* 30 percent or more of the remaining composition was made up of those associate species characteristic of the combination type (in this example, red oak and red maple). In such a situation, it could be argued that even though one species did compose a majority, it was probably just a result of chance or stand history and the stand "really" represented an example of the combination type. Similar rules were developed for all possible combinations. If a species combination composes a majority, while one or two of the title species also composes a majority (>50 percent) of the basal area, then:

when considering:
two-species types (for example, RS/BF)
- 25 percent is the lower limit for the other title species

with three-species types (for example, WB/RS/BF)
- 30 percent is the lower limit for both other title species combined
- 20 percent is the lower limit for a single species

These figures were chosen from clues given in *The forest cover types of the United States and Canada.* For example, "an added requirement was that a species must comprise at least 20 percent of the total basal area to be used in the type name" (Eyre 1980, p. 2). In the first situation, if red spruce (RS) represents 50 percent or more of the stocking and balsam fir (BF) makes up less than 25 percent, then it is not RS/BF. In the second situation, if red spruce (RS) represents 50 percent or more of the stocking and BF and WB together make up less than 30 percent of the stocking, then it is not WB/RS/BF. In the third situation, if RS/BF represents 50 percent or more of the stocking and white birch (WB) makes up less than 20 percent of the stocking, then it is not WB/RS/BF. The diagrams that were developed to depict these definitions were kept as simple as possible. Applying the above rules results in a general graphic format for each single-species, two-species, and three-species type. These are illustrated in Figure 4.

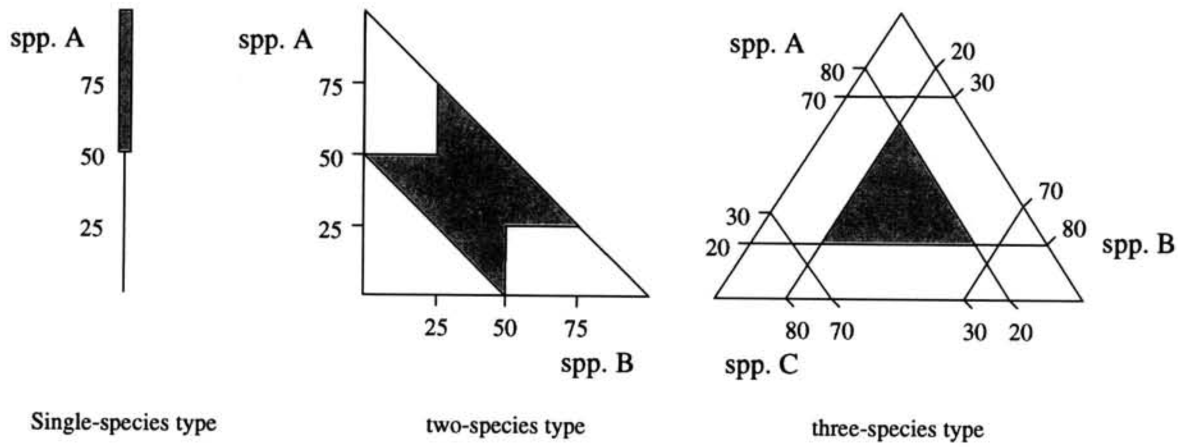

Figure 4.--The general format of composition diagrams for single-species, two-species, and three-species types when all the rules have been applied. The shading identifies that area considered to be the possible range of composition, in percent, for that type. Note the removal of the upper-left and lower-right corners of the two-species diagram. This indicates that composition is > 50 percent of one species and < 25 percent of the other. Stands falling in either of those areas would instead be classified as the corresponding single-species type. Note also the similar removal of the three corners of the three-species diagram by the 30 percent line, and the removal of the three edges by the 20 percent line.

Once the types had been made mutually exclusive, the next step was to ensure that the type definitions were exhaustive. This is necessary to avoid too many unclassified stands and to meet the assumptions of the accuracy analysis statistics. If

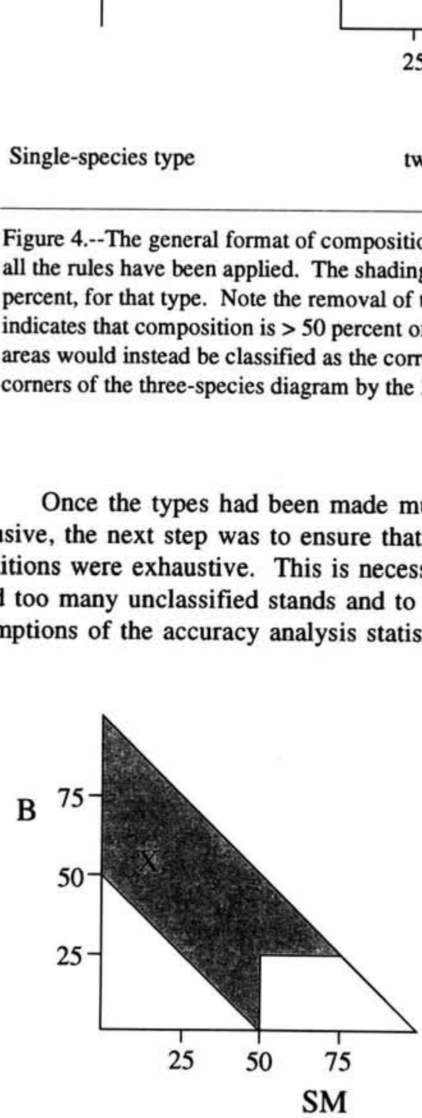

Figure 5.--This diagram is similar to that displayed in figure 4, but altered to include compositions of >50 percent B and < 25 percent SM in the Beech-Sugar Maple type because no Beech type is currently recognized in the guide.

only the types listed in the key are considered the universe of possible categories, using only the above rules allows many "holes", or possibilities that stand composition will not fit a definition and thus will not fit a type. To solve this, the constraints imposed on the range of composition were removed where the single-species (or two-species) types are not recognized as a type category in their own right. The range of composition diagram for the SM/B type provides a simple example. In this guide, sugar maple (SM) is recognized as a single-species type, but beech (B) is not. Because a B type is not recognized, the resulting range of composition diagram for SM/B looks like Figure 5. Thus, a stand with 55 percent B and 20 percent SM would be categorized (the 'x' in Figure 5) as SM/B. This removal of constraints was similarly applied to each type contained in this guide to create the range of compositions presently found on each key page.

Even after this adjustment, some exceptions remain and there are species combinations that still remain unclassified. The two problems that persist are:

(1) The diagrams do not take into consideration any species other than those mentioned

somewhere in a type in the key. In general, if the "other" species (for example, pin cherry, white spruce, black ash, black cherry and yellow-poplar) add up to more than 50 percent of the basal area in a stand, that stand could not be classified anywhere in this key. For example, a stand of 100 percent pin cherry could not be classified anywhere, and neither could a stand of 20 percent black cherry , 25 percent black ash, 10 percent yellow-poplar, and 45 percent sugar maple.

(2) A stand could not be classified even if it did contain greater than 50 percent of combined recognized species if those species combinations were not recognized as a type. An example of this would be 40 percent red maple, 20 percent yellow birch, and 40 percent hemlock, where no single species meets the 50 percent-or-more requirement, and neither RM/YB/H, RM/YB, RM/H, or YB/H are recognized types.

The advantage of an exhaustive system of type categories is that almost all of the stands found in New England would fall into some type classification. The disadvantage is that the range diagrams created are sometimes alarmingly broad, especially if no similar types are recognized. This stretches the imagination as to whether an extreme stand can still be considered that type, and probably decreases the chance that a stand at the extremes of the definitions will be classified correctly.

As already mentioned, the "holes" in the definitions were evaluated on the basis of how often such "deviant" stands occurred. The type combinations being used in this guide were chosen because they represented the majority of what can be found in New England, so the occurrence of unclassified stands should theoretically be low. If this is ever found not to be true, then perhaps a new type needs to be recognized and added to the key, and the user should feel free to do so.

Notes on Diagram Layout

The first two (single- and two-species) diagrams allow for "other" species to exist. Correspondingly, the requirement for the component species to compose 50 percent or more of a stand is shown as a boundary line in both diagrams (see Figure 6).

Such a line does not exist in the triangular three-species diagrams in this guide -- there is no space in the two-dimensional graph for the "other" species. A three-dimensional representation of the diagram, complete with the 50 percent-or-greater line, is illustrated in Figure 7.

The triangle face of the diagram in the guide thus does not represent 100 percent of the composition of the stand. Rather, it represents 100 percent of the "non-other" component of the stand (the "title" species concerned in that particular type), or the proportions of WP, RO, and RM to each other. For example, a stand of 50 percent WP, 20 percent RM, 15 percent RO and 15 percent RP would find its position in the WP/RO/RM diagram as 50/85 = 59

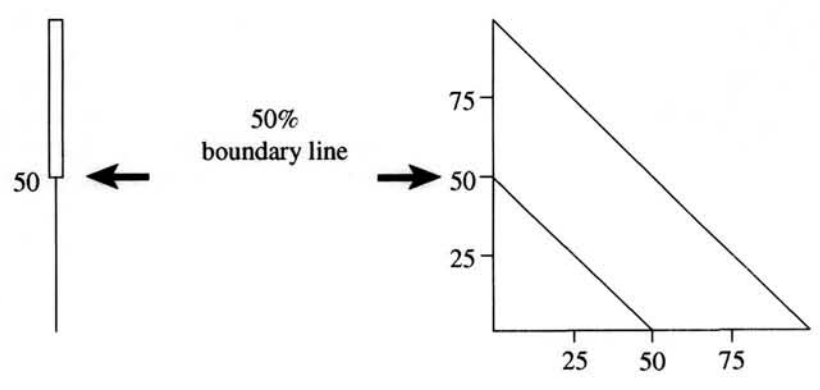

Figure 6.--All the definitions require that the species combination compose at least 50 percent of the stand. The single- and two-species diagrams illustrate the 50 percent bounding line.

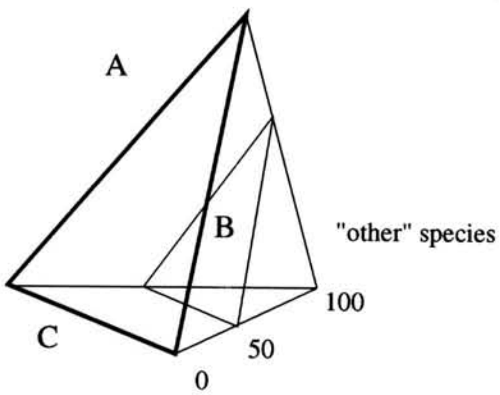

Figure 7.--A three-dimensional version of the diagram for a three-species type. The triangle face in **bold** is the part of this diagram that is presented in the guide. The smaller triangle parallel to the first represents the 50 percent minimum boundary line.

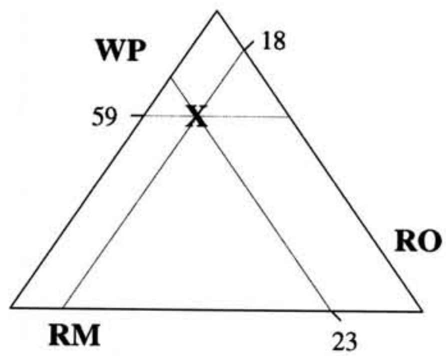

Figure 8.--To present a species composition of 50 percent WP, 20 percent RM and 15 percent RO on the three-species diagram in the guide, it is necessary to convert the values such that the component species total 100%. For example, 50+20+15=85, thus 50/85=59 percent, 20/85=23 percent and 15/85=18 percent. It is these converted species percentages that are depicted on the three-species diagrams in the guide.

percent WP, 20/85 = 23 percent RM, and 15/85 = 18 percent RO (85 = 50+20+15 = total component or "title" species) (see Figure 8). The actual percentage of composition of the component species as well as the percentage of "other" species in the example photo does not appear in the range of composition diagram, but is given in the caption under the CIR stereogram. To remain consistent with the one- and two-species diagrams, the lines representing the range of composition are with respect to all the trees in the stand, not just those of the major component species. In other words, if White Pine equals 70 percent or greater of the total species composition, it no longer fits into this type. This is a potentially confusing element, but one which is maintained for ease of use.

Figure 9 shows examples of each type of diagram and provides explanations of the boundary lines where they occur. To the left of each diagram is a written version of the composition as it is depicted in the diagram. Anything preceded by "unless" is necessary to make the compositions mutually exclusive. Such rules are incorporated into the composition diagrams of the multi-species types, but cannot appear in single-species and occasionally two-species diagrams. This information is not included on the key pages as it is in Figure 9, because it would give the range of composition diagram the appearance of being a more precise definition than it is.

Variations within a single type will always occur among stands, and the range of composition diagram gives some sense of the range of possibilities a photointerpeter may encounter.

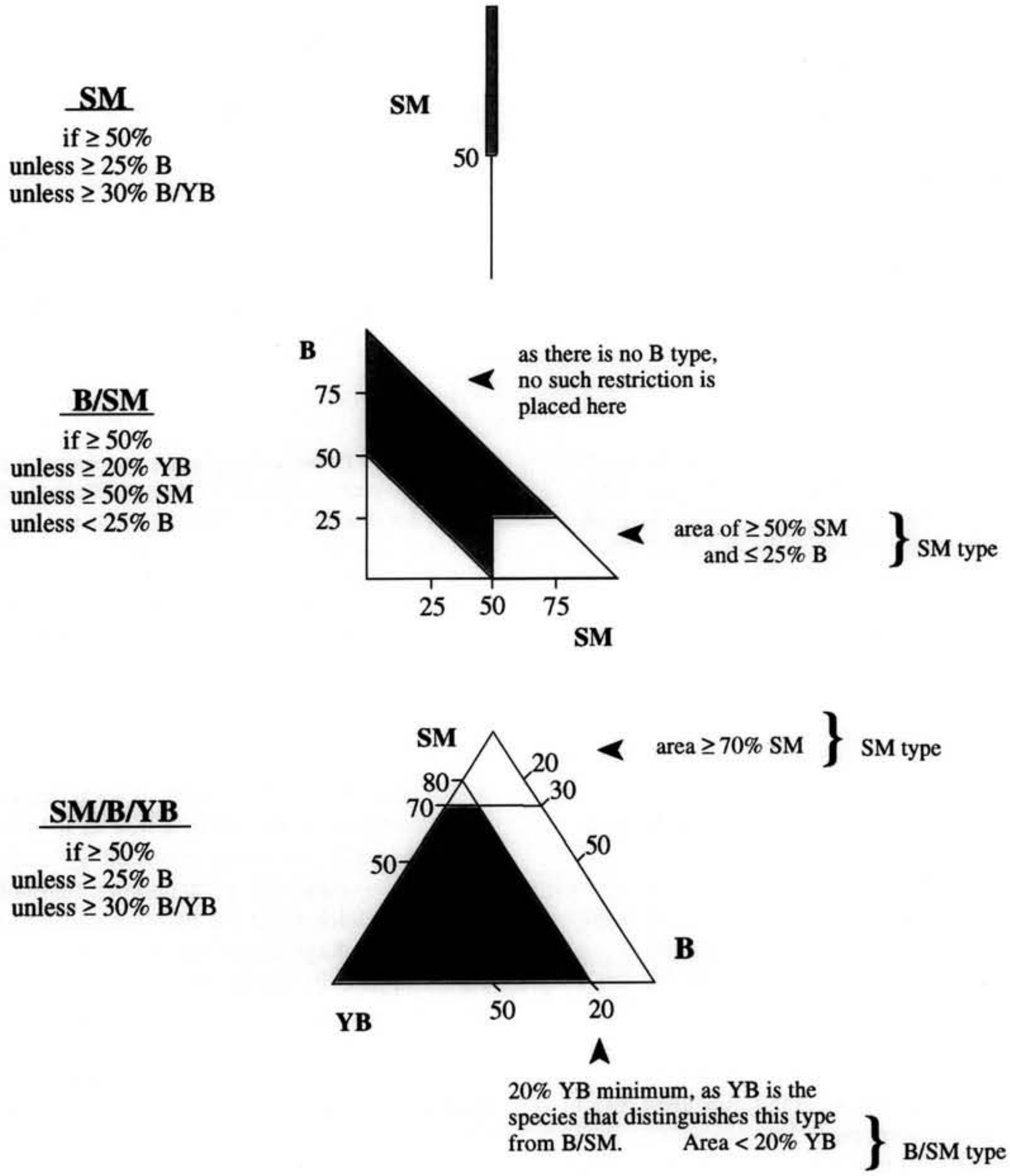

Figure 9--Development of the type definitions requires a comparison between related types. The "if" statements describe the conditions in the diagram immediately to the right. The "unless" statements, when true, direct the user to another type diagram.