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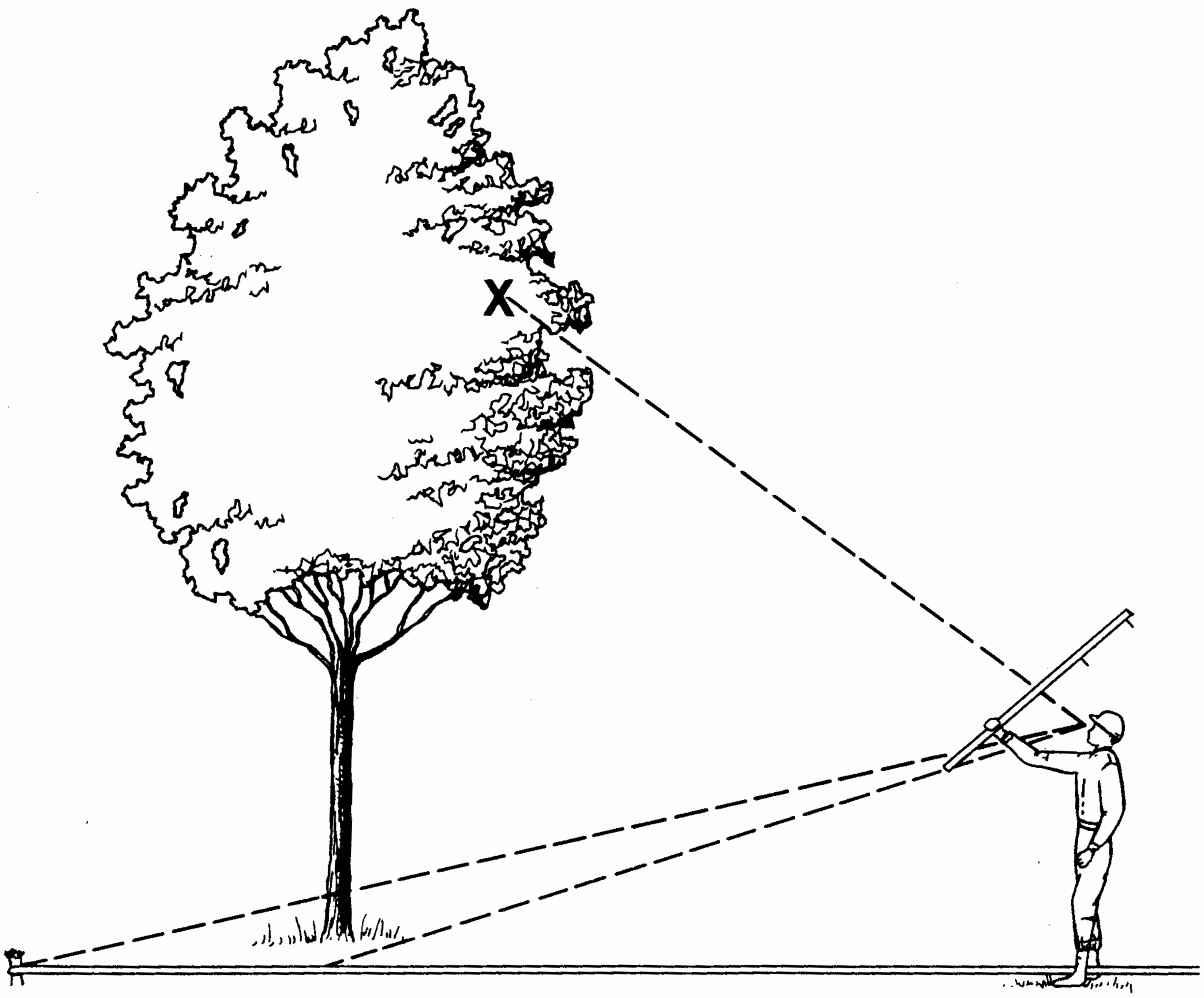
# ESTIMATING WILDLIFE HABITAT VARIABLES




Fish and Wildlife Service

**U.S. Department of the Interior**

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# ESTIMATING WILDLIFE HABITAT VARIABLES

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# 1. INTRODUCTION

## 1.1 PURPOSE

The purpose of this publication is to provide operational descriptions of several existing techniques suitable for quantitatively measuring wildlife habitat variables. As defined here, habitat variables include various characteristics of vegetation, soils, water, and landform, measurements that do not depend on the presence of a wildlife population. Therefore, the techniques described are not appropriate for directly studying wildlife populations.

The habitat variables addressed in this manual are those that have been frequently used during 2 years of habitat modelling efforts by the Habitat Evaluation Procedures Group, Western Energy and Land Use Team, U.S. Fish and Wildlife Service (FWS). We have tried to include techniques that are the most relevant and useful for measuring these variables. Consequently, other potential habitat variables and measurement techniques have not been included.

We have emphasized techniques that are inexpensive in application, require relatively inexpensive equipment, and represent the state-of-the-art. Several familiar techniques have been excluded (including the older "plotless" techniques for estimating density of plants). Several good remote sensing techniques exist for estimating certain variables, but are not included because they are described in a well written and useful handbook by Avery (1978). References to remote sensing techniques discussed in that handbook have been included herein as appropriate, and some comments on remote sensing to supplement Avery's handbook are included in Appendix B.

For many of the techniques described herein, the sample area is assumed to be "homogeneous" with respect to the variables being estimated. The significance of the assumption of homogeneity will depend upon habitat mapping conventions and the overall sampling design. This publication does not describe mapping techniques or the development of a sample design (including statistical techniques).

This publication is intended to be useful in the field as a tool for the user who is generally familiar with ecological terminology, knows the important plant species in an area, and has a working knowledge of trigonometry. Consequently, we have not included the theoretical bases for the techniques. We strongly encourage user feedback that will assist us in future revisions to improve the useability of this manual. Such comments should be sent to the Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Fort Collins, CO. 80526.

## 1.2 FORMAT

Following the introduction is a glossary of the habitat variables to be estimated. Each entry discussed includes one or more definitions, some common uses for the variable, and a list of the techniques suitable for measuring that variable. This discussion differs from conventional glossaries in that we have included multiple meanings and closely related concepts in common use among resource specialists in wildlife biology and related fields. Much ambiguity and confusion exists in the use of terms in these fields. This attempt to be relatively complete and exhaustive has the disadvantage of requiring more definitions and more complex language. Techniques referenced in the glossary are either included in this handbook, or are remote sensing techniques described in Avery (1978). Following the glossary is a table (5) showing the variables and techniques suitable for measuring them. This table is designed to assist the user in identifying the combination of techniques appropriate for measuring multiple habitat variables during the same field trip. Following Table 5 are the descriptions of the individual techniques and the appendixes.

The format for each technique description is as follows: first is the technique name. An established name was used when one was known. Otherwise the author who originated the technique may be cited, or the instrument used, or the variable being measured. Some commonly used alternative names are included parenthetically. Following this is a list of variables which can be estimated using the techniques. Next is the "Description." The first paragraph is a summary. Following this is a discussion of locating samples, collecting data, and reducing data to calculated results, as appropriate. The next section, "Accuracy," includes a general qualitative statement about the accuracy of the technique, and discusses sources of errors and how they can be minimized. (This section does not discuss either statistical techniques for increasing precision such as increasing sample size, or quantitative ways of measuring the statistical error.) "Application Notes" gives guidance on the relative cost of the technique, the number of people required to apply it, and the types of vegetation or soil conditions which may cause problems in applying the technique. The next section, "Training", includes an estimate of the length of time required to become moderately proficient in the technique. "Equipment" is listed next, with some indication of cost in 1980 dollars. The "Cost" section provides an estimate of the average number of measurements that can be collected in a given time or the amount of time required to make one measurement. This assumes that the crew size is the optimum discussed under the "Application Notes" section. The "References" section provides a list of scientific papers and other sources related to the technique. We have not tried to be exhaustive in this section. Sections were deleted if there was no significant content, e.g., negligible cost.

# 2. HABITAT VARIABLES AND TECHNIQUE SUGGESTIONS

## 2.1 INTRODUCTION

These definitions are rewritten from a large number of sources. Although we have attempted to include the more important uses of terms, we do not claim to have been exhaustive. The remote sensing techniques (indicated by "RS:") that are well suited for estimating the variables are described in Avery (1978). The entries are laid out to reflect the grouping of concepts indicated in Table 1. That table can be used as a key to locate the appropriate terms. Table 5, at the end of this section, summarizes which techniques are suitable for estimating each variable.

## 2.2 PROPERTIES OF INDIVIDUAL PLANTS

### 2.2.1 Basal Area

The area of exposed stem if the plant were cut horizontally at a specified height (Units: area; e.g., $m^2$). Ecologists and range managers typically use a height close to the ground surface (e.g., about 2.5 cm; 1 inch); foresters typically use "breast height" (1.4 m; 4.5 ft). In the United States, the ground level for the measurement of "breast height" is usually the point midway between the highest and the lowest level of the ground at the stump of a tree. Basal area is used in forestry to calculate volume of wood in the tree.

Suggested technique: Calculated Area of a Plant (p. 15).

### 2.2.2 Canopy Area

The area of a vertical projection on a horizontal surface of a polygon drawn around the plant's perimeter which ignores small gaps between branches. (Units: area, e.g., $m^2$).

Suggested technique: Calculated Area of a Plant (p. 15).

### 2.2.3 Canopy Diameter (or Crown Diameter)

The average maximum width of the polygon used for "canopy area" (above).

Suggested techniques: Crown Diameter (p. 15); Diameter Tape (p. 18); RS: Crown Wedge; and RS: Crown Diameter (Dot) Scale.

### 2.2.4 Plant Height

The mean vertical distance from the ground at the base of the plant to the level of its tallest part. The mean ground level is taken as half way between the highest and lowest points. Sometimes height is restricted to exclude reproductive structures. Plant height is used in forestry to calculate the volume of wood in the tree.

Table 1. Organization of discussions of habitat variables.

Suggested techniques: Merritt Hypsometer (p. 19); Christen Hypsometer (p. 22); Trigonometric Hypsometry (p. 25); Graduated Rod (p. 28); Optical Range Finder (p. 30); RS: Parallax Wedge; and RS: Parallax Bar. See Table 2 for a comparison of these techniques' suitability under various study conditions.

### 2.2.5 Stem Diameter

The average maximum width of the polygon formed by passing a horizontal plane through a plant at a specified mean height above the ground. Foresters typically use "breast height" (1.4 m; 4.5 ft). Ecologists and range managers typically use a height close to the ground surface (e.g., about 25 cm; 1 inch). For multistemmed plants, diameter can be given separately for each stem. Stem diameter is used in forestry to calculate volume of wood in the tree and in wildlife management to predict the suitability of the tree for hole or cavity nesting animals.

Suggested techniques: Diameter tape (p. 18); and Biltmore Stick (p. 32).

### 2.2.6 Vertical Projection of a Point to the Ground.

The point on the ground that is directly underneath a point in the air. Points are projected vertically in the Line Intercept technique and in measurements of the size of a tree's canopy.

Suggested techniques: Lindsey Sighting Level (p. 35); and Vertical Rod (p. 39).

## 2.3 PROPERTIES OF VEGETATION, LITTER, AND SOIL SURFACE

### 2.3.1 Cover

The proportion of the site included in vertical projections on to a horizontal surface of the site component referred to (e.g., oak trees or brush piles). Cover is usually expressed as a percentage. Cover may be absolute or relative. If not specified, absolute is usually intended. Absolute is calculated with respect to the area of the site. Relative is calculated with respect to the total area of all site properties of a specified type. For example, cover of oak trees can be calculated with respect to all trees. "Ten percent relative cover by oaks" means 10% of the area of all trees is made up of oaks. The sum of the absolute cover values for a site often exceeds 100% because of overlap by plants. Relative cover values must always total 100%. (For suggested techniques see Basal, Canopy, or Foliar Cover below).

### 2.3.2 Basal Cover (or Basal Area, compare with 2.2.1 above)

The projections used in the definition of cover (section 2.3.1 above) are from stems' intersection with a plane at some specified height above the ground. Foresters typically use "breast height" (1.4 m; 4.5 ft) and exclude plants smaller than a specified limit (usually 2.5 or 10 cm; 1 or 4 in). Ecologists and range managers typically use a height close to the ground (e.g., about 1 in). This is often called "basal area" in forestry, and is expressed not in percent, but rather as $m^2/ha$ or $ft^2/ac$.

Table 2. Guide to suitability of techniques for estimating plant height, under various study and site characteristics.

Note: This is a rough guide only. Consider techniques which are depicted as nearly as good as the best one(s). "A" indicates usually well suited or applicable. "a" indicates somewhat or sometimes suited or applicable. Blank indicates usually unsuited or not applicable.

| Technique | Height of plants | | | Visibility of tree bases and tops | | | Crew size | |
|---|---|---|---|---|---|---|---|---|
| | <2 | 2-15m | >15 | Low | Medium | High | 1 | >1 |
| 4. Merritt Hypsometer | | A | A | | | A | A | a |
| 5. Christen Hypsometer | | A | A | | A | A | A | A |
| 6. Trig. Hypsometry | | A | A | | A | A | A | |
| 7. Graduated rod | A | a | | a | A | A | A | a |
| 8. Optical range finder | | A | A | A | A | A | A | |

Use: In forestry to calculate total volume of harvestable wood on the site.

Suggested techniques: Line Intercept (p. 40); Bitterlich Method (p. 43); Calculated Cover (p. 50); Point Intercept - Step Point (p. 50); Point Intercept - Pin Frame (p. 52). See Table 3 for a comparison of these techniques' suitability under various study conditions.

2.3.3 Canopy Cover (and Brushpile Cover and Bare Ground)

The projection used in the definition of cover (section 2.3.1, above), is the general outline of plants, ignoring minor gaps between branches and holes in the center of the plant. This is typically used for single strata (layers) in the vegetation. It is hard to define the general outlines when plants have overlapping branches. Hence, it is used most when plants do not overlap much. It is also called "crown closure." Brushpiles can be treated with this concept. Bare ground is sometimes calculated by subtracting absolute cover values for all the plants in the community from 100%. Under this approach, litter is often treated as "bare ground", and patches of bare soil underneath trees and shrubs are not counted as "bare ground" (see also Foliar Cover, section 2.3.4). Canopy cover is used in forestry to calculate total volume of wood on a site from aerial photos, and in wildlife management as an indication of the amount of vegetation in various strata (and, hence, to indicate the availability of food and cover).

Suggested techniques: Line Intercept (p. 40); Bitterlich Method (p. 43); Calculated Cover (p. 50); Point Intercept - Step Point (p. 50); Point Intercept - Pin Frame (p. 52); Point Intercept - Spherical Densiometer (p. )55; Point Intercept - Canopy Camera (p. 56); Ocular Estimation of Cover (p. 58); and RS: Crown Density Scale; Bitterlich Method; Ocular Estimation of cover. See Table 4 for a comparison of these techniques' suitability under various study conditions.

2.3.4 Foliar Cover (and Litter Cover and Bare Ground)

The projection used in the definition of cover (section 2.3.1, above) is for each separate plant part. Thus, gaps between leaves or branches do not contribute to the measured cover. As usually applied, "foliar" also includes stems, flowers, and all other plant parts. Litter on the ground, e.g., dead leaves and branches, is usually treated with this concept. What constitutes "litter" must be clearly defined, because there is a continuum between freshly fallen plant parts and highly decomposed material whose source can no longer be recognized. Bare ground is sometimes measured directly in terms of this concept. However, bare ground is also sometimes measured wherever there are no plant parts or litter close to (above) the surface, even though taller plant parts (e.g., a tree's branches are present above the point) (see also Canopy Cover, section 2.3.3). Foliar and litter cover are used in forestry and range management to predict erosion rates; foliar cover is used in ecology to predict primary production.

Suggested techniques: Point Intercept - Step Point (p. 50); Point Intercept - Pin Frame (p. 52); Point Intercept - Spherical Densiometer (p. 55); Point Intercept - Canopy Camera (p. 56); Ocular Estimation of Cover (p. 58).

Table 3. Guide to suitability of techniques for estimating basal cover, under various study and site characteristics.

Note: This is a rough guide only. Consider techniques which are depicted as nearly as good as the best one(s). "A" indicates usually well suited or applicable. "a" indicates somewhat or sometimes suited or applicable. Blank indicates usually unsuited or not applicable.

| Technique | Growth form of plants: Trees (>2.5cm DBH) | Growth form of plants: Shrubs & small trees | Growth form of plants: Bunch grasses and cushion plants | Growth form of plants: Other herbs | Plant density: <20/ha | Plant density: >20/ha | Basal Cover: <5% | Basal Cover: >5% | Minimum cost to apply: Low | Minimum cost to apply: High | Maximum accuracy: Low | Maximum accuracy: High | Crew size: 1 | Crew size: >1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. Line intercept | | | A | | | A | | A | | A | | A | | A |
| 13. Bitterlich method | A | | | | | A | | A | A | | | A | A | |
| 14. Calculated cover | A | A | A | A | A | A | A | A | A | | | A | a | A |
| 15. Step point | | | A | A | | A | | A | A | | A | | A | |
| 16. Pin frame | | | A | A | | A | | A | | A | | A | a | A |

Table 4. Guide to suitability of techniques for estimating canopy cover, under various study and site characteristics.

Note: This is a rough guide only. Consider techniques which are depicted as nearly as good as the best one(s). "A" indicates usually well suited or applicable. "a" indicates somewhat or sometimes suited or applicable. Blank indicates usually unsuited or not applicable.

| Technique | Plant height | | | Plant density | | Cover | | | Minimum cost to apply | | Maximum accuracy | | Crew size | | Topography | | Plant crowns | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <½ m | ½ - 2 m | >2 m | <20/ha | >20/ha | <5% | 5-50% | >50% | Low | High | Low | High | 1 | >1 | Rough | Smooth | Round & full | Irregular & sparse |
| 12. Line intercept | A | A | a | | A | | A | A | | A | | A | | A | | A | A | A |
| 13. Bitterlich method | A | A | | A | A | | A | | A | | A | | A | | | A | A | |
| 14. Calculated cover | A | A | A | A | A | A | A | | A | | A | a | a | A | A | A | A | a |
| 15. Step point | A | | | A | A | | A | A | A | | A | a | A | | A | A | A | A |
| 16. Pin frame | A | | | | A | | a | A | | A | | A | a | A | A | A | A | A |
| 17. Spherical densio. | | | A | | A | | a | A | | A | | A | A | | A | A | A | A |
| 18. Canopy camera | | | A | | A | | a | A | | A | | A | A | | A | A | A | A |
| 19. Ocular est. cover | A | | | | A | A | A | A | A | | A | | A | | A | A | A | a |

2.3.5 Density

The number of individuals per unit area of site. This may be either relative or absolute (see Cover, section 2.3.1). (Units: number/area; e.g., number/ha). If not specified, absolute is usually intended. What constitutes an individual is defined variously. Often, each stem arising from the ground is considered an individual, irrespective of below ground connections between stems. Alternatively, if a plant species' growth form is typically to have many stems that are separate above ground but arising from a common rootstock, and rootstocks are distinctly separated from one another by gaps, a clump can be considered one individual. Density is used in several fields as the measure of the population size of individual species.

Suggested techniques: T-Square Nearest Neighbor Sampling (p. 62); and Quadrat (p. 65).

2.3.6 Foliage Height Diversity

An index of the structure of vegetation as calculated using the Shannon-Weiner index (see Calculated Foliage Height Diversity, section 3.22). Foliage Height Diversity is used in wildlife management as a measure of the diversity of habitats for birds.

Suggested technique: Calculated Foliage Height Diversity (p. 68).

2.3.7 Frequency

The probability of a randomly located sample plot of specified shape and area containing one or more plants of a particular species or group of species. Frequency may be absolute or relative (see Cover, section 2.3.2). Measured frequencies for the same area may differ dramatically if plot area or shape is altered. Frequency is used in ecology as a measure of the degree of inter-specific competition and diversity in spatial pattern.

Suggest technique: Quadrat (p. 65).

2.3.8 Height

The average of the heights of individual plants (see Plant Height, section 2.2.4) in a specified group. Usually, this applies to plants of a particular growth form and presumed age class, such as mature overstory trees, or mature herbs. The group referred to is rarely defined clearly. Height is used in forestry to predict total volume of wood on a site.

Suggested techniques: Averaging (p. 69) of the results of the following: Merritt Hypsometer (p. 19); Christen Hypsometer (p. 22); Trigonometric Hypsometry (p. 25); Graduated Rod (p. 28); or Optical Range Finder (p. 30).

2.3.9 Horizontal Foliar Density

This variable is used in two closely related ways. In the first, it is the extent to which horizontal visibility over a specified distance is restricted by vegetation (Units, percent cover). In the second, it is the distance over which one-half of a target's area is obscured (Units: length, e.g., m). Both are usually measured at a specified height, or several heights within a range (such as every 10 cm up to 2 m). Foliage Height Diversity is used in wildlife management as a measure of hiding cover.

Suggested technique: Vegetation Profile Board (p. 70).

2.3.10 Litter Depth

The average vertical distance from the ground surface to the top of the litter layer. Litter Depth is used in ecology to predict rate of nutrient recycling by decomposition.

Suggest technique: Averaging (p. 69) of results of Graduated Rod (p. 28).

2.3.11 Species Diversity, Evenness (or Equitability) Component

The extent to which the population densities of the species in a given area are similar. Evenness is maximum if each species has the same density. Evenness goes down to the extent that some species have high densities and others low. Usually, this is restricted to specified types of species, such as only the herbs. Species Diversity is used in ecology as a measure of ecosystem diversity.

Suggested technique: Calculated Community Dominance (p. 74).

2.3.12 Distance

Distance from a site to the nearest example of a specified feature, e.g., a road, is usually measured horizontally from the part of the site closest to the feature.

Suggested techniques: Optical Rangefinder (p. 30); Map Measurer (p. 75); Pacing (p. 76); and RS: Scale.

2.3.13 Edge Length Per Unit Area

Edge is defined as the line separating two different adjacent cover types. Edge length, then, depends on the specified classification of cover types. Typically, the edge is delineated so that it forms a more or less smooth curve and has a minimum radius of several meters. It is usually highly subjective. Edge Length per Unit Area is used in wildlife management as a measure of habitat availability for ecotonal (edge) wildlife species.

Suggested techniques: Line Intercept Measurement of Edge (p. 78); Calculated Edge/Area (p. 82).

2.3.14 Patton's Diversity Index (or Shoreline Development Index)

The ratio between the length of edge around a site to that of a circle having the same area. This is referred to as the shoreline development index when applied to lakes. Patton's Diversity Index is used in wildlife management as a measure of habitat availability for ecotonal species.

Suggested technique: Patton's Diversity Index (p. 83).

2.3.15 Site Area

The area of a continuous polygon of a particular specified cover type, ignoring (i.e., counting) inclusions of other cover types smaller than a specified area. This is dependent on the specified classification of cover types, the specified criterion for ignoring small inclusions of different cover types, and the way in which "edge" is delineated (see Edge Length Per Unit Area, section 2.3.13). Delineating boundaries, including decisions on recognizing or ignoring inclusions, is often subjective.

Suggsted techniques: Point Grid (p. 84); and RS: Scale and Geometric Formulas.

2.3.16 Site Linear Dimensions

Length is usually taken as the maximum (or average) distance between extreme ends of the site. Sometimes length is defined to require measuring along a curve that follows the middle of the site, as for riparian vegetation along a meandering river. Width is usually taken as the largest (or average) distance between points in the site perpendicular to the length.

Suggested techniques: Optical Rangefinder (p. 30); Map Measurer (p. 75); Pacing (p. 76); and RS: Scale.

## 2.4 PROPERTIES OF LANDFORM, SOIL, AND WATER BODIES

2.4.1 Slope

The dihedral angle between the horizontal and the plane of the ground surface. (Units: percent; i.e., vertical rise/horizontal run; e.g., 45° = 100%. Sometimes expressed as angle degrees). This is usually taken as an average over areas of at least 0.1 ha.

Suggested technique: Averaging (p. 69) of the results of the following: Slope and Aspect from Topographic Maps (p. 85); Clinometer and Compass (p. 87); or RS: Parallax Wedge and Scale.

2.4.2 Aspect

The direction of "downhill" on a slope. Precisely, this is the direction of "down" along the ground in a dihedral angle between the horizontal and the plane of the ground surface. (Units: compass direction in cardinal points; e.g., north, southwest, or in degrees).

Suggested technique: Averaging (p. 69) of the results of the following: Slope and Aspect from Topographic Maps (p. 85); Clinometer and Compass (p. 87); or RS: Parallax Wedge and Scale.

2.4.3 Soil Texture

The relative proportions of the inorganic particles in the following three size classes: clay, silt, and sand (less than 2 mm diameter). (Units: usually percent of each of the three classes).

Suggested technique: Soil Texture by Feel (p. 90).

2.4.4 Width of Water Body

For streams, this is usually the average distance between the water's edges perpendicular to the direction of water flow. For lakes and ponds, it is usually the maximum distance between water's edges perpendicular to the longest distance. Sometimes the width referred to is for a water level different from the current one; e.g., mean level, "bank full", or peak (for lakes).

Suggested techniques: Optical Rangefinder (p. 30); and Averaging (p. 69) of the results of the following: Map Measurer (p. 75); or RS: Scale.

2.4.5 Water Depth

This is the vertical distance from the bottom to the surface. It sometimes refers to the depth when the water level is different from the current one; e.g., mean level, or maximum or peak level.

Suggested technique: Averaging (p. 69) of the results of Graduated Rod (p. 28).

2.4.6 Surface Water Velocity

The velocity at which water is flowing at the surface of a stream. (Units: length/time; e.g., m/s). This is usually expressed as an average over a stretch of stream parallel to flow. It can also be used for the peak (i.e., the rate that is highest in the stream's cross section), or the average (i.e., the mean of the velocity of all the points in the stream's cross section).

Suggested technique: Averaging (p. 69) of the results of Floating Body (p. 92).

Table 5. Matrix of habitat variables and techniques (for Remote Sensing techniques, see Avery 1978).

| Variable | 3.1 C. Area of plant | 3.2 Crown diameter | 3.3 Diameter tape | 3.4 Merritt tape | 3.5 Christen hypsom. | 3.6 Trig. hypsometry | 3.7 Graduated rod | 3.8 Optical range f. | 3.9 Biltmore stick | 3.10 Lindsey s. level | 3.11 Vertical rod | 3.12 Line intercept | 3.13 Bitterlich method | 3.14 Calculated cover | 3.15 Step point | 3.16 Pin frame | 3.17 Spherical densio. | 3.18 Canopy camera | 3.19 Ocular est. cover | 3.20 T-square sampling | 3.21 Quadrat | 3.22 C. fol. ht. div. | 3.23 Averaging | 3.24 Veg. profile 3D. | 3.25 C. community dom. | 3.26 Map measurer | 3.27 Pacing | 3.28 Line int. m. edge | 3.29 C. edge/area | 3.30 Patton div. index | 3.31 Point grid | 3.32 Slope/a. topo map | 3.33 Clinom. & compass | 3.34 Soil texture feel | 3.35 Floating body | † Remote sensing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I. A. Basal area | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B. Canopy area | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. Canopy diameter | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| D. Plant height (litter depth) | | | | X | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| E. Stem diameter | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F. Vertical projection | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| II. A. 1a Basal cover | | | | | | | | | | | | X | X | X | X | X | | | | | | | | | | | | | | | | | | | | |
| b Canopy cover (brushpile cover) | | | | | | | | | | | | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | X |
| c Foliar cover (litter cover) | | | | | | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | | | | | | |
| 2 Density | | | | | | | | | | | | | | | | | | | | X | X | | | | | | | | | | | | | | | |
| 3 Foliage height diversity | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 4 Frequency | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | |
| 5 Height | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | |
| 6 Horizontal foliar density | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | |
| 7 Litter depth | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | |
| 8 Species diversity, evenness | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| B. 1 Distance: Site to feature | | | | | | | | X | | | | | | | | | | | | | | | | | | X | X | | | | | | | | | X |
| 2 Edge length/area | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | | | | | | | |
| 3 Pattons diversity index | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | |
| 4 Site area | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | X |
| 5 Site linear dimensions | | | | | | | | X | | | | | | | | | | | | | | | | | | X | X | | | | | | | | | X |
| III. A. Scope | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | X | X | | | X |
| B. Aspect | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | X | X | | | X |
| IV. A. Soil texture | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| V. A. Width of water body | | | | | | | | X | | | | | | | | | | | | | | | X | | | X | | | | | | | | | | X |
| B. Water depth | | | | | | | X | | | | | | | | | | | | | | | | X | | | | | | | | | | | | X | |
| C. Stream current velocity | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | |

# 3. TECHNIQUE DESCRIPTIONS

## 3.1 CALCULATED AREA OF A PLANT

### 3.1.1 Variables Estimated

Canopy or basal area of an individual plant (p. 3).

### 3.1.2 Description

In summary, the results of measurements of diameter of a plant are converted to area by calculation.

If a measured diameter (Techniques 3.2 or 3.3) is available for a plant canopy or stem that is approximately circular, its area can be calculated by assuming it to be a circle. The following formula should be used:

$$A = \frac{\pi D^2}{4} = 0.785D^2$$

where A = area (square of the units of length used for D)

D = diameter (length)

### 3.1.3 Accuracy

The accuracy of the calculated area is a function of the accuracy of the diameter measured and the degree to which the plant conforms to a truly circular shape. For plants that appear to be circular, accuracy is quite good. If the shape deviates from circularity to a degree that is obvious, error can become appreciable. For example, Loestch et al. (1973:93) show errors in calculated areas ranging from 4.3% to 16.1% using diameter measured with a Diameter Tape (p. 18).

### 3.1.4 Application Notes

This technique is most appropriate when plants conform to near circularity, and it is relatively easy to measure the diameter. It becomes less appropriate when plants deviate dramatically from circular cross section, or become so large as to make diameter measurements cumbersome.

### 3.1.5 Reference

Loetsch et al. 1973.

## 3.2 CROWN DIAMETER

### 3.2.1 Variable Estimated

Canopy diameter of an individual plant (p. 3).

### 3.2.2 Description

In summary, the diameter is measured directly with a meter tape.

Where the average for a particular kind of plant on the site is the desired variable (using Technique 3.23), the plant to be measured should be chosen randomly (as discussed in Appendix A). A meter tape is then passed horizontally through the approximate center of the plant from one side to the other. The diameter at that point is recorded. Because plants are rarely circular, it is necessary to take at least one other diameter measurement roughly perpendicular to the first. Ideally, these two diameter measurements should be made through the widest and the narrowest diameters of the canopy respectively (Fig. 1a). If it is not feasible to pass the tape measure through the center of the plant, the tape may be stretched outside of the plant's canopy at a tangent. A protractor is held to the zero end of the tape and one aligns it with the tape measure, and then sights at the 90° mark. The edge of the plants' canopy should be aligned with that 90° angle, and the end of the tape held at that point. Another crew member stretches the tape until it is straight, then moves another protractor along the tape until he can sight over the 90° mark at the other edge of the canopy (Fig. 1b).

When the final variable desired is the diameter, the mean canopy diameter is calculated with the following formula (arithmetic mean):

$$\bar{D} = \frac{\sum_{i=1}^{n} D_i}{n}$$

where $\bar{D}$ = mean diameter

$D_i$ = a single measurement of diameter

$n$ = number of diameters measured

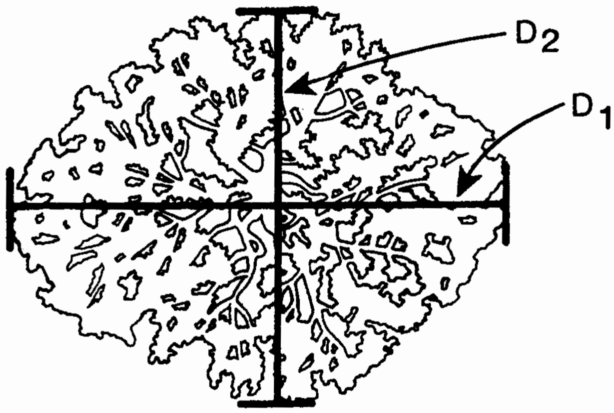
When the diameter is being used as an intermediate variable for calculating area or cover (for Technique 3.1 or 3.14), the plant's outline approximates an elipse, and the largest and smallest diameters have been measured, the geometric mean is better:

**Page 16, the equation should be:**

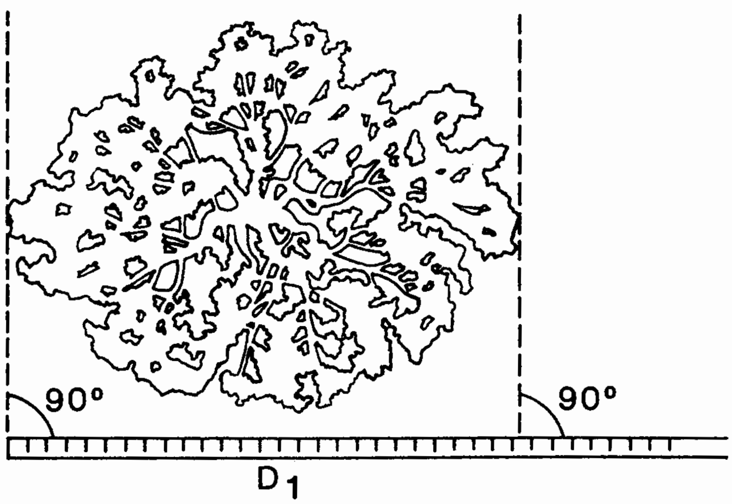
$$\bar{D} = \sqrt{D_1 D_2}$$

### 3.2.3 Accuracy

This technique can be reasonably accurate for calculating diameter. However, error is introduced by deviations of the plant's shape from circular. This deviation is usually significant. Another source of error is not stretching the tape in a straight line. When protractors are used, some misalignment is inevitable, yielding low accuracy.




a. Standard method for measuring two diameters ($D_1$, $D_2$) perpendicular to one another




b. Offset method for measuring a diameter ($D_1$)

Figure 1. Estimating canopy diameters using the Crown Diameter technique.

### 3.2.4 Application Notes

This technique is relatively inexpensive in the field. A crew size of two is needed for plants more than about one-half meter in diameter.

### 3.2.5 Training

One hour.

### 3.2.6 Equipment

Meter tape ($13-50; Forestry Suppliers, Inc. 1980).
Protractors (optional).

### 3.2.7 Cost

Five to ten minutes per plant.

### 3.2.8 References

Husch et al. 1972; Mueller-Dumbois and Ellenberg 1974.

## 3.3 DIAMETER TAPE

### 3.3.1 Variables Estimated

Canopy diameter or stem diameter of an individual plant (pp. 3-5).

### 3.3.2 Description

In summary, a meter tape or diameter tape is wrapped around the plant and diameter calculated from circumference.

If the the desired variable is the average for a particular kind of plant on a site (using Technique 3.23), the plant to be measured should be chosen randomly (see Appendix A). One wraps the tape around the plant at the height to be measured [e.g., breast height (1.4 m; 4.5 ft)]. The tape is wrapped so that it is perpendicular to the axis of the plant (i.e., usually horizontally). Where the zero end of the tape overlaps the rest of the tape, the measurement is taken. When using a diameter tape, the tape is calibrated so that the measurement read is the diameter (assuming that the plant is circular). If using a standard tape measure, it is necessary to calculate diameter with the following formula:

$$D = \frac{C}{\pi} = \frac{C}{3.14}$$

where D = diameter
C = circumference

3.3.3. Accuracy

This technique can be highly accurate. A major source of error is deviation of the plant's cross section from circularity. (If the diameter is to be used for Calculated Area (p. 15), the estimated area will always be more than the actual area. If the plant's shape is an elipse, the error is less than 5% if the largest diameter is less than 1.37 times the smallest diameter). Another source of error is holding the tape so that it is not perpendicular to the axis of the plant. Occasionally loose pieces of bark or lichen can become stuck under the tape giving an erroneously large reading.

3.3.4 Application Notes

This technique is inexpensive. A crew size of one is adequate with an appropriately designed tape. Using a standard tape measure, however, may require two people in order to hold one end of the tape while the other end is being stretched around the plant. For large plants, the best tapes have a hook of some sort which will catch on the bark while a single crew member stretches the tape around the plant. This technique can also be used for canopy diameter measurements of a shrub if its branches are sufficiently stiff so the tape can be stretched around the outside without bending the branches significantly. The Biltmore Stick (p. 32) provides a more rapid but less accurate estimate of stem diameter.

3.3.5 Training

One hour.

3.3.6 Equipment

Tape measure ($13-50; Forestry Suppliers, Inc. 1980) or diameter tape ($6-20; Forestry Suppliers, Inc. 1980).

3.3.7 Cost

Two minutes per measurement taken.

3.3.8 References

Husch et al. 1972; Loetsch et al. 1973; Forestry Suppliers, Inc. 1980.

3.4 MERRITT HYPSOMETER

3.4.1 Variable Measured

Height of an individual tree or tall shrub (p. 3).

3.4.2 Description

In summary, a specified distance is measured from the base of the plant. A special stick is held vertically a specified distance from the eye, and the height of the plant estimated by visually aligning the top and the base of the plant with the scale on the stick.

If the desired variable is the average height for a particular kind of plant on the site (using Technique 3.23), the plant to be measured should be chosen randomly (see Appendix A). Merritt hypsometers are designed to be held a specified distance from the eye (e.g., 25 in), and for a specified distance between the eye and the center of the plant to be measured (e.g., 66 ft). A point must be located at that specified distance from the plant from which both the top and the bottom of the plant can be seen. This is most conveniently done by identifying a likely direction from which the top and base of the plant can be seen, and then pacing off (or measuring with a tape measure) the specified distance along the slope, not horizontal. The hypsometer is held vertically, with its bottom the specified distance from the eye. It is then raised until its base is directly in line of sight from the eye to the base of the plant. The observer then shifts his or her line of sight up the stick until it is aligned with the top of the plant. The reading on the scale at that point gives the height of the plant.

If it is not possible to find a location at which both the top and the bottom of the plant can be seen, it may be possible to mark a point above the base part way up the plant, and then use the hypsometer to measure the distance from that point to the top of the plant. The distance from the mark down can be measured using a standard tape measure, and added to the hypsometer reading. If the plant's crown is flat or round topped, it is important to sight to the top of the plant, not just those branches reaching farthest into line of sight. Leaning plants should be measured perpendicular to the direction of the lean (Fig. 2).

### 3.4.3 Accuracy

This technique can be accurate to within ±10%. This degree of accuracy requires a precise measurement of the distance from the plant. Where distances are paced off, accuracy decreases. Accuracy is also influenced by the height of the plant being measured. Very tall plants cannot be measured as accurately as shorter ones. Major sources of error include movement of the head or hypsometer out of the appropriate distance relationships and tilting the hypsometer toward the measurer. Errors also occur by selecting a base and top which come from different plants (which is sometimes surprisingly hard to avoid).

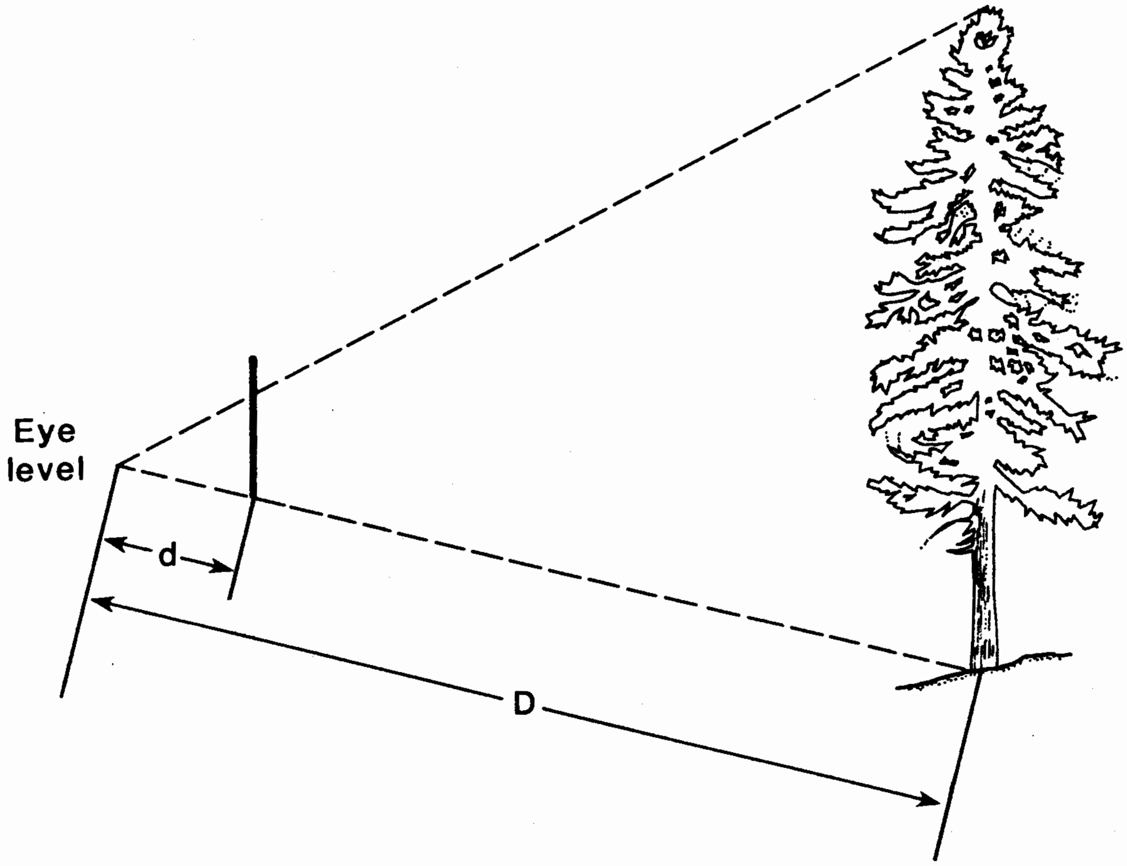
### 3.4.4 Application Notes

This technique is inexpensive. It can be applied by a single crew member. It is most appropriate where the vegetation is sufficiently open to permit one to locate a suitable vantage point quickly. If there is much undergrowth, or the vegetation is dense, the Optical Range Finder (p. 30) is better. The hypsometer is relatively bulky compared to a clinometer and tape measure used for Trigonometric Hypsometry (p. 25) or to an Optical Range Finder.

### 3.4.5 Training

The crew should become familiar with the hypsometer on objects of known height, such as buildings and flag poles. A training period of 2 hours should be adequate.

a. Use of the hypsometer. (D = distance between the plant and the eye. d = distance between the stick and the eye.)




b. Measuring perpendicular to the direction of lean.

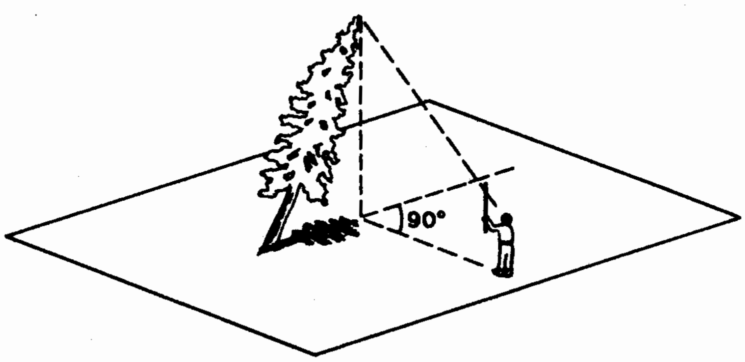



Figure 2. Estimating plant height with a Merritt Hypsometer.

3.4.6 Equipment

Merritt Hypsometer: This is available commercially as a "timber cruising stick", which also includes the Biltmore scale (p. 32). ($20 to $25; Forestry Suppliers, Inc. 1980). Tape measure (optional; $13-50; Forestry Suppliers, Inc. 1980).

A Merritt Hypsometer can be made using the following formula to calculate where the scale's graduations should occur:

$$s = \frac{d\ H}{D}$$

where s = distance on the scale from the bottom
d = distance from the eye to the bottom of the scale
k = height of the tree
D = distance between the eye and the tree (all in the same units)

3.4.7 Cost

One minute per plant measured.

3.4.8 References

Forbes 1955; Loetsch et al. 1973; Forestry Suppliers, Inc. 1980.

## 3.5 CHRISTEN HYPSOMETER

3.5.1 Variable Estimated

Height of an individual tree or tall shrub (p. 3).

3.5.2 Description

In summary, a pole of specified height is held vertically next to the plant to be measured. Another crew member holds the hypsometer at a distance from the plant, and reads the height off the hypsometer's scale.

If the desired variable is the average height for a particular kind of plant on the site (using Technique 3.23), the plant to be measured should be chosen randomly (see Appendix A).

The target pole (e.g., 4 m) is erected next to the plant so its base is at the same level as the base of the plant. It is most convenient for this pole to be held by a crew member, but it is possible to stand it against the plant, or use one that has a stake on the bottom that can be pushed into the ground. The other crew member moves away from the plant with the hypsometer until he can get a good view of the top and base of the plant and the top of the target pole (usually about 25 m). The hypsometer is held by the top, loosely in the hand, so that it hangs vertically. It is moved toward or away from the eye until the top of the hypsometer is aligned with the top of the tree at the same time that the bottom of the hypsometer is aligned with the base of the target pole (Fig. 3). The height of the plant is read off the hypsometer's scale directly in line with the top of the target pole.

If the plant is leaning, it is necessary to measure perpendicular to the direction of lean (Fig. 3). It is essential that the very top of the plant be used for alignment. If the plant is rounded or flat on top, one must look through this foliage to the true top of the plant, or seek another vantage point.

3.5.3 Accuracy

The standard Christen Hypsometer can achieve accuracy of greater than ±10%. Accuracy decreases as the height of the plants being measured increases. This source of error can be reduced by using a taller target pole (with an appropriate hypsometer). If high accuracy is needed, the modification by Eič (Fig. 3) or Trigonometric Hypsometry (p. 25) can be used. The modification by Eič permits accuracy of ±2% for plants greater than 40 m.

Sources of error include movement of the eye and hypsometer alignments, and holding the hypsometer other than vertically. Error will also occur if the plant leans toward the measurer, or has a top that is obscured by lower branches. In dense stands, it may be difficult to identify which top goes with which base.

3.5.4 Application Notes

This technique is inexpensive, but more costly than the Merritt Hypsometer (p. 19). It requires a crew size of two for efficiency, but a single person can apply the technique. It is most appropriate where vegetation is sufficiently open to be able to sight both the base and the top of the plant to be measured without difficulty. Since it does not require a specific distance from the hypsometer to the plant being measured, this technique is sometimes easier to apply in denser stands than is the Merritt Hypsometer. For the same reason, it is often easier to use in rough topography or where walking is difficult than is Trigonometric Hypsometry (p. 25). It is usually more accurate than an Optical Range Finder (p. 30). Its disadvantage is that one must carry around the target pole, which is typically about 4 m in length.

3.5.5 Training

The crew should become familiar with this technique on buildings or other features of known height. A 2 hr training session is adequate.

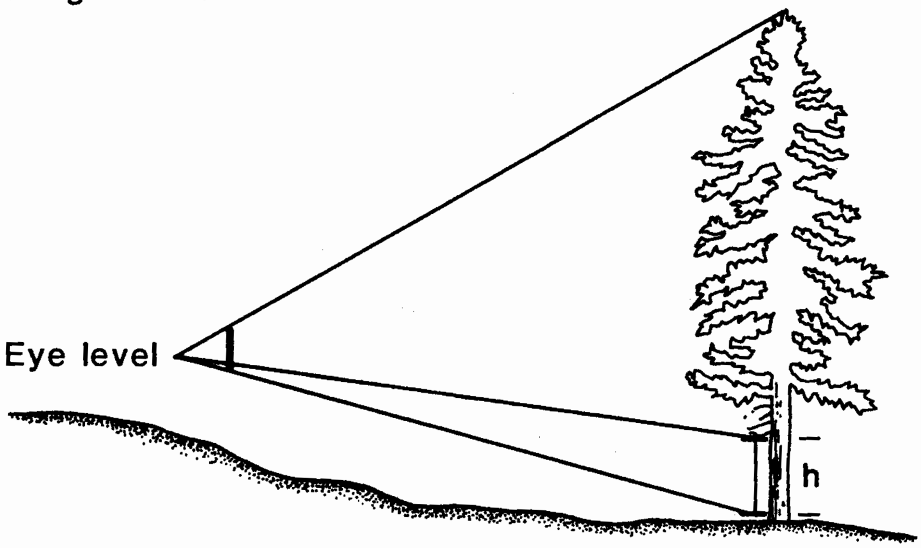
3.5.6 Equipment

Christen Hypsometer and Target Pole.

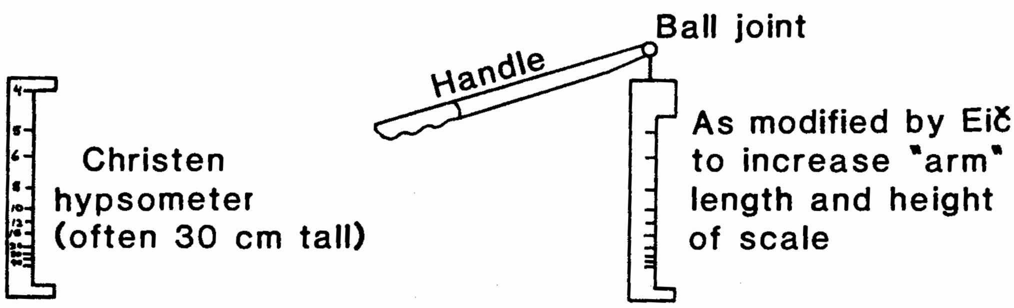
A Christen Hypsometer can be made using the following formula to calculate where the scale's graduations should occur:

$$s = \frac{h\ t}{H}$$

a. Making a measurement




b. Close-up of the hypsometer (not to scale)




h ≈ height of target pole (often 4 m)

c. Measuring perpendicular to the direction of lean

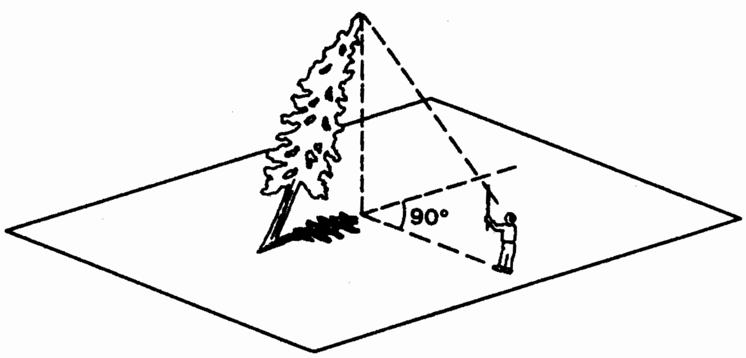



Figure 3. Estimating plant height using a Christen Hypsometer.

where s = distance from the bottom of the scale to a given graduation (m)
h = height of the target pole (constant, usually 4 m)
t = total height of the scale (constant, usually 0.3 m, or 0.5 m for the modification by Eič)
H = height of the tree (m)

### 3.5.7 Cost

No estimate available.

### 3.5.8 References

Forbes 1955; Loetsch et al. 1973.

## 3.6 TRIGONOMETRIC HYPSOMETRY

### 3.6.1 Variable Estimated

Height of an individual tree or tall shrub (p. 25).

### 3.6.2 Description

In summary, a vantage point is selected from which the top and the bottom of the plant can be seen. Angles are measured from the horizontal to the top and to the bottom, the distance to the plant is measured, and the height is calculated using a trigonometric formula.

If the desired variable is the average height for a particular kind of plant on the site, the plant to be measured should be chosen randomly (see Appendix A).

A vantage point should be selected which is at least as far away as the height of the plant being measured. From this vantage point, it must be possible to see both the top and the base of the plant. From this point, one or more angles are measured from the horizontal to the plant's top and base using a clinometer (see Fig. 4). Next, the horizontal distance from the object to the vantage point must be measured [(by tape measure, Pacing (p. 76), or Optical Range Finder (p. 30)]. If the object is on a slope, it is possible to estimate the horizontal distance to the plant by measuring the distance along the slope, plus the slope's angle from the horizontal. Calculations are shown in Figure 5.

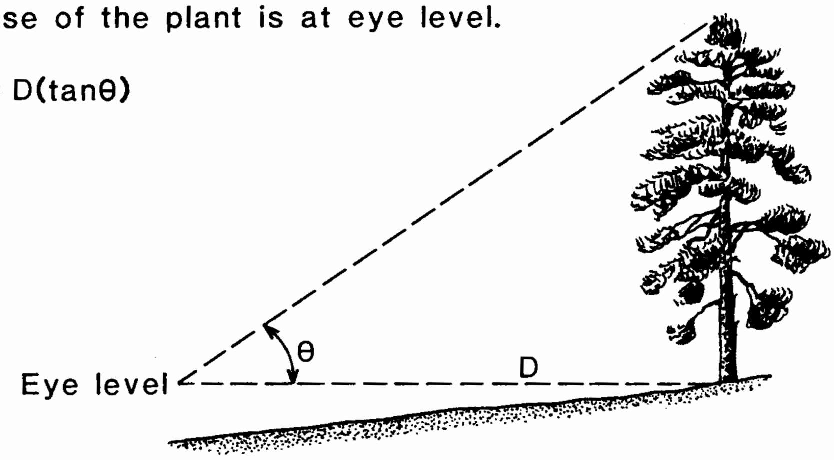
If the clinometer used has a scale that reads percent slope, calculations can be avoided if the vantage point is exactly 100 m from the object (or 100 ft, if that is the desired unit of height). Under these conditions, the height is equal to the percent slope.

### 3.6.3 Accuracy

This technique is highly accurate. Measurements using hand held clinometers can be made to less than ±3%. This degree of accuracy requires precise measurements of the distance from the vantage point to the object. The major sources of error include plants that lean, or plants that have flat or rounded

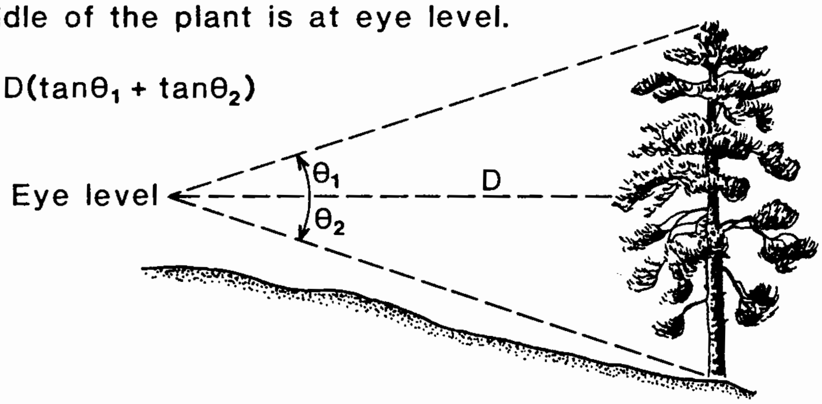
a. The base of the plant is at eye level.

$$H = D(\tan\theta)$$




b. The middle of the plant is at eye level.

$$H = D(\tan\theta_1 + \tan\theta_2)$$




c. The base of the plant is above eye level.

$$H = D(\tan\theta_1 - \tan\theta_2)$$

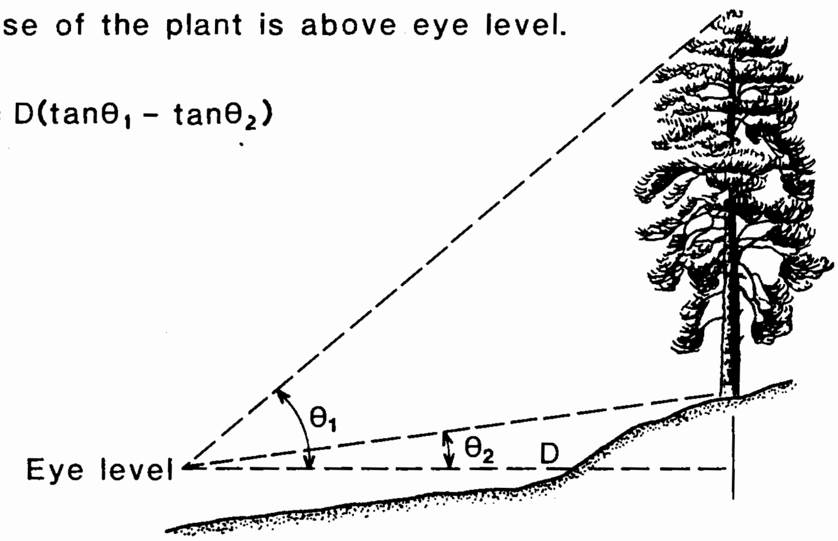
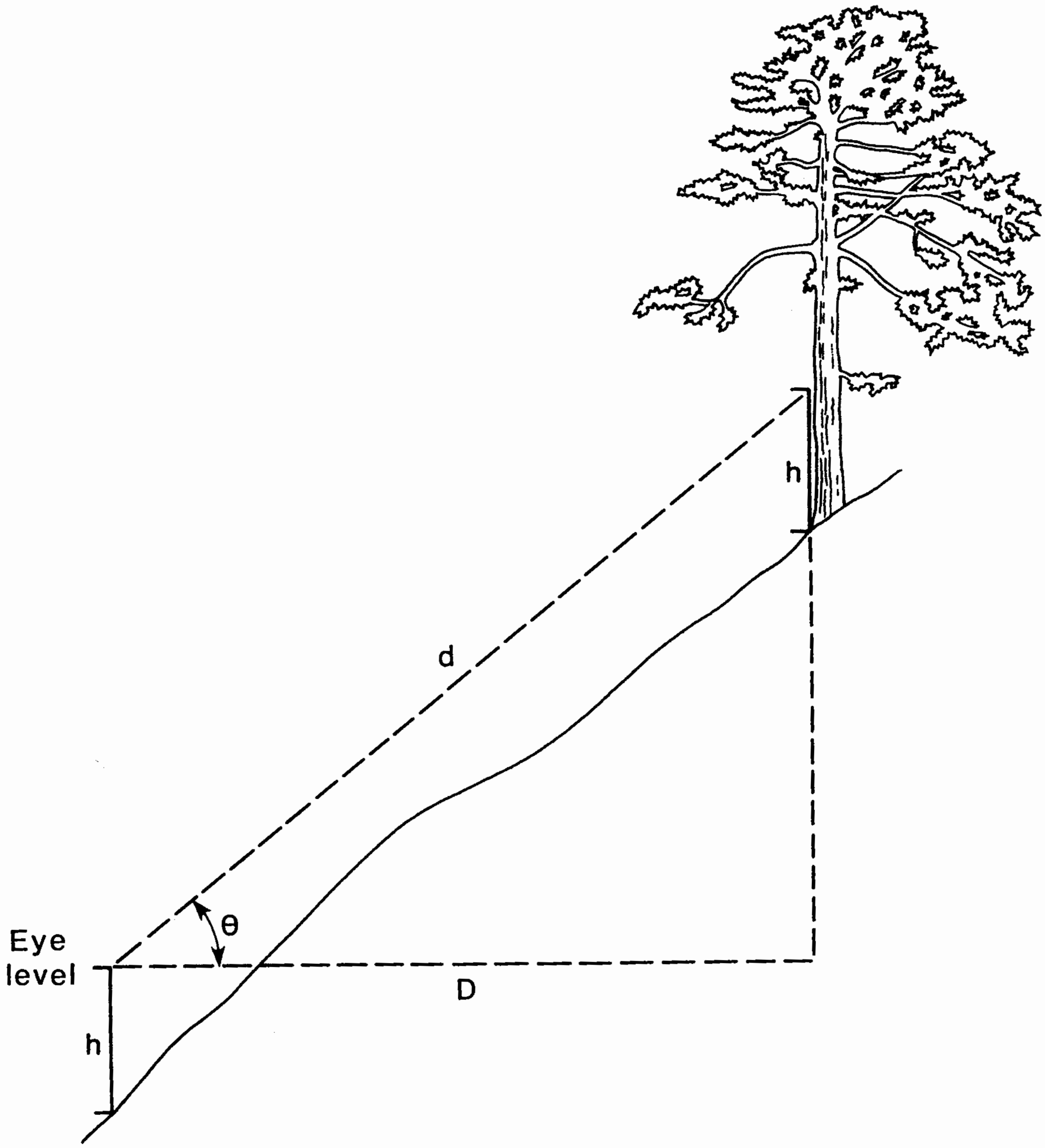



Figure 4. Estimating plant height with Trigonometric Hypsometry.




$$D = d \cos \theta$$

Figure 5. Estimating horizontal distance on a slope from measurements of slope angle and distance along the slope.

crowns which make it difficult to identify the top of the plant. The other major source of error is the distance measurement. If pacing is used, the accuracy of the measured height is substantially lower.

3.6.4 Application Notes

This technique tends to be relatively inexpensive. A crew size of one is adequate, but if distance measures are made with a tape measure, a crew size of two is preferable. It has the advantage of not requiring any bulky equipment. The major disadvantages are the cost of the equipment, and having to make distance measures. The Optical Range Finder (p. 30) and Christen Hypsometer (p. 22) do not require this distance measurement. However, the Optical Range Finder is expensive and delicate, and the Christen Hypsometer requires a long target pole.

3.6.5 Training

Sufficent familiarity with the equipment and calculation procedures required should be developed within one-half day.

3.6.6 Equipment

Clinometer. Several kinds of instruments can be used. They include specific devices such as the clinometer manufactured by Suunto ($40) and other vertical angle measuring devices such the Abney level ($35-135), and multipurpose instruments such as the pocket transit ($90-120) and Relaskop ($600). At least one device is available which includes both a clinometer and an optical range finder ($96).

Tape measure or optical range finder for measuring the distance from the vantage point to the plant (tape measures $13-50, optical range finders $25-75). (Prices from Forestry Suppliers, Inc. 1980).

3.6.7 Cost

No estimate available.

3.6.8 References

Forbes 1955; Loetsch et al. 1973; Forestry Suppliers, Inc. 1980.

## 3.7 GRADUATED ROD

3.7.1. Variable Estimated

Height of an individual short tree, shrub, or herb; or litter depth; or depth of water (pp. 4, 11, 13).

3.7.2 Description

In summary, a pole with a linear scale marked on it is used to measure the height or depth involved.

If the desired variable is an average for a site, the plant or location to be measured should be selected randomly (see Appendix A).

When short plants are being measured, the graduated rod is simply held vertically and rested on the ground next to the plant, and the person holding the rod simply notes the scale value at the height of the plant. When the plant is sufficiently tall to require a telescoping rod, one crew member stands at the base of the plant and elevates the rod section by section. Another crew member stands at a distance and indicates when the top of the rod is even with the top of the plant. The first crew member then reads off the height from the scale. When litter depth is being measured, a hole is scooped through the litter leaving a vertical, undisturbed cut. The rod is held vertically next to this surface, and the depth read off the scale. When reading, it is important to look as horizontally as possible to minimize parallax error. When water depth is being measured, the rod is simply lowered to the bottom and the depth of the water read off the scale. In fast moving water, it is necessary to read the scale from the side of the pole, because the water will tend to pile up on the upstream side and be depressed on the downstream side of the pole.

### 3.7.3 Accuracy

This technique can be highly accurate. The largest sources of errors are misreading the scale or misrecording data. If a telescoping pole is used, error can arise from reading the scale's alignment with the top of the plant at an angle, rather than horizontally. This error can be minimized by holding the pole as close as possible to the top of the plant, and having the observer stand as far away as possible.

### 3.7.4 Application Notes

This technique is inexpensive as long as a telescoping pole is not needed. A crew size of one is adequate for plants up to about 2.5 m tall. For taller plants, a crew size of two is required. It is the preferred technique for short plants. For plants about 3-15 m tall in dense vegetation, the telescoping pole is better than other techniques when high accuracy is needed. If lower accuracy is acceptable, the Optical Range Finder (p. 30) is preferred. If the plants are in this height range and the vegetation is sufficiently open, the Merritt or Christen Hypsometers or Trigonometric Hypsometry (pp. 19, 22, 25) would usually be better.

### 3.7.5 Training

Two hours are adequate to become familiar with the equipment, and with the techniques for reading the scale or lining up the top of the pole with the top of a plant.

### 3.7.6 Equipment

Graduated pole, such as a meter stick for short vegetation, or telescoping pole for taller vegetation (telescoping measuring rods from about $90 for 7.5 m length, or $200 for 15 m length; Forestry Suppliers, Inc. 1980).

It may be necessary to attach a flat plate to the bottom of the rod, if the substrate is soft.

### 3.7.7 Cost

About 1 min/plant for a nontelescoping pole.
About 3 min/plant for a telescoping pole.

### 3.7.8 References

Loetsch et al. 1973; Forestry Suppliers, Inc. 1980.

## 3.8 OPTICAL RANGE FINDER

### 3.8.1 Variables Estimated

Height of an individual tree or tall shrub, distance from a site to the nearest example of a specified feature, or linear dimension of a site or width of a water body (pp. 3, 11, 13).

### 3.8.2 Description

In summary, one stands at one end of the distance to be measured and looks at the other end through an optical device. The device is adjusted to form a specified image and the distance read off the adjusting knob.

If the desired variable is an average for a site, the plant or distance to be measured should be chosen randomly (see Appendix A).

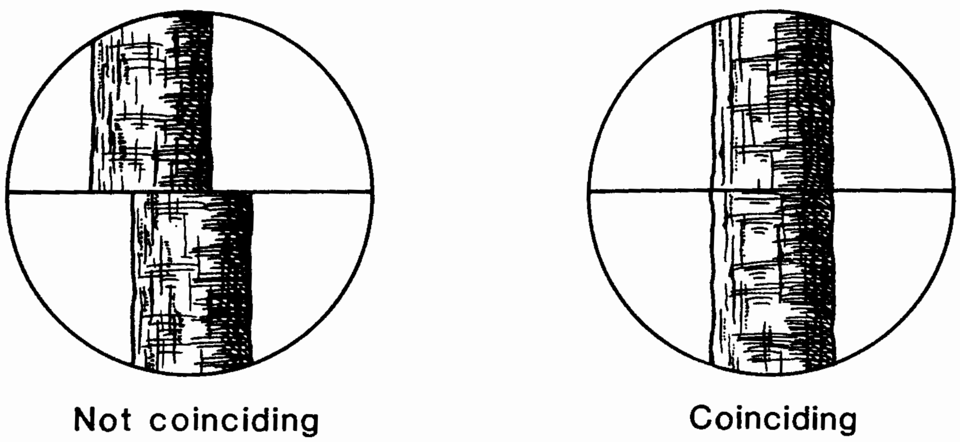
For measuring horizontal distances, one stands at one end of the distance to be measured in a location from which the other end can be seen. One then selects an object at the other end which has a distinct vertical or nearly vertical line, such as the side of a tree trunk or a fence post. One then views that object through the range finder. The range finder shows two images. The range finder is then adjusted until the two images merge into one (Fig. 6). The distance is read off a scale on the range finder.

When measuring a vertical distance, one stands as close to directly underneath the top of the object as possible. The range finder is adjusted as before. The total distance must be calculated by adding the height of the eye above the base of the object being measured. This is most conveniently determined with a tape measure. For accurate measurements, the height measured must be corrected for the viewing angle. The angle can be measured using one of the clinometers listed on p. 28. Calculations are shown in Figure 6.

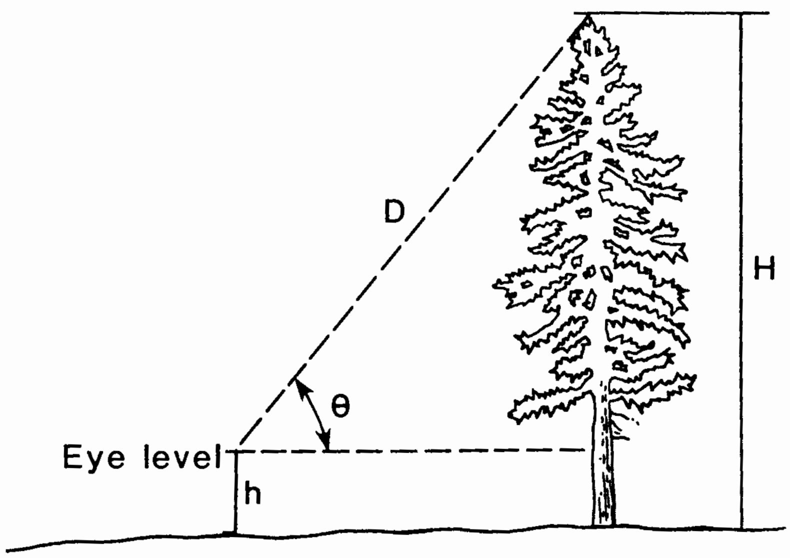
### 3.8.3 Accuracy

The technique is moderately accurate at short ranges, and involves more substantial errors at long range. The accuracy is a function of the size (and expense) of the instrument. Typical accuracies (manufacturer specifications) are ±1 m at a range of 30 m, and ±100 m at a range of 1000 m (Forestry Suppliers, Inc. 1980).

a. View through an optical rangefinder.




b. Angle correction of height measurement.




$$H = D(\cos(90-\theta)) + h \quad (\theta \text{ in degrees})$$

$$H = D[\cos(\arctan(\theta/100))] + h \quad (\theta \text{ in percent})$$

Figure 6. Estimating distance with an Optical Range Finder.

Measurements of the heights of trees can be inaccurate due to the fact that often no suitable straight edge exists to use as a target. The error introduced into measurements of height by sighting at an angle is 5% or less for angles greater than 72° (about 300% slope). Accuracy can be reduced dramatically if the instrument is damaged (which is easy to do). Such damage is often not apparent unless one checks the instrument on a known distance.

### 3.8.4 Application Notes

This technique is inexpensive. It can usually be applied by a crew of one. An additional crew member may be desirable to hold a target pole in areas without a naturally occuring suitable target. It is the method of choice for measuring the heights of trees (over 15 m tall) in dense forests, provided the top can be seen clearly from the ground. However, it requires more expensive equipment than the Merritt or Christen Hypsometers (pp. 19, 22). In vegetation less than 15 m tall, the Graduated Rod (p. 28) may be better. For distance on the ground, the Map Measurer (p. 75) or RS: Ruler is usually better. The Optical Range Finder is, however, better than Pacing (p. 76) over uneven terrain or across water.

A crew size of one is adequate for using the technique. It may be applied in any type of vegetation or soil conditions in which a clear view is available over the distance being measured.

### 3.8.5 Training

1/4 hour.

### 3.8.6 Equipment

Optical Range Finder (range 2-30 m, about $25; range 46-1000 m, about $75, Forest Suppliers, Inc. 1980).

Clinometer (optional, see Equipment section on p. 28).

### 3.8.7 Cost

About 2 min/measurement without correction for viewing angle; about 5 min/measurement with correction.

### 3.8.8 References

Forestry Suppliers, Inc. 1980.

## 3.9 BILTMORE STICK

### 3.9.1 Variable Estimated

Stem diameter of an individual tree (p. 5).

3.9.2 Description

In summary, the diameter of an individual tree stem is estimated using a stick graduated with a special scale. The stick is held against the tree, and the estimated diameter is read directly off the stick.

If the desired variable is the average for the trees on a site, the tree to be measured should be chosen randomly (see Appendix A).

On approaching the tree, one should estimate its diameter and grasp the Biltmore stick near the middle. Place the stick horizontally against the tree trunk at the height to be measured (usually "breast height", 1.4 m or 4.5 ft, Fig. 7). The stick should be perpendicular to the eye. With one eye closed, one aligns the stick so that the center of the stick is the appropriate distance from the eye (usually 64 cm or 25 in.) with the zero end of the scale aligned with the edge of the tree trunk. Without moving one's head, read the number off the scale which aligns with the other side of the tree trunk.

3.9.3 Accuracy

This technique is crude. Sources of error include deviations of the tree from circular in cross section and, most importantly, errors in holding the stick horizontally, perpendicular to the eye, and precisely the specified distance from the eye. Accuracy increases as tree size decreases. Diameter readings for small trees can be measured to about the nearest 2 cm.

3.9.4 Application Notes

This technique is inexpensive. It is usually the best technique if low accuracy is acceptable. One person can apply the technique without difficulty. It is appropriate except where tree growth form deviates radically from circular.

3.9.5 Training

One-half hour.

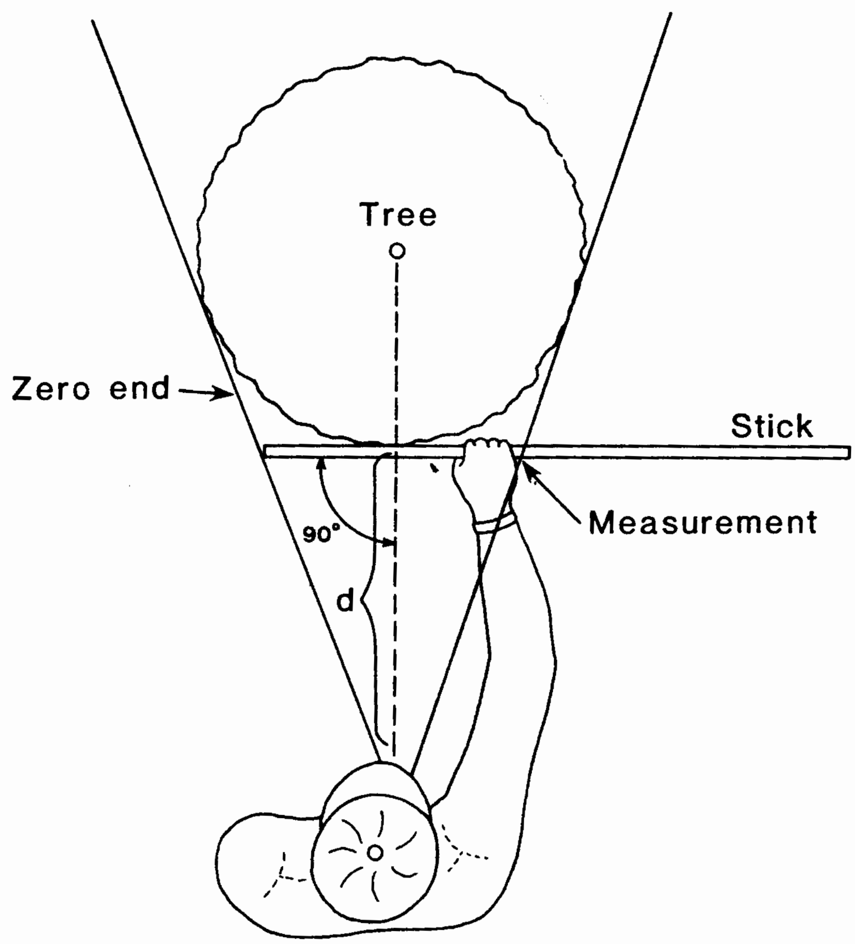
3.9.6 Equipment

Biltmore stick ($20-$25; Forestry Suppliers, Inc. 1980).

A stick can be made using the following formula to calculate where the scale graduations should occur:

$$s = d\sqrt{\frac{a}{a + d}}$$

where s = distance on the Biltmore stick's scale from the zero end
d = diameter of circular trunk
a = distance between the eye and the center of the stick (all in the same units of length)




d = Specified distance between eye and tree trunk for the Biltmore stick being used

Figure 7. Use of the Biltmore Stick to estimate the diameter of a tree.

Biltmore scales are commonly included in commercially available "timber cruising sticks" (which typically also include the Merritt Hypsometer, p. 19).

3.9.7 Cost

About 0.5 min/plant.

3.9.8 References

Forbes 1955; Forestry Suppliers, Inc. 1980.

## 3.10 LINDSEY SIGHTING LEVEL

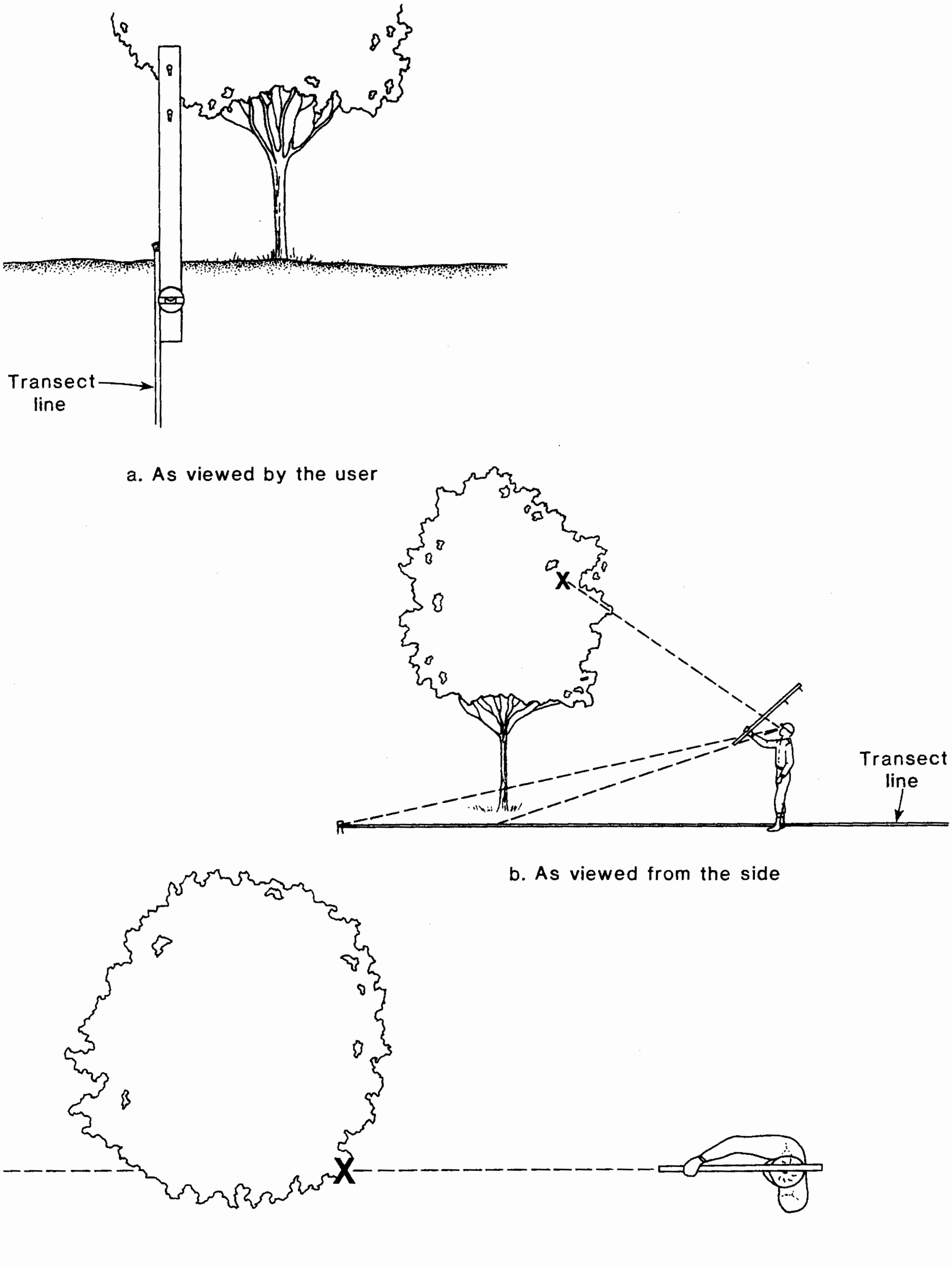
3.10.1 Variable Estimated

Vertical protection of the edge of a tree's canopy to a transect line on the ground (p. 5).

3.10.2 Description

In summary, one uses the Lindsey sighting level to identify a vertical plane directly above and parallel to a line transect, and then to project a point on the edge of a tree canopy down to the transect line.

This technique assumes the transect line has been laid out. The transect must extend beyond the point to be projected by about 5 m. This may require extending the transect line beyond the point where sampling will be stopped. For projecting all the intercepts on a line transect, one starts at one end of the transect and walks along it until about 2-10 m from the edge of a canopy that seems to extend over the transect line. To project the intercept, the first step is to identify the point on the canopy to be projected. To do this, one stands directly over the transect line, 2-10 m away from the edge of the canopy, but with that edge of the canopy in sight. One then holds the Lindsey sighting level (stick) out in front of the eye with the top tilted back towards the top of the head (Fig. 8). The lower portion of the stick is viewed so that it can be aligned with the transect line. The level on the stick is also watched, and the stick is rotated left or right until the level shows that the stick is not canted either way. At this point, the bottom portion of the stick should still be aligned with the transect line, and the level should indicate that the stick is not canted except toward the eye (Fig. 8). The stick is, then, defining a vertical plane parallel with the transect line. Without moving one's head, one then shifts one's gaze up along the stick and looks at the tree canopy to be projected. Where this plane cuts the tree's canopy, several points can be identified. The point which is closest to the observer (which will be the outer margin of the canopy) should be selected (Fig. 8). The second step is to locate the point on the transect line directly underneath this point on the canopy. To do this, one walks to a point underneath the canopy and stands facing the transect line. Next, one extends the stick so that the level tube is parallel to the transect line and one is sighting across the nails of the stick toward the previously selected point of the canopy. If the level bubble shows that the stick is not vertical, one moves sideways along the transect line until the level indicates that it is (Fig. 9). Finally, one lowers the stick as a pendulum until it touches the




a. As viewed by the user

b. As viewed from the side

c. As viewed from the top

Figure 8. Step one of using the Lindsey Sighting Level to project a point on a plant's canopy to a transect line.

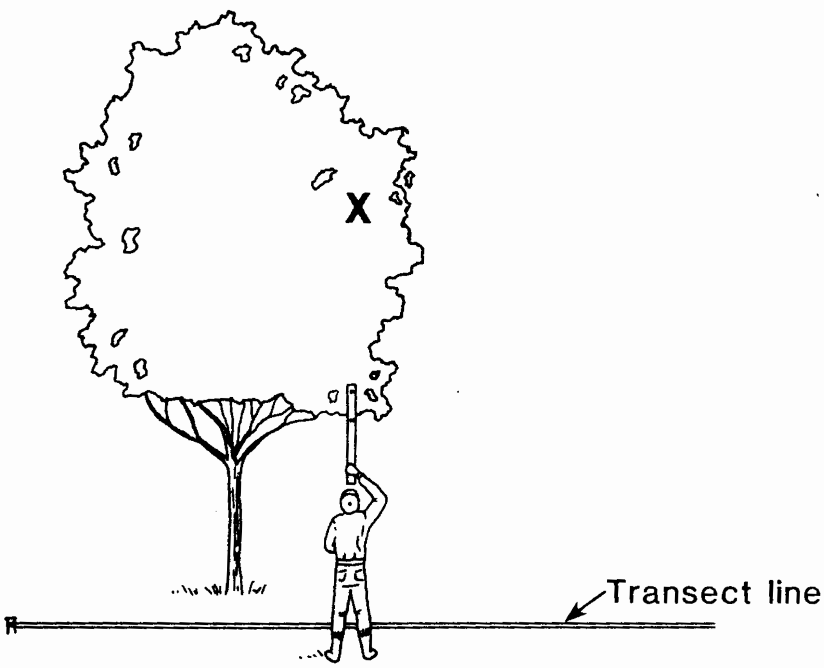



Figure 9. Step two of using the Lindsey Sighting Level.

transect line. This is the point at which the trees canopy has been projected vertically down to the line transect.

For canopies less than about 5 m high, for lower precision studies, or where one's sight is obstructed for step one, that step can be omitted. One then begins with step 2, standing at the point that seems by eye to be under th edge of the canopy. (To check whether one has selected the right point on the canopy margin to project, one can stand directly underneath it, facing parallel to the transect line. One then sights at the point projected as for step two. If the right point was selected, the bubble should show "level".)

### 3.10.3 Accuracy

This technique can be highly accurate. The major sources of error are misreading of the level, and moving the stick or eye during the first step. Another error can arise if the point selected during the first step is not over the transect line. If this is true, it should be obvious during the second step of the method.

### 3.10.4 Application Notes

This technique is inexpensive. One person can apply the technique (but setting up the transect line is easier with two people). It is appropriate in vegetation taller than about 3 m. In lower vegetation, the Vertical Rod (p. 39) is better. As in other methods involved in projecting canopies to a transect line, it must be obvious where the limits of the canopy are for each individual plant. Where canopies are highly irregular in outline, this can be difficult to determine. Canopy irregularity can present especially difficult problems for this technique since the first phase requires identifying a specific point on the canopy margin. If this "point" is actually an interpolated line between two projecting branches, the technique cannot be applied readily. Canopies that extend over much of the height of the tree, such as many conifers, are also difficult to work with.

### 3.10.5 Training

One hour for familiarization.

### 3.10.6 Equipment

Lindsey sighting level. This is a stick, such as straight one-quarter-round doweling. Lindsey used a 5 ft length. A pair of small screws or nails should be added near one end of the stick (Fig. 8). About a foot from the lower end on the same side as the nails, he fastened a glass "bubble tube" replacement for a carpenters level, so that the bubble was centered when the stick was held vertically and the bubble could be viewed while sighting across the nails. Total cost, less than $5.00 (no known commercial source).

### 3.10.7 Cost

Approximately two minutes per point projected.

### 3.10.8 References

Lindsey et al. 1958.

## 3.11 VERTICAL ROD

### 3.11.1 Variable Estimated

Vertical projection of a point to the ground (p. 5).

### 3.11.2 Description

In summary, one moves along a transect line. When it appears that the transect intercepts the limits of a plant's canopy, the rod is held vertically over the transect line and moved along until the canopy's edge is touched. It is then lowered to the transect line and a reading taken.

This technique assumes the transect line has been laid out. As one moves along the transect line, edges of plant canopies apparently above the transect line are examined. For each of these, the rod is erected vertically (using the bubble level) over or resting on the transect line, and moved along it until the edge of the canopy is intercepted. The tip of the rod's intersection with the transect line can then be read as the intercept point.

### 3.11.3 Accuracy

This technique can be highly accurate. The major source of error is in deviations of the rod from a truly vertical position.

### 3.11.4 Application Notes

This technique is inexpensive. One person can apply the technique. (However, setting up the transect line is easier with two people). It is most appropriate in shrubby vegetation between 0.5-3 m high. If the vegetation is extremely dense, it can be difficult to move the rod around.

### 3.11.5 Training

Approximately one-half hour of practice in identifying prospective points and projecting them to the ground.

### 3.11.6 Equipment

Virtually any kind of straight rod of length sufficient to use in the vegetation being analyzed will do. One or more levels should be fixed to the rod so that it can be determined when it is being held precisely vertically. The best way to do this is to affix a small "shelf" at about 1 m from the base. On this shelf is mounted a two way circular level. This should be adjusted so that the bubble is centered when the rod is precisely vertical. Total cost can be less than $5.00. (No commercial source known).

3.11.7 Cost

Less than 3 min per point projected.

3.11.8 References

Mueller-Dumbois and Ellenberg 1974.

## 3.12 LINE INTERCEPT (OR LINE TRANSECT)

3.12.1 Variables Estimated

Basal or canopy cover of herbs, shrubs, or trees (pp. 5, 7).

3.12.2 Description

In summary, a meter tape is stretched out to form a line in the site. The crew moves along the meter tape and records the measurement at which the line passes over or under the edges of the individual plants.

A randomly located straight line transect is laid out in the site (see Appendix A for a discussion of how to establish a random transect and how to lay it out on the ground). The crew moves along the tape and projects the plant canopies (or basal areas) vertically to the tape and records the length of the line segment and the kind of plant involved (Fig. 10). If individual plants overlap, each is measured separately. When the line passes close to the intercepted parts of the canopy, it is possible to "eyeball" the vertical projection from the plant to the line. If the line passes farther from the intercepted parts of plants (e.g., tree canopies), it is important to use a precise method of projecting, such as the Lindsey Sighting Level (p. 35) or the Vertical Rod (p. 39). After completing the transect, pulling on the end of the tape should permit one to break or pull out the anchor stick, so the tape can be rewound.

Calculations are generally as follows for each plant type (X) (e.g., plant species) recorded:

$$C_x = \frac{\Sigma I_x}{\ell} (100)$$

where $C_x$ = cover of x (%)

$\Sigma I_x$ = sum of intercepts with x

$\ell$ = lengths of the line transect

3.12.3 Accuracy

This technique gives quite accurate results. Accuracy is highest if the plants measured have the same growth form and similar crown diameters

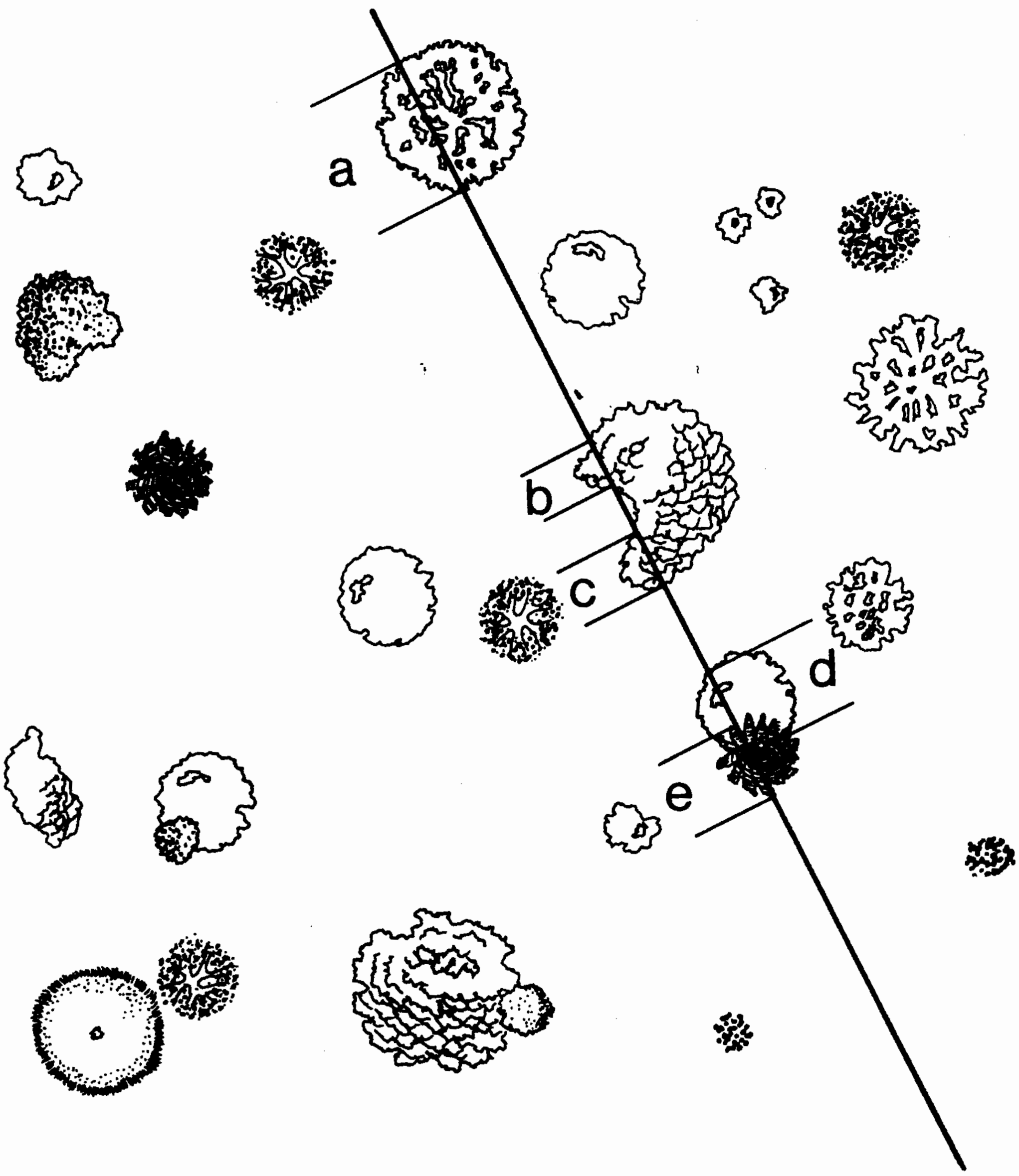



Figure 10. View from above of the Line Intercept technique showing a transect line with intercepts indicated.

throughout (Oosting 1956:53). Accuracy is lower when it is difficult to set up a straight line using a stretched tape. It is also necessary to be able to clearly see the projection of the canopy (or basal area) of the plant on the line. As for other techniques for examining canopy cover, if canopies intermingle or are highly irregular, it becomes difficult to say precisely where the margin of a plant's canopy is and, consequently, accuracy is affected. It is desirable to use multiple line transects, rather than a single line, to ensure adequate coverage of the site and a random sample.

Bauer (1943) found that estimating cover in dense chaparral using this technique gave results that compared favorably with those obtained by mapping quadrats.

3.12.4 Application Notes

For a crude but inexpensive technique, Ocular Estimation of Cover (p. 58) is often best. However, the Line Intercept technique is relatively inexpensive compared to other similarly accurate field techniques for measuring canopy cover, if lines can be laid out easily. One person can apply the technique (if the vegetation is suitable for anchoring the ends of the tape measure), but it is usually much more efficient if two people are available. Two can more easily lay out the lines in the first place, and one person can read off the intercept points while the other records. This technique is somewhat slower to apply than the Bitterlich Method (p. 43) or Calculated Cover (p. 50). However, it can be applied in any vegetation type and gives more accurate results. When suitable equipment and imagery are available, the most satisfactory technique for estimating canopy cover of the overstory is often RS: Bitterlich Method or Crown Density Scale. If intercepts occur rarely, as for estimating basal cover of trees or canopy cover of very open vegetation, the Bitterlich Method (p. 43) or Calculated Cover (p. 50) are better.

The Line Intercept technique is most appropriate in conditions in which it is easy to lay out straight lines. This implies a relatively open vegetation at a height of less than 2 m. In extremely uneven topography, it can be difficult to stretch a tape straight because of the need to go up and down the slope. This change in vertical direction can lead to difficulty in projecting canopies to the transect line. It must also be relatively easy to perceive the margins of the canopies from the ground. This implies either an open vegetation type or regularly shaped and dense canopies.

The Line Intercept technique is applicable to vegetation ranging from low herbaceous growth to the tallest forests. It is necessary to modify the length of the transect line and the precision with which intercept points are recorded under these various conditions. For low or herbaceous vegetation, it is often desirable to use lengths of about 10 m. Data should often be recorded to the nearest centimeter. In shrubby vegetation and in forests, it is often desirable to use transects of ≥ 100 m length. Data should be recorded to the nearest 10 cm. For vegetation with multiple strata, it is often desirable to run separate transects to deal with the different layers. The layers measured can be defined arbitrarily. It is often convenient to use strata similar to the following: < 2 m, 2-5 m, and > 5 m (Mueller-Dumbois and Ellenberg 1974)

3.12.5 Training

One-half hour training and 1 day of practice to obtain consistency is adequate (Richard Francis, pers. comm.).

3.12.6 Equipment

Tape measure ($13-50; Forestry Suppliers, Inc. 1980). It is desirable to use one with a sturdy case, so it can be tossed without damage.

3.12.7 Cost

Approximately 1 hour per 25 intercepts. This can be a 10 m transect in herbaceous vegetation to a 250 m transect in a forest.

3.12.8 References

Canfield 1941; Bauer 1943; Oosting 1956; Lindsey et al. 1958; Mueller-Dumbois and Ellenberg 1974; Forestry Suppliers, Inc. 1980.

## 3.13 BITTERLICH METHOD (OR VARIABLE PLOT SAMPLING, PRISM CRUISING, OR THE SHRUB ANGLE GAUGE)

3.13.1 Variables Estimated

Basal cover of trees and tall shrubs, canopy cover of shrubs (pp. 5, 7).

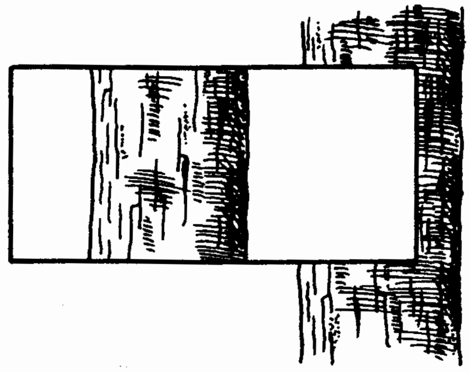
3.13.2 Description

In summary, random points are selected in the plot. From each point, a count is made of all plants larger than a certain critical size (which is a function of the diameter of the plant and its distance from the sample point).

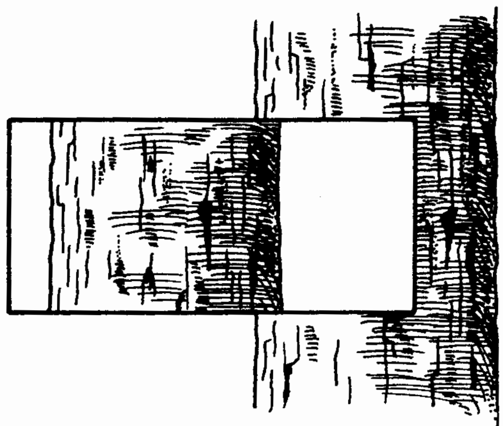
Within the site, a random point is selected (Appendix A). The observer stands close to the point, and turns 360° while keeping the gauge directly over the sample point. Each plant seen as the observer turns is inspected using an angle gauge (see equipment section, below). The plant is usually viewed at breast height (1.4 m or 4.5 ft) for trees, or at the widest point for canopy cover of shrubs. If the plant viewed is sufficiently large or sufficiently close to be wider than the critical angle, it is counted (Figs. 11 and 12). (See instructions with the gauge used). It is necessary to be careful not to count the first plant twice. The procedure is repeated at several sample points.

For accurate results, it is important that these measurements be made horizontally or corrected for slope (see below). If the observer is measuring low shrubs, it may be necessary to stoop or lie down to get a horizontal measurement. If one is making measurements on a slope, calculated cover will be less than actual cover. For best results, a slope-correcting angle gauge (such as the Relaskop) should be used. If one is not available and small errors are acceptable, ignoring gentle slopes is justified. If the slope is less than 17°, the error due to ignoring slope will be less than 5%. For accurate results, the count at each sample point should be divided by the

Do not count this tree.



Count this tree.



Borderline tree. Count as one-half, or measure the diameter and distance.

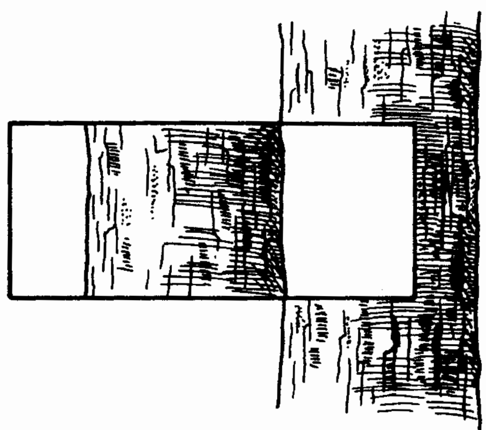


Figure 11. Use of a prism to apply the Bitterlich Method.

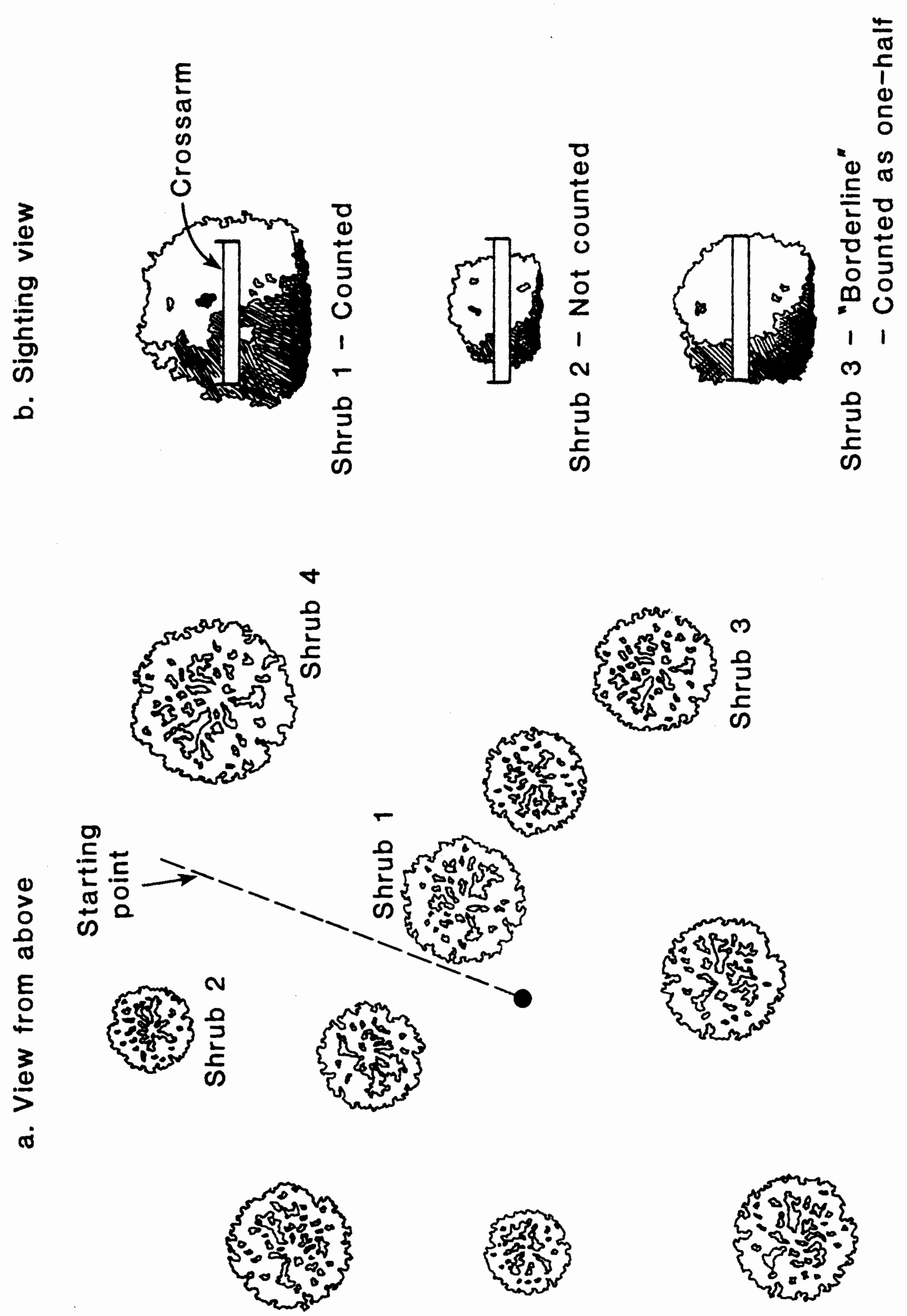



Figure 12. Sampling with a shrub angle gauge.

cosine of the slope angle at that point (i.e., multiplied by the secant). The gauge must be perpendicular to the line of sight and vertical (not tilted to the left or right). When small errors are acceptable, individual plants that fall precisely on the critical angle should be counted as one half (Fig. 11). When accurate results are needed, borderline plants should be examined by measurement. When measuring, a plant should be counted if

$$D^2 \leq \frac{0.174\ W^2}{BAF} \quad \text{(percent)}$$

$$D^2 \leq \frac{0.25\ W^2}{BAF} \quad \text{(metric)}$$

or

$$D^2 \leq \frac{75.625\ W^2}{BAF} \quad \text{(English)}$$

where D = distance from sample point to center of plant (m for percent and metric, ft for English)
W = width (diameter) of plant (cm for percent and metric, in for English)
BAF = basal area factor (percent cover/plant, $M^2$/ha plant, or $ft^2$/ac plant)

It is more accurate to count as "in" all plants that clearly are, and to measure D and W for each plant that is "borderline."

No plant should be counted more than once from a single sample point, even though it may be more than twice as wide as the critical angle. From different sample points, however, it should be counted every time it is larger than the critical angle.

Basal cover is calculated with the following formula. The angle gauge's "basal area factor" (BAF) must be known. (If unknown, this may be determined as described in the Equipment section below).

$$B = \frac{(\Sigma n)}{p}\ (BAF)$$

where B = basal area ($m^2$/ha or $ft^2$/ac)
$\Sigma n$ = total number plants counted at all sample points
p = number of sample points
BAF = basal area factor ($m^2$/ha plant, or $ft^2$/ac plant)

Basal area in $m^2$/ha or $ft^2$/ac can be converted to basal cover in percent by multiplying by a conversion factor. The conversion factor for basal area expressed in $m^2$/ha = 100/10,000 = 0.01. The conversion factor for $ft^2$/ac = 100/43,560 = 0.0023.

3.13.3 Accuracy

This technique can be moderately accurate. The principal sources of error are in systematic errors in using the angle gauge (e.g., systematically including more plants than should be included, or an inaccurate gauge) and deviations of the plants from circular cross section. Error can be introduced if sample points are not selected randomly. In dense stands, errors can arise by one plant being behind another. Sampling on slopes introduces error if no correction is made. If the observer stands on the sample point, rather than holding the gauge over the point, an error of about +4% results.

3.13.4 Application Notes

This technique is inexpensive. One person can apply the technique. It is particularly applicable in vegetation that is relatively open at eye level. Basal area of the trees in dense forest can be handled if there is relatively little understory growth to obscure the line of sight.

Shrub cover can be measured provided the density of the shrubs is not so great that some individuals are partially obscured by closer individuals, and provided the shrub canopies are nearly circular.

For measuring basal cover of trees, the Bitterlich Method is usually preferred because of its accuracy and low cost. However, if visibility is limited or steep slopes are present, Calculated Cover (p. 50) may be preferred. For measuring shrub canopy cover, the Bitterlich Method is a rapid but crude technique. For low shrubs, Ocular Estimation of Cover (p. 58) may be nearly as accurate but faster, especially if quadrats are needed anyway to estimate density or cover by herbs. For accurate results, the Line Intercept (p. 40) is preferred. Of course, RS: Crown Density Scale or RS: Ocular Estimation of Cover is often much less expensive.

3.13.5 Training

Instruction and field practice require about 4 hr.

3.13.6 Equipment

There are several types of angle gauges on the market for measuring basal areas of trees. These include: glass prism ("cruising prism"); Relaskop; the Cruz-all; and others (Forestry Suppliers, Inc. 1980). The instrument should be accompanied by its specified BAF. If not, the BAF may be calculated as follows: Set up a target of 0.5-1 m in width (e.g., a horizontal board of appropriate length). Move directly away from the target until the angle gauge precisely measures or displaces the width of the target (Figs. 11, 12). Now measure the distance from the target to the eye. BAF is calculated as follows:

$$\text{BAF (percent/plant)} = 0.174 \frac{W^2}{D}$$

$$\text{BAF (m}^2\text{/ha plant)} = 0.25 \frac{W^2}{D}$$

$$\text{BAF (ft}^2\text{/ac plant)} = 75.625 \frac{W^2}{D}$$

where BAF = base area factor ($m^2$/ha plant or $ft^2$/ac plant)
W = width of target (cm for percent and metric, in for English)
D = distance to target (m for percent and metric, ft for English)

Foresters usually use a gauge with a BAF of 4 $m^2$/ha plant (or 10 $ft^2$/ac plant). In stands of large, old growth trees, a BAF of 8 $m^2$/ha is preferable, while in open stands of small (pole-sized) trees, a BAF of 2 $m^2$/ha plant should be used. This minimizes the number of borderline trees and the number of trees that should be counted which are hidden behind others.

The shrub angle gauge (Fig. 13) needs to be calibrated for each user. Cooper (1957) recommends a BAF of 0.5% plant. Convenient dimensions for the gauge are a 10 cm bar width and an eye-bar distance of about 70.7 cm. To adjust the gauge so it has a BAF of 0.5, set up a horizontal target 2 m wide and move directly away until the distance from the eye to the target is 14.14 m. The length of the chain should be adjusted until the target appears exactly "borderline." The observer should then check the calibration by moving toward the target, then slowly backing away until the target is "borderline," and then checking the distance. It is essential that each user recalibrate and readjust the shrub angle gauge to compensate for individual variation in the way the instrument is held.

Commercially available angle gauges cost from about \$3 for the Cruz-all, \$15-20 for prisms, and \$600 for the Relaskop (Forestry Suppliers, Inc. 1980). The shrub angle gauge can be constructed for \$2-3.

A low cost (i.e., \$2-3), but less convenient angle gauge for use in forests, can be constructed similar to the shrub angle gauge, but using a stick instead of a chain for determining the distance between the eye and the crossarm. Convenient dimensions are a 1 in crossarm and a 33 in stick. This gives a basal area factor of 10 $ft^2$/ac plant.

### 3.13.7 Cost

5 min per sample point.

### 3.13.8 References

Cooper 1957; Loetsch et al. 1973; Mueller-Dumbois and Ellenberg 1974; Forestry Suppliers, Inc. 1980.

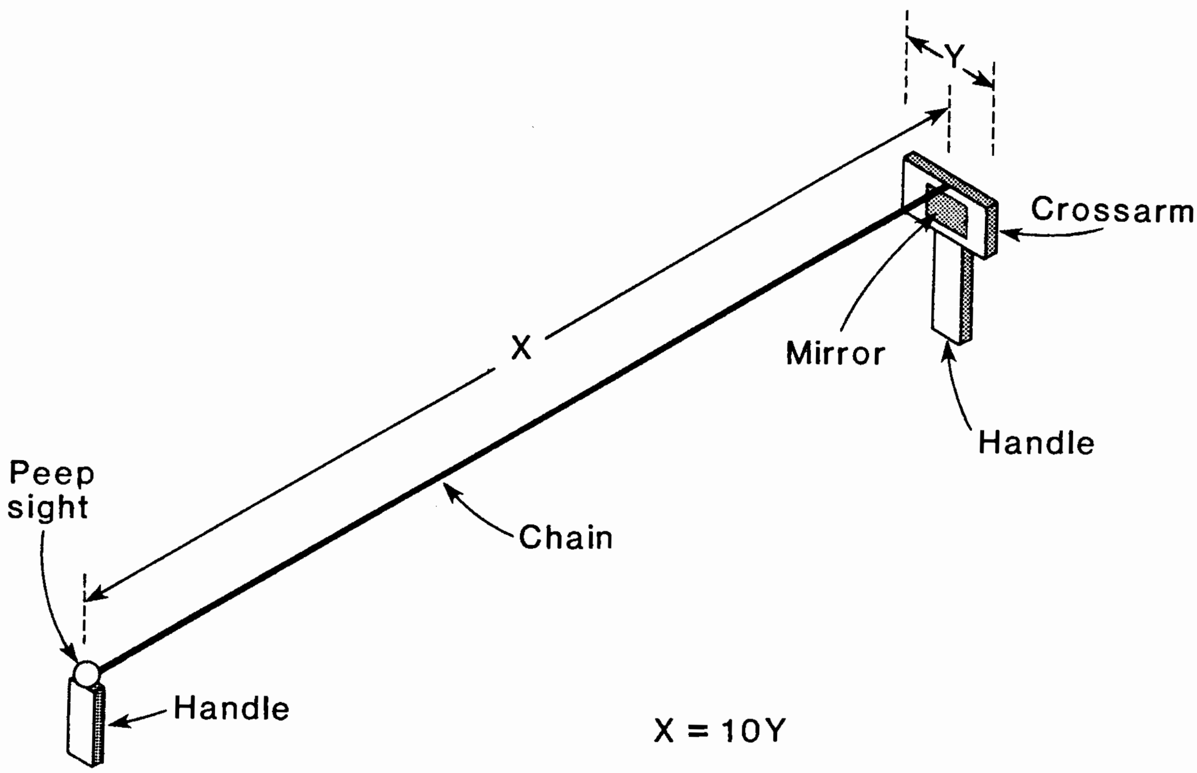



Figure 13. The shrub angle gauge. When the gauge is held so the crossarm is horizontal and perpendicular, the reflection of the chain in the mirror will align with the chain.

## 3.14 CALCULATED COVER

### 3.14.1 Variable Estimated

Canopy or Basal Cover of trees or shrubs(pp. 5, 7).

### 3.14.2 Description

In summary, the results of a measurement of density and of mean canopy area or basal area for the same site are used to calculate cover.

If data are available on density (Techniques 3.20 or 3.21) and mean canopy or basal area for plants (Techniques 3.1 and 3.23) on the same site, these estimates can be combined to estimate cover. The following formula applies:

$$C = 100\ AD$$

where C = cover (%)
A = mean area per plant (area)
D = density of plants (number per unit area, where the area units are the same as area for A, above)

### 3.14.3 Accuracy

The accuracy of the calculated cover is a function of the accuracies of the constituent measurements of density and mean area . For basal area of trees, it is usually medium to low in accuracy. For canopy cover, it tends to have low accuracy, due to deviations of canopy shape from circular.

### 3.14.4 Application Notes

This technique is most appropriate where the separate measures of density and canopy or basal area are required for other purposes. A convenient sampling approach is to combine T-square Nearest Neighbor Sampling (p. 62) for density with Crown Diameter (p. 15) or Diameter Tape (p. 18) and Averaging (p. 69). Each plant measured for the T-square sampling can also be used for area measurement. If the average area per plant is not required, it is usually preferable to measure cover with the Line Intercept (p. 40), Bitterlich Method (p. 43), Point Intercept-Spherical Densiometer (p. 55), or RS: Crown Density Scale at the same time density is being measured. One convenient way to do this is by combining a Line Intercept (p. 40) for measuring cover with a belt Quadrat (p. 65) for measuring density. The line transect forms one side of the belt quadrat.

## 3.15 POINT INTERCEPT-STEP POINT

### 3.15.1 Variables Estimated

Canopy cover of herbs, shrubs or trees, basal cover of herbs, foliar cover of low herbs, litter cover, or bare ground (pp. 5, 7).

3.15.2 Description

In summary, data are collected by recording what is present at (or directly above) the toe of a boot as one walks a line transect.

A V-shaped notch is cut in the sole at the toe of one boot of the person that makes the measurements (see Equipment section, below). Within the site, one or more line transects are laid out (see Appendix A). The observer walks along the transect and records a sample point each time the notched boot is placed on the ground. It is essential to walk straight and maintain a constant step length irrespective of barriers, briar patches, change in slope, and other factors. For each sample point, the observer records the item which occupies the line of sight for the majority of the notch. The observer must take care to exclude litter and vegetation which is pushed out of its undisturbed position. It is often desirable to record separately for each point the data for herbs, shrubs less than eye height, and taller trees and shrubs. The taller plants can be sampled by visual estimation of the location of a vertical line above the notch, or using the Vertical Rod (p. 39), which is more accurate.

General calculations are as follows for each category (X) recorded (e.g., plant species):

$$\%\ \text{ground cover} = \frac{\text{no. hits on X}}{\text{total no. sample points}} \times 100$$

This method has been modified by the addition of a pointed pin or rod (R. Francis, pers. comm.). The toe of the boot is lifted upward, and the pin or rod can be slid through the notch and used to select the sample point.

3.15.3 Accuracy

This technique is rather crude. Errors in pacing the transect invariably occur, usually resulting in underestimation of shrubs and other obstacles. In addition, it is often hard to eliminate errors caused by moving vegetation out of its original position. The pointed rod may alleviate some of this bias (R. Francis, pers. comm.). Estimation of taller vegetation (e.g., trees) by line of sight is even less accurate than the results for low grasses and forbs, but using the Vertical Rod (p. 39) will give results whose accuracy is comparable to those for herbs. Error can also result from the uniform spacing of points. This can be minimized by using several short transects, rather than one or two long ones.

3.15.4 Application Notes

This technique permits collection of many data points quickly. This is an advantage if the site is relatively heterogeneous. One person can easily apply this alone. It is best in grasslands, savannas, and open forests on even terrain. If conditions make it difficult to walk in a straight line, or if accuracy is needed, an alternative technique should be used such as: Line Intercept (p. 40); Bitterlich Method (p. 43); Point Intercept-Pin Frame (p. 52), Spherical Densiometer (p. 55), or Canopy Camera (p. 56); or RS: Crown Density Scale.

3.15.5 Training

This technique can be learned in less than 1 hr. A 1/2 hr practice session in the field is usually adequate (J. Hagihara, pers. comm.). Complex communities may require 4 hr of practice (R. Francis, pers. comm.).

3.15.6 Equipment

Pointed rod (option). One notched boot (The notch should be in the tip of the toe, 0.3 cm (1/8 in) wide and 0.15 cm (1/16 in) deep.

3.15.7 Cost

One-half to 1 hr per 200 m transect.

3.15.8 References

USDA Forest Service 1970.

## 3.16 POINT INTERCEPT-PIN FRAME

3.16.1 Variables Estimated

Basal, canopy, or foliar cover of low shrubs and herbs (pp. 5, 7).

3.16.2 Description

In summary, a frame is repeatedly set up in the site. The frame is used to identify specific points on the ground. Each point is scored for what is present.

A random point is selected within the site (see Appendix A). This point locates one end of the frame. Next, a random direction is selected (see Appendix A) to determine the location of the other end of the frame. The frame is erected by pushing the points into the ground or by using the support rod (see equipment section below).

A sample point is determined either by sighting through the frame's crosshairs, or by lowering a pin until its tip first contacts a plant or the ground (Fig. 14). What is contacted is recorded for each point. For basal cover, it may be necessary to look beneath the first contact (or extend the pin) until it is clear what is contacted at the specified height for measurement. For canopy cover, it must be decided whether or not the point lies within a plant canopy's projection. After reading all the points in the frame, a new location is selected and the process is repeated.

Cover is calculated by:

$$\text{Cover of X (\%)} = \frac{\text{Number of hits on X}}{\text{Total number of points}} (100)$$

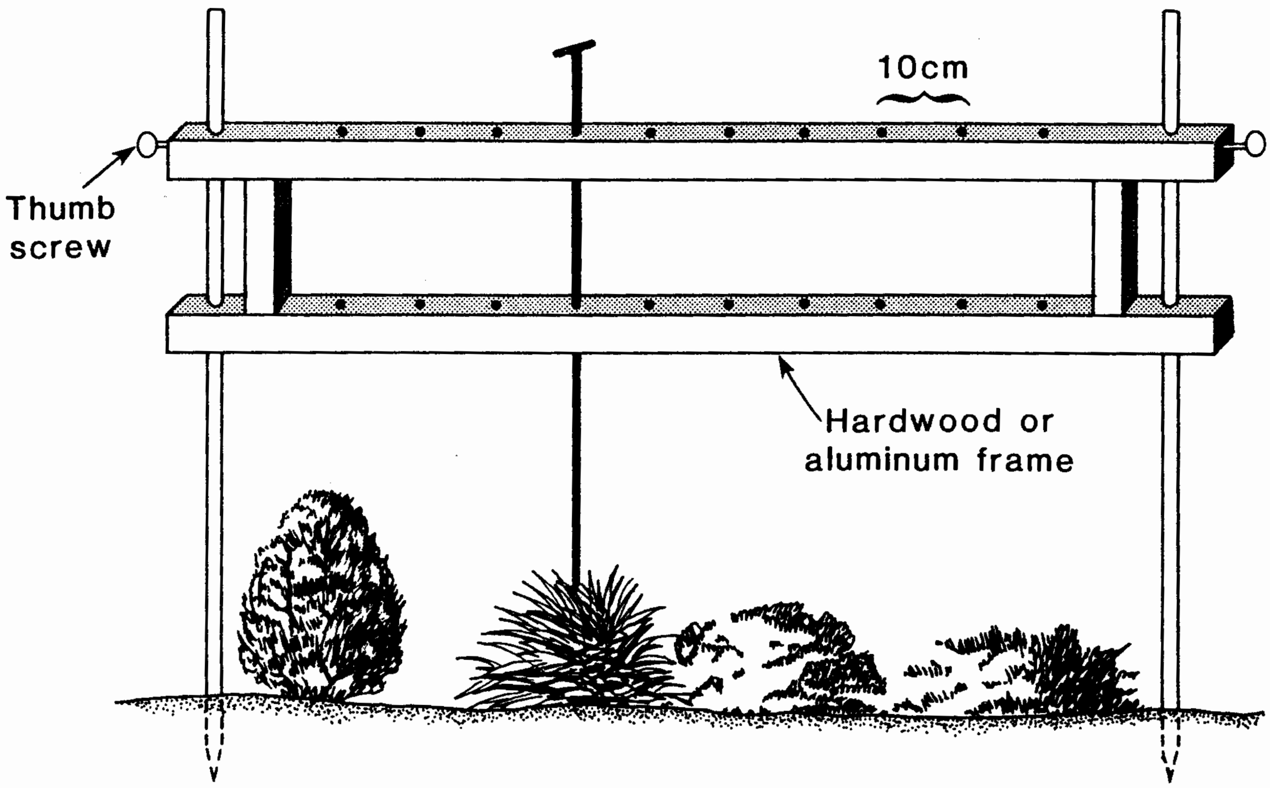



Figure 14. A 10 pin frame (only one pin is shown).

3.16.3 Accuracy

This technique can be highly accurate in estimating foliar cover. There is an inherent tendency to overestimate grasses and underestimate leafy herbs with a pin frame (McLean and Cook 1968:81). This error can approach 100% (Goodall 1952). Error is minimized by using very sharp pins or the optical sighting device modification.

Error in estimates of basal or canopy cover is likely to be small, but one should check for systematic bias in what constitutes a "hit." Systematic bias can often be reduced by having more than one person read questionable points and averaging the results.

3.16.4 Application Notes

This technique is relatively slow, and the equipment may be unwieldy. It is best applied to grasslands, savannas, and open forests, but can be used anywhere the vegetation is low enough to be underneath the frame, provided the frame can be stably erected. Wind makes the technique essentially unusable. This technique is the preferred one for highly accurate measures of foliar cover of herbs and low shrubs. Where lower accuracy is acceptable, the Point Intercept-Step Point (p. 50), using the pointed rod modification, or even Ocular Estimation (p. 58) may be used. For measurements of basal or canopy cover of herbs and low shrubs, similar accuracy can be achieved at lower cost using the Line Intercept (p. 40). For lower accuracy estimates of these variables, Ocular Estimation (p. 58) or the Point Intercept-Step Point (p. 50) are often better.

3.16.5 Training

The observer must learn what constitutes a "hit". The technique should take about one-half hour training instruction and 1 day of practice to develop consistency (R. Francis, pers. comm.).

3.16.6 Equipment

A frame (Fig. 14) holding vertical or inclined sharp pins (usually 10) is used as a measuring device (Avery 1975:214). The spacing between each pin or rod is 4 to 15 cm. For use on hard soil, a prop rod or stick can be affixed to each end of the frame at the top using a screw or nail. No commercial source is known, but a frame can be constructed for $5-25 in materials.

A modification is to use two sets of crossed wires as a "crosshair" sighting device, rather than movable rods (Winkworth and Goodall 1962).

3.16.7 Cost

Ten minutes per 10 pins (for a 10 pin frame).

3.16.8 References

Goodall 1952; Winkworth and Goodall 1962; Loveless 1967; McLean and Cook 1968; Mueller-Dumbois and Ellenberg 1974; Avery 1975.

## 3.17 POINT INTERCEPT-SPHERICAL DENSIOMETER

### 3.17.1 Variables Estimated

Canopy and foliar cover of the very tall shrubs and trees (pp. 5, 7).

### 3.17.2 Description

In summary, a spherical densiometer is set up at randomly located sampling locations in the site. The densiometer optically identifies a series of points in the canopy above the sampling location. The observer records what each point hits.

Random sampling locations should be selected (see Appendix A). At each location, the densiometer is set up following the manufacturer's instructions. The crew then sequentially looks at each of the points on the densiometer and records sky or the kind of plant which is intercepted. For foliar cover, if a point falls on a plant, the species should be recorded. If the point hits plant parts from more than one species, all should be recorded as hits. For estimates of canopy cover, the crew must judge where the outer perimeter of the canopies of individual plants lie, and then record for each sample point whether or not it falls within a plant's perimeter. The only data that need to be recorded are the total number of points intercepting each category of interest; e.g., trees by species, and sky. Data are most easily collected by sequentially observing in four directions (north, east, south, west) at a sample location.

To calculate cover for a particular category of data (e.g., plant species X), the following equation is used:

$$C_x = \frac{n_x}{\Sigma n}(100)$$

where $C_x$ = cover of X (%)

$n_x$ = number of dots intercepting X

$\Sigma n$ = total number of dots sampled

This formula may be applied for either foliar cover or canopy cover, depending upon how the data were collected. Commercially available densiometers use a 96 dot grid. Approximate measures of cover may be made by assuming one dot equals 1%, on the average. This will give an error of less than 5% due to the difference between 96 and 100.

### 3.17.3 Accuracy

Lemmon (1956) reported that the spherical densiometer consistently produces accurate measurements regardless of the operator, but does not provide data which substantiates its accuracy. Densiometer measurements were found to be highly correlated with those taken with a canopy camera (Hoffer 1962).

3.17.4 Application notes

This technique can be applied by one person. It is particularly appropriate to use where vegetation is dense and the user wants to estimate cover by species (e.g., mixed deciduous forest). It is also relatively easy to use in highly uneven terrain where the Line Intercept (p. 40) technique is difficult to apply. Where canopies do not overlap, and canopy cover is the desired variable, Line Intercept (p. 40), RS: Crown Density Scale, Bitterlich Method (p. 43), or Ocular Estimation (p. 58) are often preferred techniques.

3.17.5 Training

Instructions included with the instrument are adequate. However, field experience is necessary to improve operator consistency. Fifteen minutes instruction and 0.5 hr practice is adequate (R. Francis, pers. comm.).

3.17.6 Equipment

Spherical densiometer (about $47, Forest Densiometers 1980). Two types are available: convex and concave. Measurements from the two types should be calculated separately, because slightly different results can occur.

3.17.7 Cost

Three minutes per sample location (four directions) for sparse communities; 12 minutes per sample location for dense communities (R. Francis, pers. comm.)

3.17.8 References

Lemmon 1956; Lemmon 1957; Hoffer 1962; Forest Densiometers 1980.

## 3.18 POINT INTERCEPT-CANOPY CAMERA

3.18.1 Variables Estimated

Canopy or foliar cover of herbs, shrubs, and trees (pp. 5, 7).

3.18.2 Description

In summary, photographs are taken vertically upward using a wide angle lens. After development, these photographs are scored using a dot overlay. The proportion of dots intercepting the species of interest is a measure of cover.

Random sampling locations should be selected following one of the methods in Appendix A. The camera is erected over a sample location pointing vertically upward (for shrubs or trees) or downward (for herbs or low shrubs), and the canopy is photographed. After development and printing in the lab (usually involving enlargement to 4x5 or 6x8 in prints), an acetate grid is overlayed on each photograph. This grid should be dropped haphazardly multiple times on the photograph. Each time it is dropped, the species of interest or the absence of any species should be recorded for each point. If a point falls on more than one plant, each should be counted. For measurement of canopy cover, it may be desirable to draw the perimeter of each individual plant on the photograph. This facilitates determining whether a sample point on the acetate grid lies within a plant or outside of it.

Calculations are as follows for each category of data (e.g., plant species X):

$$C_x = \frac{n_x}{\Sigma n} (100)$$

where $C_x$ = cover of species x (%)

$n_x$ = number of dots falling on x

$\Sigma n$ = total number of dots sampled

The same equation is used for canopy cover or foliar cover.

3.18.3 Accuracy

Canopy cover, as obtained by use of a canopy camera, was found to be highly correlated with that obtained by a densiometer (Hoffer 1962). A permanent record is produced documenting results and permitting additional analysis if desired.

3.18.4 Application Notes

This technique tends to be relatively expensive in terms of equipment but saves field time. Much of the total staff time required can be spent in the office instead of in the field. One person can apply this technique without difficulty. It is applicable in all kinds of vegetation. For use in low vegetation, it may be necessary to dig a hole into the ground surface so that the camera lens is at about ground level. Difficulty can arise if the wind is blowing. The slow speed of the appropriate film means that leaf flutter will blur the image. This technique is the preferred one for measuring foliar cover of shrubs or trees. If appropriate camera equipment is not available, the Spherical Densiometer (p. 55) can provide equivalent data, but at a larger cost in field time. For foliar cover of herbs or low shrubs, the difficulty in placing the camera and in getting an adequate amount of area photographed usually makes it better to use a Pin Frame or Step Point (pp. 50, 52).

For canopy cover, this technique is justified where field time is limited, but office time is abundant. Total time for an estimate of comparable accuracy is less if Line Intercept is used (p. 40). Lower accuracy estimates can be made at lower cost using Calculated Cover (p. 50), Step Point (p. 50), or Ocular Estimation of Cover (p. 58).

3.18.5 Training

One-half hour instruction and two hours of field practice is adequate (R. Francis, pers. comm.).

3.18.6 Equipment

An adequate camera is a 35 mm single lens reflex with a 28 mm lens. Many technical books recommend a "fish eye" lens, which gives a very broad angular view of the canopy. However, this lens is more appropriate for ecological studies involving light interception at the surface than for measurement of the canopy and foliar cover over a point. This is because the broad angular view means that many of the sample points will be nearly horizontal, which would intercept many canopies. To optically measure canopy and foliar cover in the sense defined here, a 28 mm lens is the widest angle that should be used. A bubble level is desirable to level the camera. A tripod should often be used to hold the camera pointing vertically.

A fine grained black and white film such as a panchromatic should be used. A filter should be used to increase contrast (blue for clear skies, red for overcast). The picture should be shot with the lens closed down to at least f11 to ensure a high quality image with good depth of field.

For interpretation, a grid of 100 equally spaced dots should be laid out in a square pattern on acetate. This grid should approximate two-thirds the size of the final enlarged photo.

3.18.7 Cost

Fifteen minutes per sample location to photograph and 15 minutes to analyze the photo.

3.18.8 References

Evans and Coombe 1959; Brown 1962; Hoffer 1962; Anderson 1971; Ben Meadows Co. 1977; Forestry Suppliers, Inc. 1980.

3.19 OCULAR ESTIMATION OF COVER

3.19.1 Variable Estimated.

Canopy or foliar cover of herbs and low shrubs (p. 7).

3.19.2 Description

In summary, a sample of known area (quadrat) is laid out on the ground or on a photo. One then estimates cover "by eyeball."

This technique includes three separate similar approaches for ocular estimation of canopy cover: the "grid" (Fig. 15), "plant cramming", and "plant counting." The grid technique is particularly appropriate if the cover values being estimated are simply broad classes. For example, Daubenmire (1959) proposed a scale of cover classes as follows: 0-5, 5-25, 25-50, 50-75, 75-95, and 95-100%. Braun-Blanquet (1932) suggested the scale: <1, 1-5, 5-25, 25-50, 50-75, and 75-100%. When using broad cover classes, it helps to have marks on the sides of the quadrat to indicate the critical limits of cover class areas for comparison with the cover of particular species (as shown in Fig. 15). The "plant cramming" technique is most appropriate when

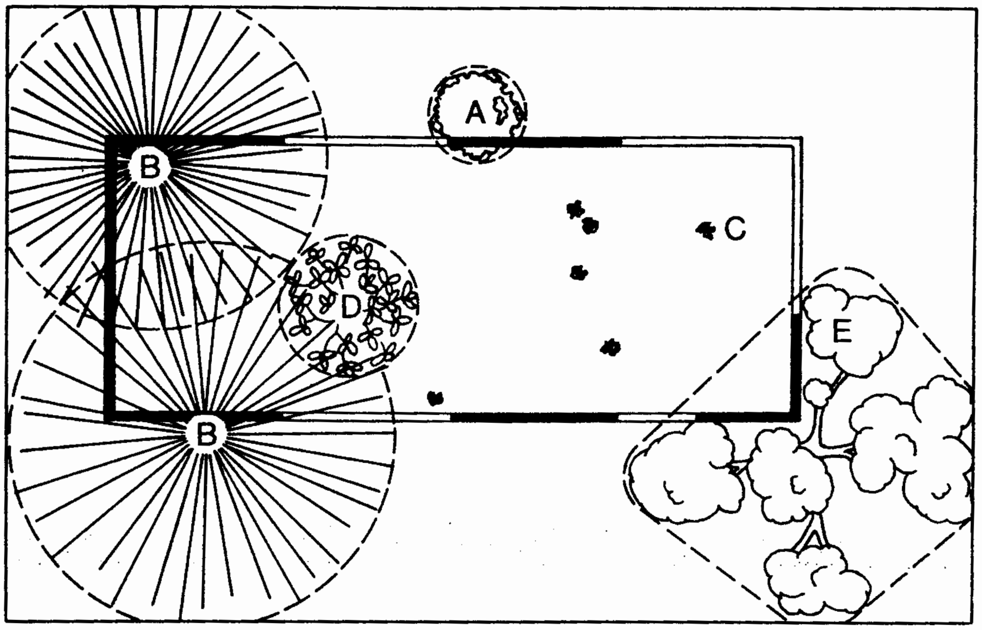



Figure 15. The grid technique of Ocular Estimation of Cover (redrawn from Daubermire 1973). Note the marks along the sides of the frame which lay out areas of 5, 25, 50, 75, and 95%. Cover classes of species shown are: A, <5%; B, 25-50%; C, <5%; D, 5-25% and E, <5%.

plants differ greatly in size within the same species. The "plant counting" technique is particularly appropriate when plants of a given species are very similar in size. If foliar cover is being estimated, the "grid" approach is likely to be the best.

The next decision is that of quadrat size. The "grid" technique is most appropriately used in the field with a solid-framed quadrat of about 1/10-1 $m^2$. It is usually square or rectangular in shape. The "plant cramming" and "plant counting" techniques work best using rectangular or round quadrats scaled so that approximately 8 to 20 individuals will fall within the quadrat. The latter two approaches have been proposed for estimating cover on aerial photos (Pope 1960), but should be usable in the field.

One next locates a quadrat in the site to be sampled. If the estimates are to be used to characterize the average cover over the site, the sample points should be selected randomly (Appendix A).

To collect data using the "grid" technique, one simply makes a direct estimate from observing the plot. If cover classes are used, one can ocularly estimate the area of a square or rectangle equal to each class limit by referring to the reference marks on the frame. These known areas are then ocularly compared to the areas covered by the plants of interest (Fig. 15). When the "grid" technique is used for foliar cover, it is important to not include in the estimate the area of gaps in the plants canopies.

To collect data using the "plant cramming" technique, "the plot is mentally divided into sections--usually quarters - oriented according to the way the trees are grouped. Then, trees are ocularly moved from the scattered sections to fill up holes in the denser sections. When all trees are visually crammed together, the interpreter estimates what proportion of the plot is occupied by crowns" (Pope 1960, Fig. 16).

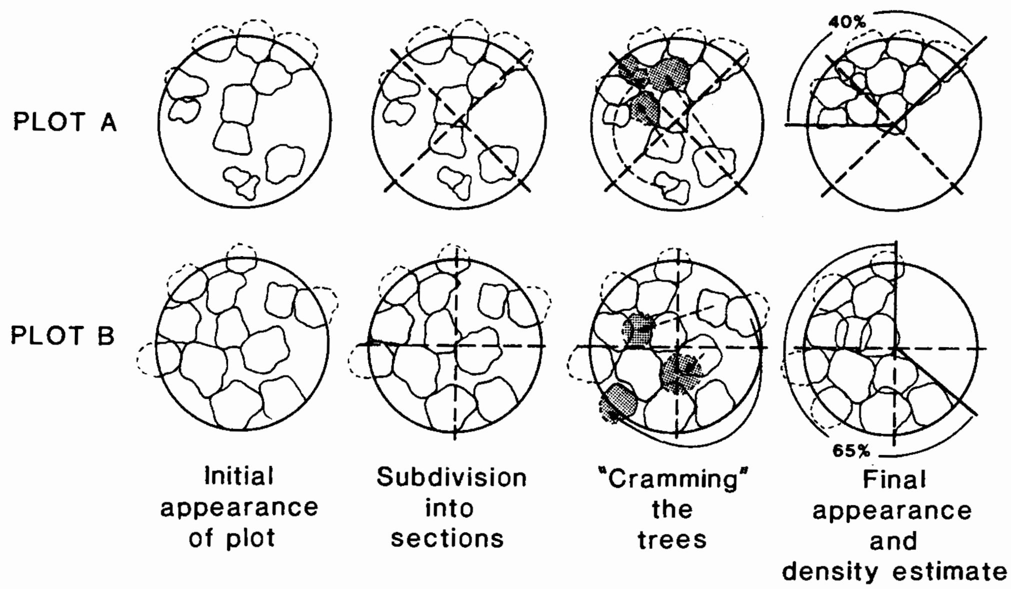
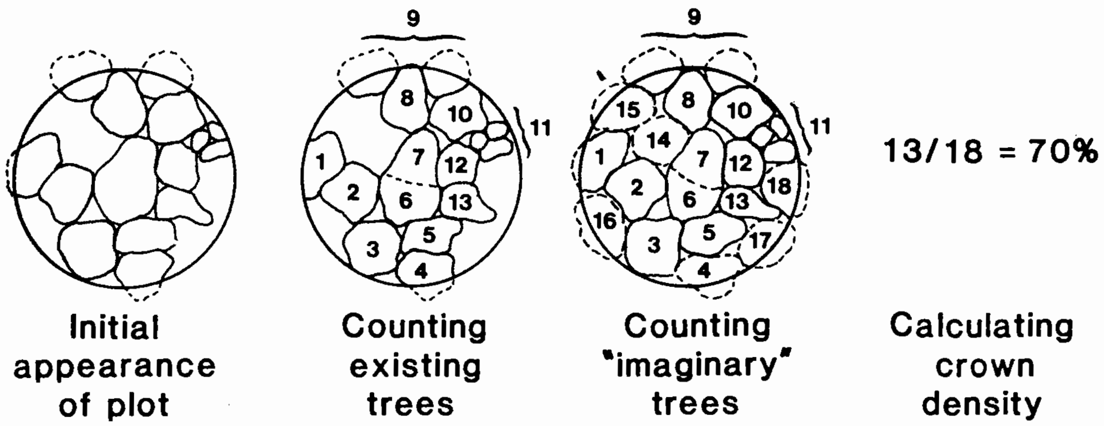



Figure 16. Plant cramming technique (after Pope 1960).

To collect data using the "plant counting" technique, "first, the existing crown cover is tallied in terms of numbers trees of average crown diameter. Next, the crown canopy is mentally filled in to 100 percent density by counting the number of average-sized crowns necessary to fill all the gaps in the existing cover. Crown density [canopy cover] is then determined by the ratio of the existing tree count to the 100 percent tree count" (Pope 1960, Fig. 17).




Note that in both "plant cramming" and "plant counting," the plants do not fit together perfectly, so the observer should try to balance holes with overlaps.

3.19.3 Accuracy

This technique can be moderately accurate. Errors have been reported on application to aerial photos in forests arising from shadows being interpreted as part of canopies. Error also arises simply from inadequate training. The latter kind of error can be minimized by making quantitative measurements of cover using one of the other techniques (e.g., line intercept), and then "training the eye" against these known values. Accuracy can also be increased if one attempts multiple ocular estimation techniques on each quadrat.

3.19.4 Application Notes

This technique tends to be inexpensive. Estimates can be made very quickly. It is most appropriate when there is a good contrast between the plants being examined and the background. Since it must be possible to view the plants within a clearly limited quadrat, ocular estimation can be applied in the field only to low vegetation. It is also necessary for the plants' canopies to be distinct. Where greater accuracy is required, Line Intercept (p. 40) or one of the Point Intercept (pp. 50-56) techniques can be used.

3.19.5 Training

Two to four hours per type of vegetation. If more than one person will be making readings, it is important that they "calibrate" themselves by estimating several plots together until satisfactory agreement is reached. This should be done at the beginning of each day, and checked again every two hours or so.

3.19.6 Equipment

Quadrat frame for field use (see Fig 15). A frame 20 by 50 cm (inside dimensions) is sufficiently rigid if made of 3/16 in steel. Sharpened legs 3 cm long can be attached to each corner to hold the frame in place above the plot being sampled (Daubenmire 1959). For office use, quadrats can be drawn on clear acetate.

3.19.7 Cost

About 5-25 min/10 quadrats.

3.19.8 References

Hanson and Love 1930; Braun-Blanquet 1932; Daubenmire 1959; Pope 1960; Daubenmire 1973.

## 3.20 T-SQUARE NEAREST NEIGHBOR SAMPLING

3.20.1 Variable Estimated

Density of trees or shrubs (p. 10).

3.20.2 Description

In summary, random points are selected on the site. At each point the distance to the nearest plant, and the distance from that plant to a neighbor is measured.

A random point is selected within the sample area (see Appendix A). The closest plant to this point is identified. The distance from the sample point to the center (e.g., the base of the stem) of the nearest plant is measured. A line perpendicular to the original line and passing through the plant is laid out using a magnetic compass or right angle prism. It is usually obvious which plant should be selected. The compass or prism should be used to be certain whether or not a plant near the perpendicular line is on the appropriate side. One then identifies the nearest plant to the one previously sampled which lies on the opposite side of the perpendicular line from the sample point. The distance between the centers of the two plants is measured (see Fig. 18). Additional sample points are identified, and the process is repeated.

This process may be done to estimate density for a particular kind of plant, e.g., for evergreen species, by ignoring other kinds of plants. It is legitimate to sample multiple classes of plants from the same sample point by considering each type independently. That is, a random location can be

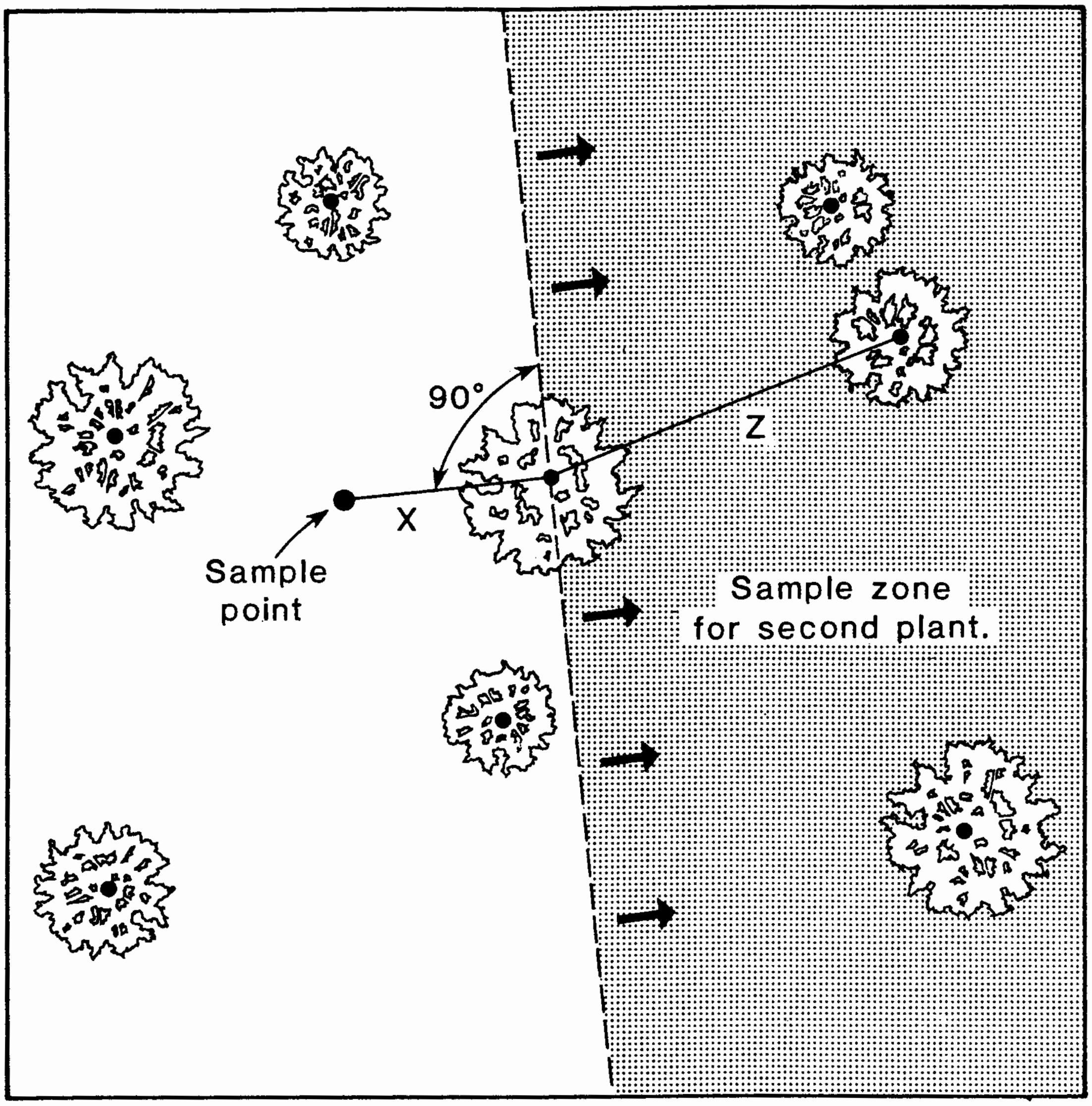



Figure 18. T-square Nearest Neighbor Sampling. X = the distance from the sample point to the nearest plant. Z = the distance from that plant to its nearest neighbor in the 180° sample area.

identified. The nearest evergreen plant and its nearest evergreen neighbor can be identified and measured. The same process can be repeated for deciduous plants or for individual species starting from the same random point.

General calculations are as follows for each category of plants included:

$$D = \frac{\sqrt{2}\, n}{\pi\, [(\Sigma\, x^2)\, (\Sigma\, z^2)]^{\frac{1}{2}}}$$

where D = density (number of individuals per unit area, in the square of units used to measure the distances)
n = the number of random points sampled
x = the distance from the random point to the nearest plant
z = the distance from the nearest plant (to the random point) to its nearest neighbor (see Fig. 18)

To convert to number per hectare, or to number per acre, multiply the calculated "D" by the appropriate factor in Table 6.

Table 6. Conversion factors for density measurement

| Calculated density units | Desired density units | Multiply by |
|---|---|---|
| Number/$m^2$ | Number/ha | 0.001 |
| Number/$dm^2$ | Number/ha | 0.000 001 |
| Number/$ft^2$ | Number/ac | 0.000 023 |

3.20.3 <u>Accuracy</u>

This technique can be moderately accurate. Currently, it is considered the best estimator among the various plotless sampling techniques in the literature (e.g., Nearest Neighbor, Point Quarter). Major sources of error can include not selecting truly random sample points and mismeasuring distances to the appropriate plants. The technique is not suitable for sampling plant distributions that are highly clumped (i.e., several tight clusters, each of which contain more than one individual).

3.20.4 Application Notes

This technique is relatively inexpensive compared to using Quadrats (p. 65) for large plants. It ordinarily requires a crew of two. It is most suitable for use in forests and shrubland which can be walked through without great difficulty. When determining density for small shrubs or herbs, Quadrats (p. 65) are often more efficient.

3.20.5 Training

Less than 4 hr.

3.20.6 Equipment

Tape Measure ($13-50), right angle prism (from $32), or compass (from $19) (prices from Forestry Suppliers, Inc. 1980).

3.20.7 Cost

This technique is similar to four techniques described by Cottam and Curtis (1956:451). They found that compared with the standard quadrat technique, a saving of about 90% in time was common.

3.20.8 References

Cottam and Curtis 1956; Diggle 1975; Forestry Suppliers, Inc. 1980.

3.21 QUADRAT

3.21.1 Variables Estimated

Density or frequency of herbs, shrubs, or trees (p. 10).

3.21.2 Description

In summary, the quadrat technique involves laying out on the ground a defined two-dimensional area, such as a square or rectangle, and then counting the number of individual plants contained within the area.

The first step is to determine the appropriate quadrat size and shape. Circular quadrats are relatively easy to lay out where the vegetation is fairly open. A central point can be identified and a line of predetermined length (e.g., a meter tape) can be swung as a radius through 360°. For a less accurate estimate, an Optical Range Finder (p. 30) can be used in place of the line. Data can be recorded as this radius is swung. Circular quadrats also have a minimum ratio of circumference to area, and so are relatively less susceptible to error due to inclusion or exclusion of plants lying at the margin. Square quadrats are convenient to use for low vegetation, since a frame of approximately 1 m on a side can be constructed to define the boundary of the quadrat. This makes it realatively easy to locate the margins of the quadrat. Rectangular quadrats (with width: length ratios ranging from 1:3 up to the so called "belt transects" or "strip" quadrats that can be a few hundred meters long and a half a meter wide) have been found to be more efficient in estimating density than square or round ones. This is because a rectangle tends to cut across clumps of individuals of species and, hence, gives a lower variation between quadrats in the count of the number of individuals. This factor also means that frequency is relatively less meaningful using elongated quadrats, because frequency is maximized with a rectangular quadrat.

A variety of quadrat sizes have been used. Oosting (1956:42) recommends a plot 0.25 X 4 m for maximum efficiency in measuring density in low herbaceous vegetation. Bormann (1953) found that in a forest, the best estimate of density was obtained with strips 4 X 140 m and 10 X 140 m with a long axis of the plot crossing the countours and vegetational banding. Forest vegetation has often been sampled using square quadrats 10 m on a side. Square quadrats 4 X 4 m have been used frequently for woody vegetation up to about 3 m tall. Square quadrats 1 m on a side have often been used for herbs (Oosting 1956:48).

For very long and narrow quadrats ("strip" quadrats or "belt transects"), it is often best to establish a line transect (Appendix A) as one side of the quadrat. A rod of length equal to the quadrat width can then be used as a gauge to determine whether or not a particular plant is close enough to the transect line to be "in". Frequency in this situation can be estimated by treating short segments of the quadrat as separate quadrats.

The center of a round quadrat, or the corner of a square or rectangular quadrat, is located in the site by selecting a random point (Appendix A). Quadrats that are not round should be oriented randomly (Appendix A). Quadrats made on the spot using a rope for the sides are constructed ensuring that the corners are right angles (using a compass or right angle prism).

Data are recorded by simply counting the number of individuals of each category of plant (e.g., species) within the plot. This requires an operational definition of what an individual is. Ecologists have variously used clumps or individual above ground stems as the operational definitions. This problem is only significant when the plants reproduce vegetatively using below ground runners, or where multiple intertwining individuals grow from seeds in very close proximity to one another. Individuals falling exactly on the line are counted as one-half. For measurements of frequency, it is necessary to only record the presence or absence of the categories of plants of interest. For a species whose only representative is one individual falling exactly on the line, it should be included or excluded randomly (e.g., by flipping a coin).

Density for the plants in category X (e.g., a species) may be calculated as follows for a quadrat on flat ground:

$$D_x = \frac{n_x}{a}$$

where $D_x$ = density of x (number per $dm^2$, $m^2$, or $ft^2$)

$n_x$ = number of plants of type x

$a$ = area of the plot ($dm^2$, $m^2$, or $ft^2$)

If the quadrat is on a slope, the area should be corrected by multiplying by the cosine of the slope angle (see p. 87).

Densities can be converted to number per hectare or acre by multiplying by the appropriate conversion factor from Table 6 (p. 64).

Frequency can be calculated as follows for a quadrat on flat ground:

$$F_x = \frac{P_x}{n_p}(100)$$

where $F_x$ = frequency of x (%)

$P_x$ = number of plots containing at least one individual of x

$n_p$ = total number of plots

### 3.21.3 Accuracy

On sloping ground, the quadrat should be laid out to correct for slope. This can be somewhat difficult to do. For instructions, see Loetsch et al. (1973:321). Errors in counting and recording can be very hard to avoid in some kinds of vegetation. It is also a problem to decide whether some plants close to the boundry should be included within the plot or excluded. This problem is especially acute in long, narrow, rectangular quadrats where there is a high ratio of boundary to area. The error caused by slope (if uncorrected) is less than 5% at slopes less than 18°.

### 3.21.4 Application Notes

This technique can be relatively inexpensive where it is easy to distinguish individual plants from one another, and where quadrats can be established only with difficulty. It is usually possible for one person to do small quadrats using a quadrat frame. However, a crew of two is usually needed to establish the quadrat, and for one individual to record information while the other one counts the plants. This technique can be applied in any kind of vegetation. However, where extremely dense herbaceous vegetation exists, it may be difficult to position, on the ground, a quadrat that is small enough to make counting the plants within it practical.

### 3.21.5 Training

Instruction time for 10 x 10 m is 20 min, 1 hr for 4 x 4 m, and 2 hrs for 1 x 1 m quadrat. At least 1 day of field practice is necessary for any size quadrat (R. Francis, pers. comm.).

### 3.21.6 Equipment

Designs for quadrats are many. A simple square quadrat (1 $m^2$) frame can be constructed out of wood at minimal costs. It is convenient to use a meter tape to lay out large quadrats. Alternatively, a rope tied in a loop with knots tied to indicate corners, can be used. A compass (from $19) or right angle prism (from $32) is a convenient way of ensuring the quadrat's corners are 90° angles. (Prices from Forestry Suppliers, Inc. 1980).

3.21.7 Cost

(crewhours per quadrat. R. Francis, pers. comm.):

10 x 10 m simple community - 0.02
10 x 10 m complex community - 2
4 x 4 m simple community - 0.02
4 x 4 m complex community - 2.5
1 x 1 m simple community - 0.02
1 x 1 m complex community - 4

3.21.8 References

Raunkiaer 1934; Bormann 1953; Oosting 1956; Greig-Smith 1964; Loetsch et al. 1973; Mueller-Dumbois and Ellenberg 1974; Forestry Suppliers, Inc. 1980.

## 3.22 CALCULATED FOLIAGE HEIGHT DIVERSITY

3.22.1 Variables Estimated

Foliage height diversity (p. 10).

3.22.2 Description

In summary, measurements of the amount of foliage at various levels above the ground are converted into an index of diversity mathematically.

The first step is to determine which measurement of quantity of foliage will be used as data. MacArthur and MacArthur (1961) used the average horizontal foliar density measured at heights of 6 in, and 2, 5, 10, 20, 30, 45, and 60 ft, using the "variable distance" approach with the Vegetation Profile Board (p. 70). Other measurements of the amount of foliage, such as cover or biomass, can be used.

These data must be converted into a proportion of foliage at each height. For horizontal foliar density measurements, distances must be converted to quantity of foliage with the following equation (MacArthur and MacArthur 1961):

$$k_i = 0.693/D_i$$

where $k_i$ = the quantity of foliage at height i
$D_i$ = the average distance measured at height i

Next, the proportion of foliage at each height must be calculated:

$$p_i = \frac{k_i}{\Sigma k_i}$$

where $p_i$ = proportion at height i (dimensionless)

$k_i$ = the amount of foliage at height i (from the first equation or from other data, such as cover or biomass)

$\Sigma k_i$ = the sum of $k_i$ values over all heights

Finally, the index is calculated by applying the Shannon-Weiner function (MacArthur and MacArthur 1961):

$$FHD = \Sigma p_i \ln p_i$$

where FHD = the foliage height diversity index (dimensionless)

$p_i$ = the proportion of foliage at height i from the second equation (above)

3.22.3 Accuracy

This technique's accuracy depends upon the accuracy with which the individual measurements of amount of foliage are made. The number of layers recognized is also important. While quantitative guidelines are not available, enough layers should be recognized to permit one to draw smooth curves of the amount of foliage versus height.

3.22.4 Application Notes

This technique is inexpensive. It provides a widely used index of habitat diversity for birds.

3.22.5 References

MacArthur and MacArthur 1961.

## 3.23 AVERAGING

3.23.1 Variables Estimated

Vegetation layer height, litter depth, slope, aspect, water body width, water depth, or surface water velocity (pp. 10, 11, 12, 13).

3.23.2 Description

In summary, individual measurements are averaged mathematically to estimate homogeneous properties of the sites.

The general formula for calculating an arithmetic mean from individual measurements is as follows:

$$\bar{D} = \frac{\sum_{i=1}^{n} D_i}{n}$$

where $\overline{X}$ = mean

$X_i$ = an individual measurement

n = total number of individual measurements

This technique can be applied to any set of data. However, samples should be taken randomly (Appendix A) to estimate the properties of vegetation, litter, the soil surface, landform, soil, and aquatic system characteristics.

The individual measurements are averaged without change for most characteristics. The exception is aspect. Individual measurements of angle from the north can be used as long as the aspect is not generally north. If measurements appear both west of north and east of north, it is necessary to convert them into positive angle from the north (the recorded numbers which are close to zero) and negative angles from the north (360° minus the recorded numbers for angles which are approaching 360°).

3.23.3 <u>Accuracy/Precision</u>

If an adequate sample has been taken, this technique can be highly accurate. Statistical references detail how to establish the confidence bands (degree of precision) for any calculated mean. If the individual measurements contain systematic error, the calculated mean will, of course, be in error to the same degree.

3.23.4 <u>Application Notes</u>

This technique is usually most practical where it is difficult to measure the "homogeneous" property directly.

3.23.5 <u>References</u>

Sokal and Rohlf 1969; Remington and Schork 1970; Freese 1974.

## 3.24 VEGETATION PROFILE BOARD

3.24.1 <u>Variable Estimated</u>

Horizontal Foliar Density (p. 10).

3.24.2 <u>Description</u>

In summary, a narrow board is erected in the site. The observer stands a distance from the board, looks at it from a prescribed height, and estimates "by eyeball" the extent to which the board is obscured by vegetation.

A sample point and sample direction are selected in the site. If the average of the site is the desired variable, this should be done randomly (see Appendix A). Two approaches are used: fixed distance and variable distance. For fixed distance, the profile board (Fig. 19) is erected vertically over the sample point facing in the sample direction. The observer then moves off the

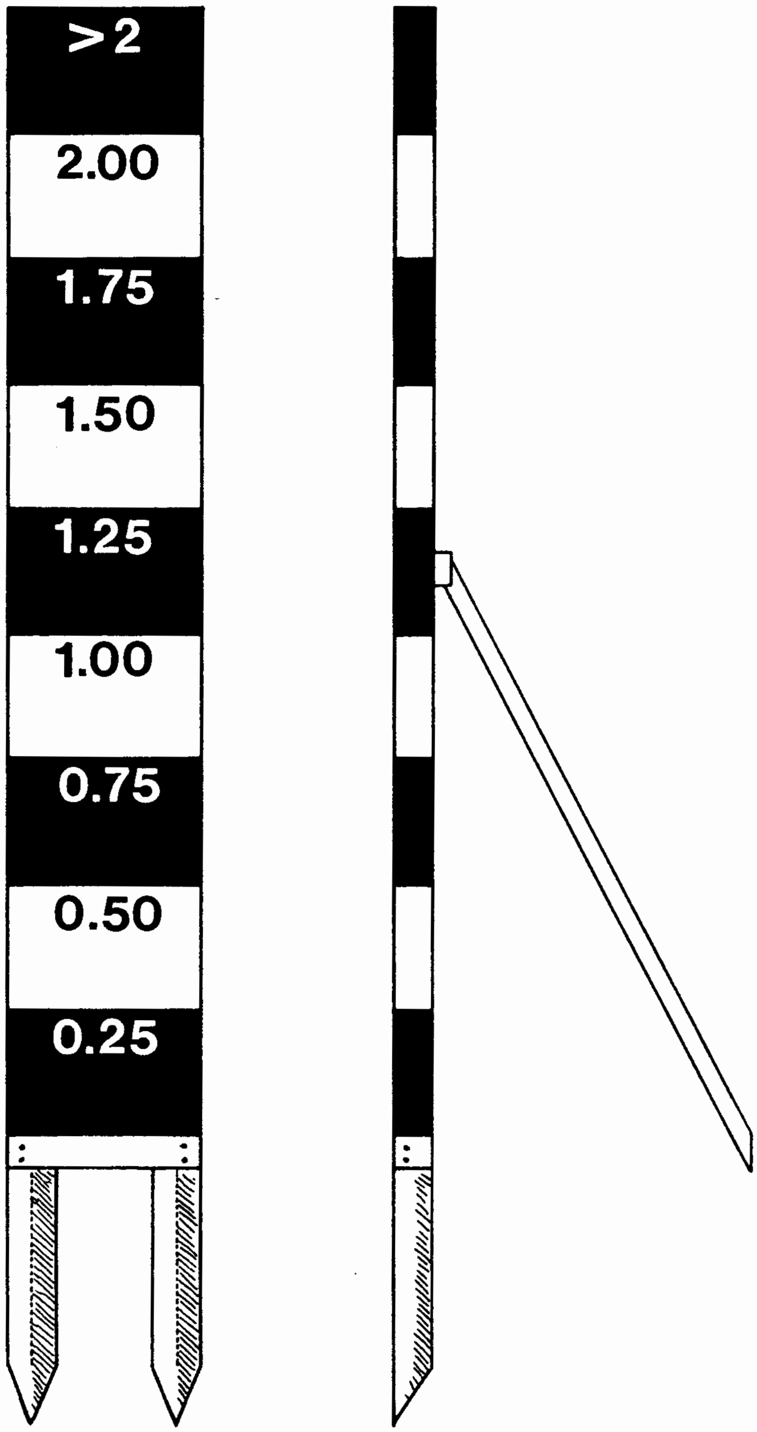



Figure 19. A Vegetation Profile Board for use close to the ground (after Nudds 1977). A simple square target is attached to the end of a long pole for use above 2 m.

prescribed distance from the point and observes the target successively at the different heights (usually at least every 0.25 meter). Nudds (1977) found that a distance of 15 m gave the best descrimination between vegetation types. At each observation height, one records the ocular estimation of the amount of the target (at that height) that is obscured by plant parts in the line of sight. This is usually done to the nearest 20% (e.g., 0 to 20, 20 to 40%, etc.), and is facilitated by using a comparator (Fig. 20). For a discussion of approaches to ocular estimation, see p. 58.

For the variable distance approach, the observer positions himself at the sample point with his eyes at the sample height. Another crew member moves away from the observer in the sample direction and positions the target at the sample height. If the target is 50% obscured, the distance between the observer and the target is measured. If not, the target is moved toward or away until it is 50% obscured.

If one is characterizing the average for the site (see p. 69), it is necessary to take multiple measurements. A convenient way to do this is to select four random orientations from each sample point, and simply rotate the target or observer as appropriate. If the random direction taken yields the same value twice at a given sample location, data should be recorded for both.

3.24.3 Accuracy

This technique is moderately accurate for measuring this parameter. However, the parameter is usually used as an indication of something else, such as "perceived sight distance" for a given wildlife species, or for estimation of the quantity of vegetation at a given height in a stand. Its accuracy under these conditions becomes largely a function of the extent to which there is a direct relationship between the measured horizontal foliar density and the variable of which it is used as an indicator. Precision is largely a function of one's ability to ocularly estimate the amount of the board which is obscured. (For characterizing a site, precision also becomes a function of the sample size).

The major sources of error include selecting points which are not truly random; e.g., avoiding standing in briar patches when the randomly selected location would put you there, not moving along the sample direction in a straight line, and errors in the ocular estimation of the amount of the board which is covered. The error in ocular estimation can be minimized by using a "comparator" (Fig. 20). It is probably minimal in the variable distance approach.

3.24.4 Application Notes

This technique is relatively inexpensive to apply. For best results, a crew size of two is desirable. One person may use this technique, but it requires more time than if one person can be the observer, and the other person can manipulate the target board. It is applicable in any vegetation or soil condition provided the surface topography is relatively smooth. It becomes more difficult to use as vegetation becomes so dense that it is hard to move through. The fixed distance approach is best for measurements up to about 2.5 m. For higher measurements, the variable distance approach is usually easier. The two approaches should not be combined in the same study.

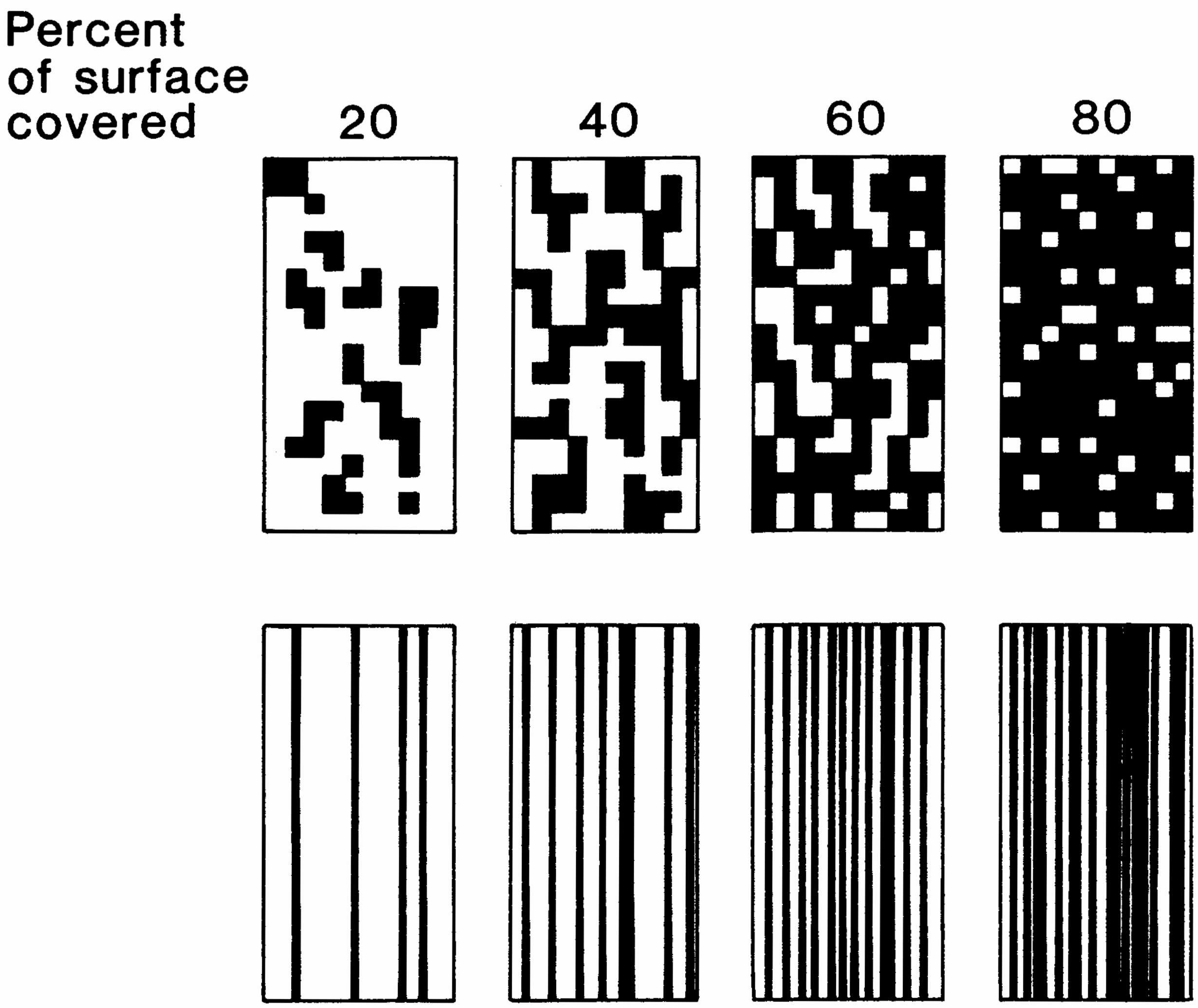



Figure 20. A percent cover comparator for use with a Vegetation Profile Board. The top row is useful in vegetation having large broad leaves, while the lower is best for grass and plants without leaves.

3.24.5 Training

Four hours to develop consistency in estimation.

3.24.6 Equipment

For the fixed distance approach, a "Vegetation profile board" (Fig. 19) is used as the target. Nudds (1977) found that a profile board 2.5 m high, 30.5 cm (12 in) wide, made from 0.95 cm (3/8 in) plywood marked in alternate colors, black and white at 0.5 m intervals is a suitable target. Nudds attached aluminum spikes to the lower end of the board to hold it upright in the ground, and a hinged support was attached to the back to hold it upright if the prongs were not easily inserted into the ground. Morris (cited in Nudds 1977) used a similar technique for small mammal studies. He measured with a target of 1 m height, at intervals of 0.5 m. For the variable distance approach, MacArthur and MacArthur (1961) used a white board 25.4 by 45.7 cm (18 in) attached to a long pole (no commerical source known). Materials should cost less than $10.

Tape measure ($3-50), piece of rope of length equal to the distance over which measurements will be taken, or an optical range finder ($25) (see p. 32). A ladder may be necessary to observe from the appropriate height. An aluminum sectional ladder is recommended for heights above 3 m ($139/10 ft section prices from Forestry Suppliers, Inc. 1980).

3.24.7 Cost

No estimate available.

3.24.8 References

MacArthur and MacArthur 1961; Nudds 1977; Forestry Suppliers, Inc. 1980.

## 3.25 CALCULATED COMMUNITY DOMINANCE

3.25.1 Variable Estimated

Community Dominance, an indicator of the "evenness" component of species diversity (p. 11).

3.25.2 Description.

In summary, measurements of some estimate of dominance of some of the species on a site are converted by calculation into an estimate of the community dominance.

The class of plants being examined must be defined. This may be, for example, all tree species or all forbs. Next, it must be determined what the measurement of "dominance" will be. If plants are of approximately the same size, density may be the easiest. If plants differ greatly in size, canopy or foliar or basal cover may be more suitable. Data to be used must be collected from the site as follows: Based upon reconnaissance of the site, the two species which contribute the most to the "dominance" (as defined above) must be identified. The "dominance" indicator (e.g., density) must be measured for these two species, and for all species taken together (including those two).

The community dominance index is a calculated as follows:

$$C.D.I. = \frac{Y_1 + Y_2}{\Sigma Y} \times 100$$

where C.D.I. = community dominance index (percent)

$Y_1$ = "dominance" of the species with the greatest "dominance"

$Y_2$ = "dominance" of the species with the second greatest "dominance"

$\Sigma Y$ = sum of "dominance" values for all species (it is not necessary to know Y for each species, just the total)

The community dominance index is always between 0 and 100%. In most natural communities, if the "evenness" (equitability) measure of species diversity is high, the community dominance index is low.

### 3.25.3 Accuracy

This technique's accuracy depends upon the accuracy with which the individual "dominance" values have been measured. The greatest source of error is likely to be mistakes in determining to which species an individual belongs.

### 3.25.4 Application Notes

This technique is inexpensive. It provides a reasonable and easily measured index of the "evenness" component of species diversity.

### 3.25.5 References

Krebs 1972.

## 3.26 MAP MEASURER

### 3.26.1 Variables Estimated

Distance from a site to the nearest example of a specified feature, site linear dimensions, or width of water body (pp. 11, 12, 13).

### 3.26.2 Description

In summary, the map measuring instrument is moved over the distance to be measured on a map or aerial photo of known scale. Its reading is converted mathematically to distance on the ground.

It is first necessary to make or acquire a map or aerial photo which can be used as a map of known scale. To determine scale for aerial photos, see a standard reference in remote sensing, such as Avery (1978:8-9). One then identifies the points on the map or photo whose distance is to be measured, and runs the map measurer's wheel over this distance. The scale on the map measurer is read and converted using the necessary factor to calculate distance on the ground (Avery 1978:9-10).

### 3.26.3 Accuracy

This technique is fast and can be moderately accurate. Inexpensive map measurers will often give a systematic error within about 5%. Going around sharp corners can create additional error due to moving the wheel over an incorrect path or due to slippage. For example, one inexpensive map measurer we examined had a 2.8% systematic error and a 6.5% maximum error on a jagged path. Error can be minimized by calibrating the map measurer using a known distance drawn on a sheet of paper.

### 3.26.4 Application Notes

This technique tends to be inexpensive for measuring linear distances. If the distance is a straight line, it is often preferable to measure it directly with a ruler. If the distance to be measured is on a curve, however, the map measurer is often the method of choice. For measuring edge length (for Calculated Edge/Area, p. 82), the map measurer is preferable if the total amount of edge to be measured is small. If the amount to be measured is large, however, Line Intercept Measurement of Edge (p. 78) is often less expensive.

### 3.26.5 Training

Less than 1 hr to develop consistency.

### 3.26.6 Equipment

Map measurer (from about $5; Forestry Suppliers, Inc. 1980)

### 3.26.7 Cost

No estimate available.

### 3.26.8 References

Avery 1978; Forestry Suppliers, Inc. 1980.

## 3.27 PACING

### 3.27.1 Variables Estimated

Distance from a site to the nearest example of a specified feature, or site linear dimensions (pp. 11, 12).

3.27.2 Description

In summary, the length of one's step is used as a measure of linear distance.

The pace is defined as the average length of two natural steps, counting each time the same foot is placed on the ground. To calibrate the pace, a known horizontal distance (150 to 300 ft, or 50 to 100 m) is staked out over level terrain and paced several times until a consistent gait is established. (This is established when one's variation over the same distance is less than 3 paces in 100.) A ratio of paces to distance is calculated and can be used to compute the sample distance:

$$x = \frac{d}{c} (p)$$

where
- x = unknown distance (m or ft)
- d = distance of the calibration interval (m or ft)
- p = number of paces over the unknown distance
- c = paces over calibration interval

Obstructions in the path may cause special problems which may require individual ingenuity upon encountering them, such as stepping sideways a specific number of counts before reaching the obstacle, and then back after the obstruction is passed. Slopes, uneven ground, dense vegetation, and difficult terrain tend to make one decrease the (horizontal) length of the natural pace. Do not try to maintain the same pace length as the natural one on a flat even surface. Rather, correct the calculated distance. This requires calibrating one's pace over known distances in these kinds of conditions. (The desired distance is the horizontal one). To set up a calibration interval on a slope where the distance along the slope and the slope angle are measured, the horizontal distance is equal to the distance along the slope times the cosine of the slope angle. Slope angle can be measured using a clinometer (p. 88). Experienced pacers correct by reducing the count of paces as they go along. For example, on moderate slopes, the count may be reduced by repeating the count of every tenth pace (i.e., counting ... 8, 9, 10, 10, 11, ...). On steeper slopes, they repeat every fifth pace. On the steepest slopes, and other extreme conditions, every pace may be repeated. Good judgment of how to apply this correction can only come from considerable experience in calibrating under various kinds of conditions.

3.27.3 Accuracy

Errors of 5% are typical for average pacers, while experience pacers can achieve errors of 2.5% or less (Forbes 1955). Experienced pacers have demonstrated that a natural pace is much more accurate than an artificial pace (e.g., trying to pace precisely 1 m). Accuracy requires periodic practice and calibration. It declines appreciably when the pacer encounters slopes and uneven ground. Accuracy may be increased by using a written tally or by using a hand tally meter to avoid errors in counting.

3.27.4 Application Notes

This technique is particularly suitable where moderately accurate distance measurement is required, and suitable maps or photos are not available. One person is adequate. It is appropriate in open and low vegetation, and on smooth, reasonably firm soil. Under conditions that make pacing difficult, alternative techniques (e.g., Optical Range Finder, p. 30; Map Measurer, p. 75; or RS: Ruler) should be used if possible.

### 3.27.5 Training

About 15 min are needed to calibrate the pace over even ground, but 1 hr of practice may be required to achieve an even pace (R. Francis pers. comm).

### 3.27.6 Equipment

Some other means of measuring distance is required for the original calibration of the paces, such as a tape measure ($13-50; Forestry Suppliers, Inc. 1980).

Hand tally meter (optional).

### 3.27.7 Cost

12-20 min/km, or 10-30 min/mi.

### 3.27.8 References

Forbes 1955; Avery 1975; Forestry Suppliers, Inc. 1980.

## 3.28 LINE INTERCEPT MEASUREMENT OF EDGE

### 3.28.1 Variable Estimated

Edge length per unit area (p. 11).

### 3.28.2 Description

In summary, a map of an area containing several sites is analyzed using an overlay. The overlay has a series of lines on it, and a count is made of the number of times the lines on the overlay intercept the boundary between sites on the map.

It is first necessary to acquire or construct a map of the area to be analyzed. This map must be in terms of polygons with sharp boundaries, each of which is considered a "homogeneous site" for the purpose of analysis. It is possible to use aerial photos as maps if the edges between the different cover types are completely clear on the photos. Next, an overlay (Fig. 21) is constructed of suitable size for the map. Ideally, it should be about 1/10 the area of the map. The overlay is located randomly on the map (Appendix A) (or dropped haphazardly). If the overlay falls entirely within the mapped area, the entire overlay is sampled. Sampling is done by examining each line segment on the overlay. For each of these, the number of contact points between the line on the overlay and edges on the map (between adjacent polygons) is counted. If a line segment lies directly on top of a segment of the map boundary, one intercept is counted. If the overlay lies so that part of it is outside the mapped area, all those lines segments on the overlay lying totally

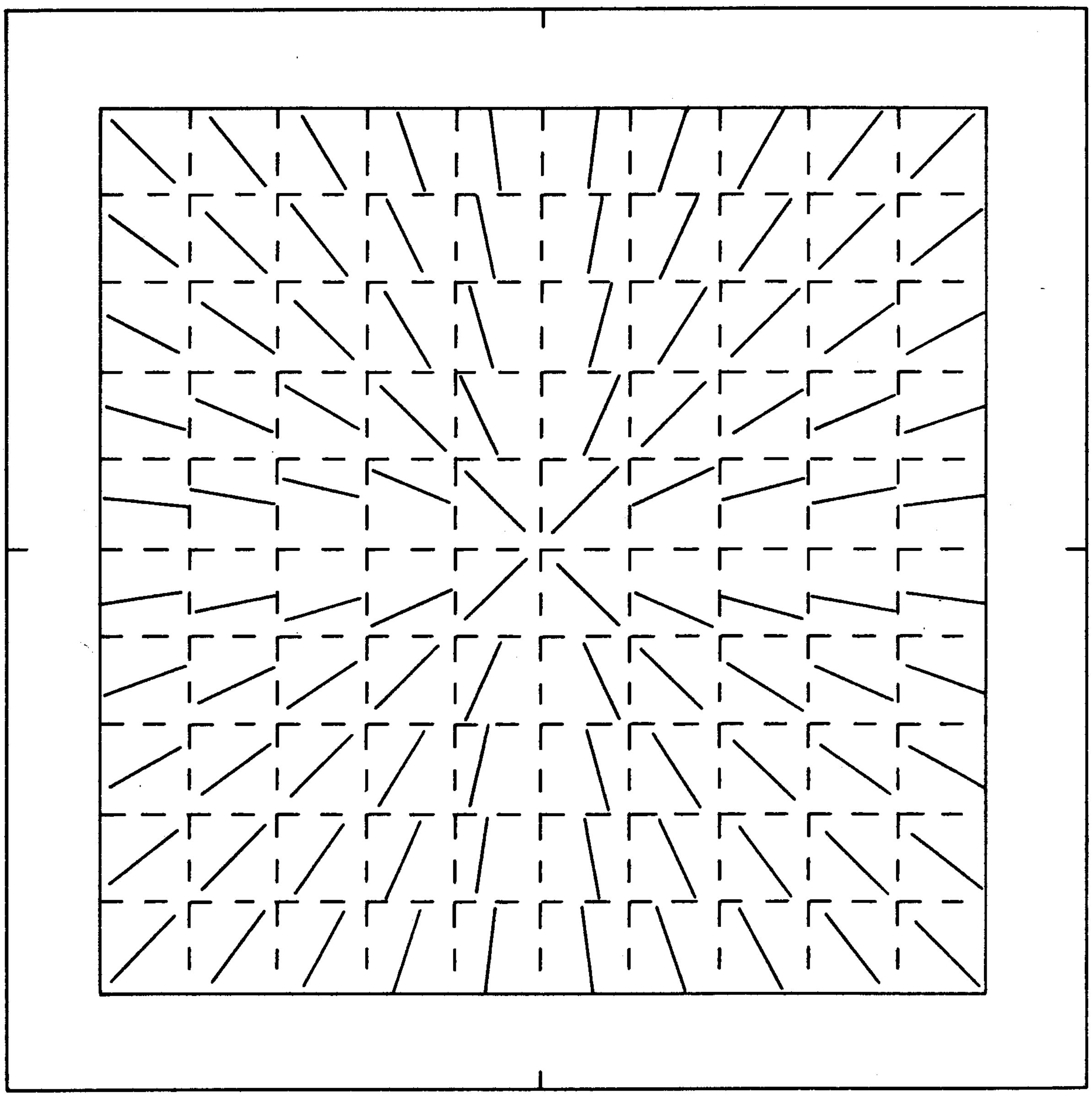


Figure 21. Radial line overlay for estimating edge per unit area (after Schuerholz 1974).

within the mapped area should be treated as before. Segments which cross the boundary should be handled by measuring the length of the overlay segment inside the mapped boundary, and counting the number of its intercepts with polygon boundaries on the map. Sampling should continue with different random overlay positions until the entire map has been adequately sampled.

The calculated length of edge per unit area can be determined from the data collected above, in conjunction with a calibration factor which is calculated as follows. An artificial map should be constructed with straight boundaries randomly distributed (Fig. 22). The overlay should be located on this artificial map using the same technique as discussed for the real samples. Approximately 15 replicate samples should be taken. The calibration factor is calculated as follows:

$$C = \frac{\Sigma\ \ell c\ \ \Sigma\ \ell o}{A_c\ \ \ n_o}$$

where C = conversion factor [(cm edge) (cm sample line)]/[(cm² map) (intercept)]

$\Sigma\ \ell c$ = total of the lengths of the lines on the calibration map (cm)

$A_c$ = area of the calibration map ($cm^2$)

$\Sigma\ \ell o$ = total of the lengths of the line segments on the overlay as sampled [i.e., number of whole segments in the map x length of each segment + total of the lengths of the partial segments sampled (cm)]

$n_o$ = total number of interception points between segments of the overlay and lines on the map (dimensionless)

For the real sample, the length of edge on the map per unit area is calculated by:

$$E = \frac{C\ n_s\ S\ \ 10^6}{\Sigma\ \ell s}$$

where E = edge length per unit area (m edge/ha)

C = conversion factor from above equation (cm edge map) (cm sample line)/($cm^2$ map intercept)

$n_s$ = number of intercept points on sample

S = map scale (in decimal fraction) (dimensionless)

$10^6$ = conversion factor to get m edge per ha

$\Sigma\ \ell s$ = total of the lengths of the line segments on the overlay as sampled

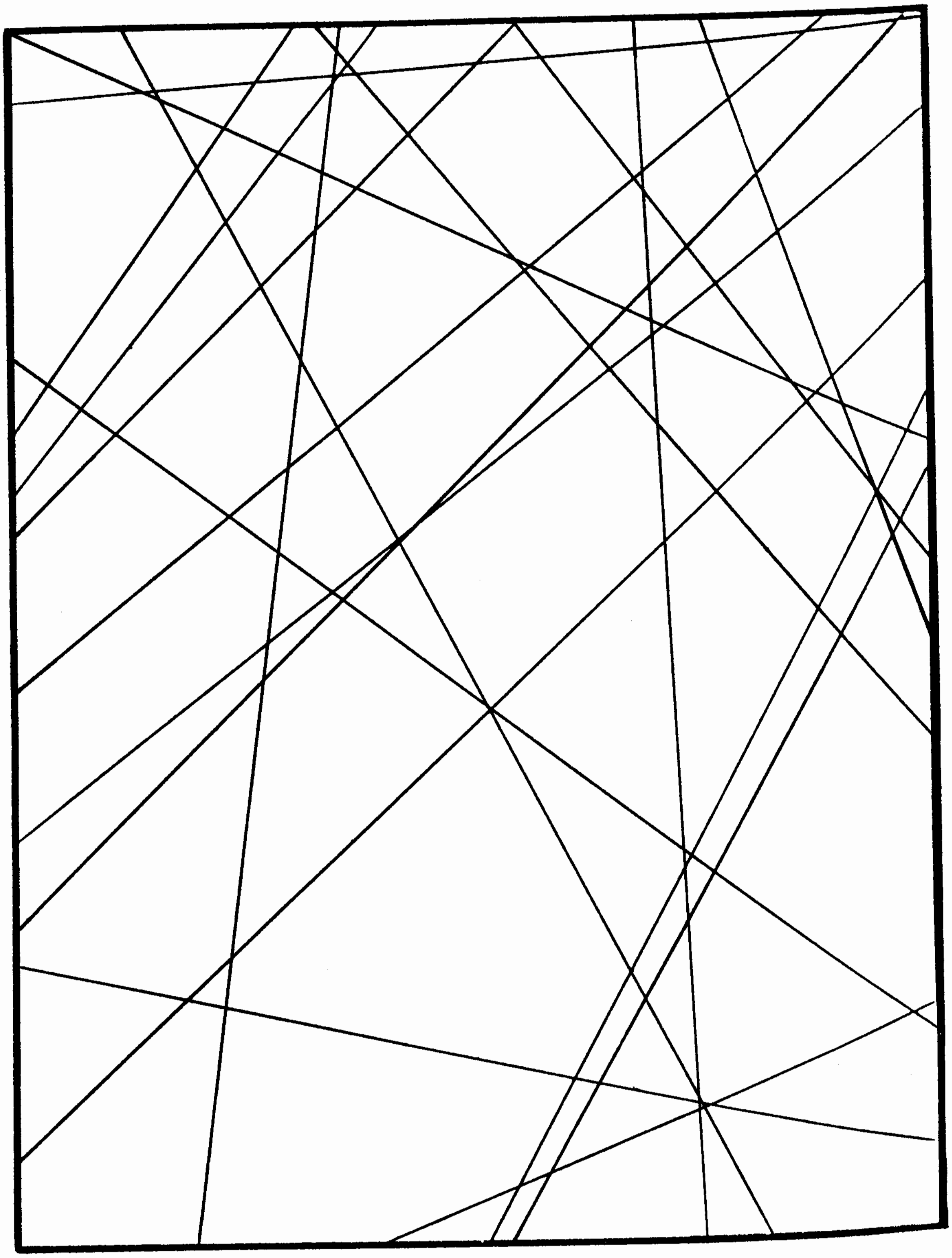


Figure 22. Calibration map for Line Intercept Measurement of Edge (area = 29,850 mm², length = 3,119 mm, 1/a = 0.104 mm/mm²).

### 3.28.3 Accuracy

This technique can be moderately accurate. Major sources of error include errors in counting and measurement of line segments, and inconsistency in the way in which counts are taken.

### 3.28.4 Application Notes

This technique tends to be inexpensive for large areas when a suitable map or photo is available. It is easily applied by one person. It is most appropriately used in situations in which clear edges can be seen on area photos. Such edges should be relatively infrequent so that a single line segment on the overlay rarely hits more than two or three edges. If the area being sampled is small, the Map Measurer (p. 75) is usually less expensive. If no map or photo is available, it may be best to measure edge length in the field using Pacing (p. 76) and Calculated Edge/Area (p. 82).

### 3.28.5 Training

Less than one hour to develop consistency.

### 3.28.6 Equipment

The special overlay (Fig. 21) can be constructed to any scale. Each line segment should be of the same length and be centered on the center point of the square in which it lies. (No commerical source known).

The calibration map (Fig. 22) can be constructed to any size. It consists of a field with several randomly oriented straight lines. The total length of the lines and the area of the field must be measured.

### 3.28.7 Cost

No estimate available.

### 3.28.8 References

Schuerholz 1974.

## 3.29 CALCULATED EDGE/AREA

### 3.29.1 Variable Estimated

Edge length per unit area (p. 11).

### 3.29.2 Description

In summary, independent measurements of edge within a study area and the area of this study area are combined mathematically to calculate edge length per unit area.

The limits of the study area being analyzed must be defined. Next, the length of the edge between adjoining "homogeneous" sites within this area must be measured (Map Measurer, p. 75; Pacing, p. 76). Then the area of the study area must be determined (Point Grid, p. 84 or calculation from geometry). The units of these measurements are converted into the appropriate ones (usually m or ft for edge length, and ha or ac for area). Edge length per unit area is calculated simply by dividing the area into the length.

3.29.3 Accuracy

This depends upon the accuracy of the separate measurements of length and area. There are no additional significant sources of error introduced by this technique.

3.29.4 Application Notes

This technique is usually less expensive to apply than Line Intercept Measurement of Edge (p. 78) where the total length of edge is relatively small. This is because of the additional cost and difficulty in calibrating the overlay used with that technique for the particular scale of map or photo.

## 3.30 PATTON'S DIVERSITY INDEX (EQUIVALENT TO THE SHORELINE DEVELOPMENT INDEX)

3.30.1 Variable Estimated

Patton's diversity index for cover type "edge" (p. 11).

3.30.2 Description

In summary, a ratio is calculated relating the relative edge of a site (or water body) to the area.

In order to apply this index, it is first necessary to measure the length of the edge around the site or water body (Map Measurer, p. 75; Pacing, p. 76), and the area (Point Grid, p. 84, or calculation by geometry) that the site covers. The ratio of edge to area is compared to that of a circle having the same area as the site. The following formula is used:

$$DI = \frac{\ell}{2\sqrt{A\pi}}$$

where $DI$ = Patton's diversity index (dimensionless)
$\ell$ = length of edge (m or ft)
$A$ = area of the site (square of the units used for $\ell$)

A deviation in the shape of the site from that of a circle causes a DI value to be larger than one. The more deviation from a circular shape, the greater the DI value will be.

3.30.3 Accuracy

The accuracy of this technique is dependent upon the accuracy of the constituent data elements. Calculation error may also occur.

3.30.4 Application Notes

This technique is inexpensive to apply, provided the data are available. It can be applied in any situation in which an edge between the site and adjacent cover types can be clearly determined. This is most easily done on aerial photos, but sometimes suitable maps are available.

3.30.5 References

Hutchinson 1957; Patton 1975.

## 3.31 POINT GRID

3.31.1 Variables Estimated

Site Area (p. 12).

3.31.2 Description

In summary, the site to be measured is delineated on an aerial photo or a map. A transparent overlay consisting of a grid of dots is placed on top of the area, and the number of dots falling within the site are counted.

The site to be measured must be delineated clearly with the fine line on a single area of photo or on an accurate map (e.g., USGS topographic map). A transparent point grid of appropriate total size and density of dots (see Equipment section, below) is placed over the site in a haphazard or random manner (Appendix A). The site must fall entirely within the dot grid. The number of dots falling within the site is counted. Dots falling precisely on the line should be counted as one-half. This process should be repeated if highly accurate results are desired. To convert from the number of dots to a measure of area (ha or ac), measure the average distance between dots on the grid. This is best done with repeated measurements of the distance between dots that are 10 dots apart, rather than adjacent dots. The conversion factor is: (average distance between dots)$^2$/[scale (decimal fraction) of the photo or map]$^2$. To calculate the area of the site, multiply the number of dots counted by the conversion factor.

3.31.3 Accuracy

The Point Grid technique can be accurate within 1 to 2%, using practical numbers of replicate counts on the site. Accuracy of ± 5% can be achieved with grids that would put approximately 70 dots in the site area (Loetsch et al. 1973:35). Sources of error include the accuracy with which the point grid is drawn, and the errors involved in determining whether a dot is inside or outside of the site area.

3.31.4 Application Notes

This technique is the least expensive for measuring areas of irregular shape. Square or rectangular areas can be more accurately and quickly determined by measurement of the sides and simple calculation using geometric formulas.

3.31.5 Training

Less than one-half hour to develop consistency.

3.31.6 Equipment

Point grid. An appropriate grid should be selected for the size of the areas to be measured on the photos or maps. The grid should give approximately 70 dots inside the area of a typical site to be measured. It should be about two times the area of the typical site to facilitate haphazard placement ($1 and up, Ben Meadows Co. 1977).

3.31.7 References

Loetsch et al. 1973; Ben Meadows Co. 1977.

## 3.32 SLOPE AND ASPECT FROM TOPOGRAPIC MAPS

3.32.1 Variables Estimated

Slope and aspect (p. 12).

3.32.2 Description

In summary, contour lines on topograpic maps are used to indicate differences in height over some measured horizontal distance on the ground, and slope is calculated. The direction over which the slope is calculated is used to indicate aspect.

The location to be sampled must be selected and located on the topographic map. If the sample is to be used as an indicator of the average slope or aspect of a site (Averaging, p. 69), these samples should be selected randomly (Appendix A). If this point falls precisely on top of a contour line, another point should be selected. If the point falls between contour lines that are farther than 2 to 3 mm apart, one can use a straight edge and rotate it slowly around the point until the shortest distance between the two contour lines is found. Measurements of the distance must be made so that no contour line is crossed (Fig. 23). This distance is measured with a precise ruler and recorded. If aspect is desired, the direction of the straight edge should be converted to angular degrees using a protractor (Fig. 23). When contour lines are close together, it is often desirable to use only the contours printed with a "heavier" or wider line (usually every fifth line).

Elevation between the contour lines is given as "contour interval" on the map. (If contour lines are close together, and one is using the heavier contour lines, the elevational difference is, of course, five times the stated contour interval).

Slope is calculated by the following formulas (%):

$$S = \frac{E\ m\ 100{,}000}{d} \quad \text{(metric)}$$

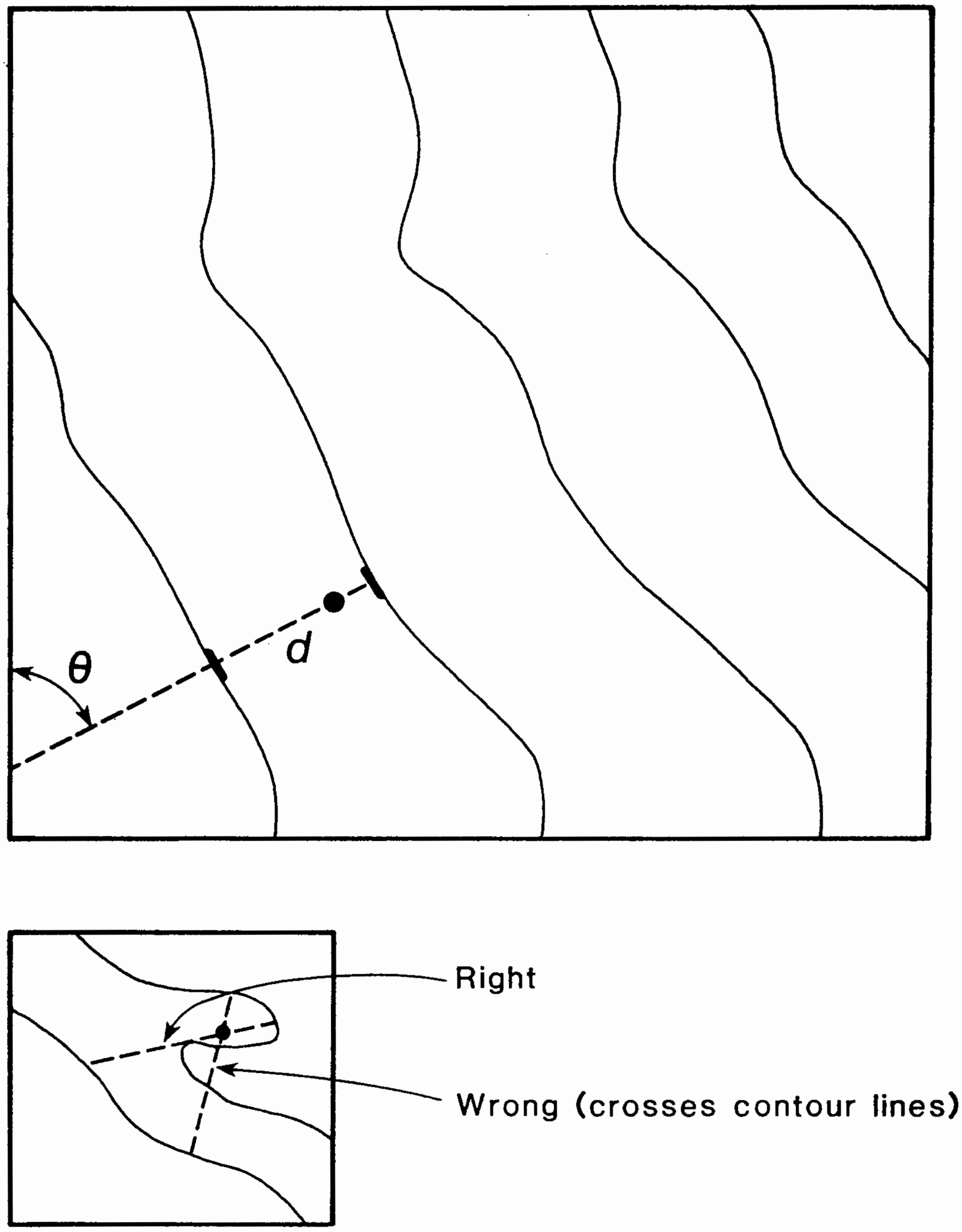



Figure 23. Slope and Aspect from Topographic Maps (d is the distance between contour intervals, 0 is the angle from N).

$$S = \frac{E\ m\ 1{,}200}{d} \quad \text{(English)}$$

where S = slope (%)
E = difference in elevation on the ground between two points (m or ft)
m = the map scale (decimal fraction)
d = the distance on the map between the two points (mm or in)

If S is wanted in angular degrees,

**Page 87, the equation should be:**

$$S = \arctan \frac{S(\%)}{100}$$

3.32.3 Accuracy

This technique can be highly accurate. U.S. Geological Survey (USGS) topographic maps are very high in precision. However, the specific geographical location of a particular elevation on the ground may be different from the location shown. This error can typically be eliminated using averaging of several measurements (p. 69). The technique also introduces error if slope changes rapidly over the surface of the ground. Under these conditions, contour lines will clearly not parallel one another.

3.32.4 Application Notes

This technique is the least expensive for measuring slope and aspect. One person can apply it without difficulty under any circumstances in which topographic maps are available.

3.32.5 Training

One-half hour.

3.32.6 Equipment

Topographic maps (the USGS and some States and counties do topographic mapping); an accurate ruler, such as a drafting scale; and a protractor are used.

## 3.33 CLINOMETER AND COMPASS

3.33.1 Variables Estimated

Slope and Aspect (p. 12).

3.33.2 Description

In summary, two points are selected on a slope and the angle from the horizontal measured with a clinometer. Aspect is measured with a compass over the same direction.

If the desired variable is an average for the site, sample locations should be selected randomly (Appendix A). From the sample point, two measuring locations should be identified, one directly down the aspect from the sampling point and the other directly above. Ideally, these locations should be approximately 60 m apart (see Pacing, p. 76). Where visibility is restricted, or the slope changes angle rapidly, it may be necessary to use two locations that are closer together. The most convenient way to identify the aspect line is often to start with one of the two sampling points, and then locate a point on the ground which has the same elevation, using the clinometer (slope angle = 0). The second sample point should then be 90° from this location. Where the slope is changing rapidly, it is often adequate simply to estimate the direction of the aspect line ocularly. One crew member holds a target at one of the sample points, and the other measures the angle of the target from the horizontal using the clinometer (Fig. 24). Aspect is measured with the compass. It should be corrected for differences between magnetic north and true north. The most convenient source for the correction is a USGS topographic map for the general vicinity.

3.33.3 Accuracy

Most clinometers can be read with a precision of approximately 1%, or 1°. Since slope is a statistical property that can usually be determined to only the nearest several percent or degrees due to the unevenness of the ground surface, it is not ordinarily meaningful to speak of accuracy at this level. Aspect can be measured to about 2° with most compasses. It is extremely difficult (and probably not meaningful) to determine aspect when slope is within a few degrees of zero. The major sources of error include failure to measure directly down the aspect line, and sampling error caused by small variations in elevation affecting the height of the target or the clinometer. Error due to differences between magnetic north and true north can be up to 20° in the contiguous 48 States.

3.33.4 Application Notes

This technique is relatively inexpensive and substantially more accurate than "eyeball estimation." One person may be adequate, but a crew of two is much more efficient for multiple readings. This technique may be used under most site conditions. If the visibility is very limited or slope is highly uneven, this technique is less effective than using topographic maps (p. 85).

3.33.5 Training

This technique requires direct measurement, so the only significant training is in understanding the use of the instruments. The typical clinometer and compass can be mastered in about 15 minutes.

3.33.6 Equipment

Clinometer [$40, including other instruments that can measure slope such as the Abney level (from $80), Pocket transit compass (from $90), Compass (from $19)]. (Prices from Forestry Suppliers, Inc. 1980).

The target should be a stick with a mark at the same height as the measuring crew member's eye level. Two types of targets are used. One type is held by another crew member and is simply rested on the ground. The second type is used when the crew consists of a single individual. This is a stick with a

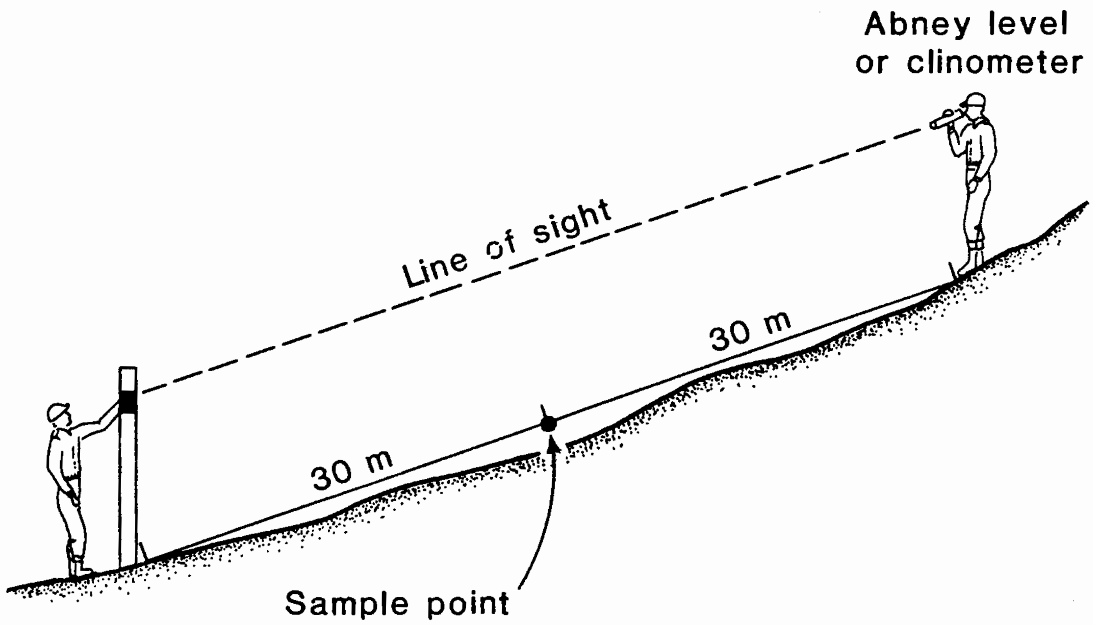



Figure 24. Measuring slope using a clinometer or Abney level. Aspect is measured over the same path using a compass.

metal spike affixed to the bottom that can be pressed into the ground to hold the stick vertical. A mark should be present on the bottom of the stick to indicate ground level when inserted to the appropriate depth. A piece of tape of a color contrasting with that of the stick makes an adequate target. It is also possible to use a hatband or neck scarf of a crew member as a target.

3.33.7 Cost

No estimate available.

3.33.8 References

Forbes 1955; Forestry Suppliers, Inc. 1980.

## 3.34 SOIL TEXTURE BY FEEL

3.34.1 Variable Estimated

Soil Texture (p. 12).

3.34.2 Description

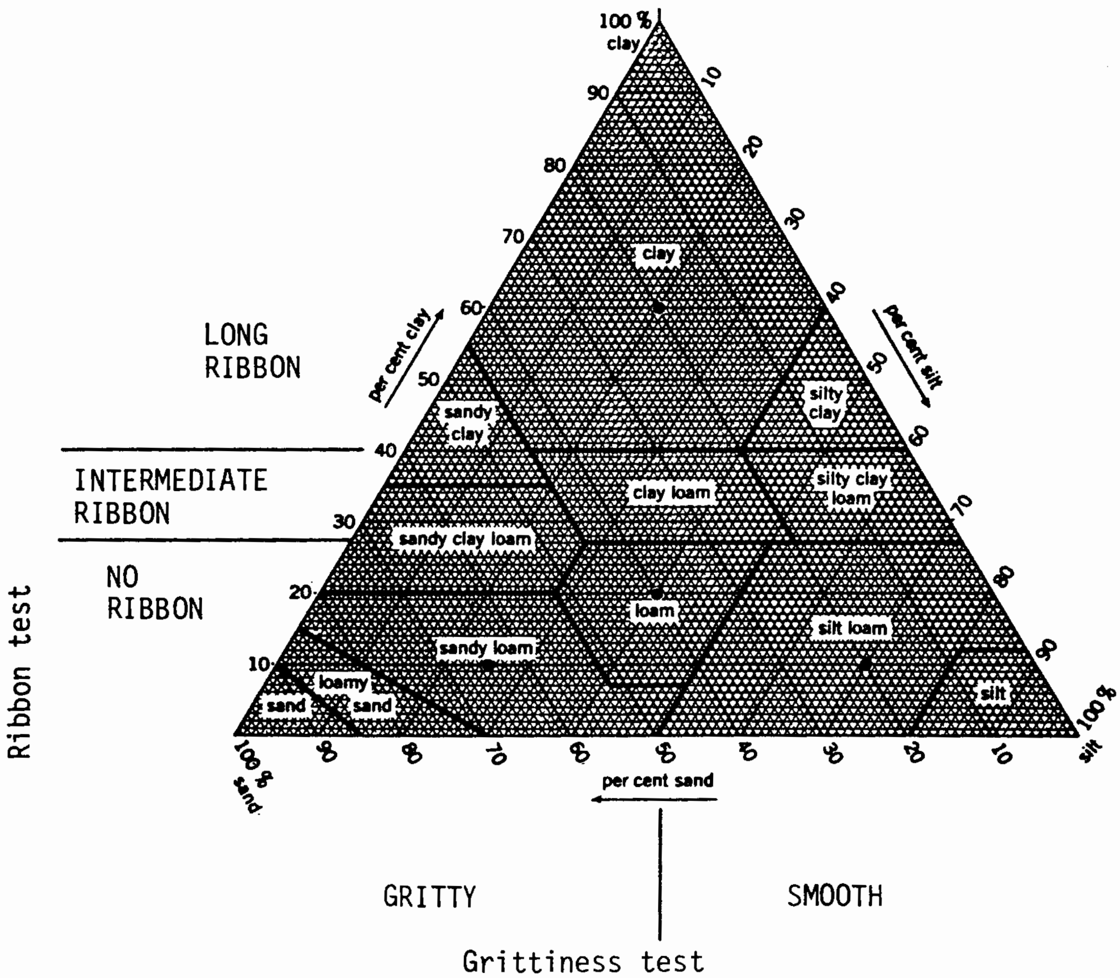
In summary, soil texture is estimated from its plasticity when extruded, and by feeling its grittiness.

The "ribbon" and "grittiness" tests are used to divide soils into broad categories based on sand, silt, and clay composition. A sample of soil is collected, and any rocks larger than 2 mm diameter are removed. If the average texture of the soil on a site is the desired variable, samples should be taken at randomly selected sites (see Appendix A).

1. Ribbon test: A teaspoonful of the sample is held in the palm of the hand and moistened until it has the consistency of workable putty. It is then pressed and squeezed to extrude a horizontal ribbon from between the thumb and forefinger. This ribbon should be about 1 cm wide and 2 mm thick. The ribbon will break if it is longer than a critical size. If this maximum length is less than 2.5 cm, the clay content is probably less than 27% (Fig. 25). A ribbon longer than 12.5 cm indicates that the sample is 40% or more clay. Intermediate ribbons have between 27 and 40% clay content.

2. Grittiness test: This test is to determine whether sand or silt predominates in the soil. Using the same sample discussed in test 1, the investigator feels the texture of the soil by rubbing some between thumb and forefinger. If the sample is rough and coarse with a gritty feel, then sand occurs in greater quantities than does silt. If the sample has a smooth, talc-like feel, then silt predominates.

The results of these two tests can be used to identify soil texture class using Fig. 25.




Dots shown represent (by percent):

| Sand | Silt | Clay |
|---|---|---|
| 20 | 70 | 10 |
| 20 | 20 | 60 |
| 65 | 25 | 10 |
| 40 | 40 | 20 |

Figure 25. Soil texture classification (after Donahue et al. 1971). Interpretation for any point in the graph is read as follows: % Clay, move horizontally to the left; % Silt, move parallel to the Clay Axis, up and to the right; % Sand, move parallel to the Silt Axis, down and to the right.

3.34.3 Accuracy

This technique can be moderately accurate for the level of precision indicated in the description. Experienced field soil scientists can achieve estimates of percent compostion of the three particle size classes of ± 5%. Significant error can be introduced if the soil contains high levels of organic material (causing an estimate of too much clay).

3.34.4 Application Notes

This technique is inexpensive. It can be applied to all types of soil that do not contain high levels of organic material.

3.34.5 Training

The investigator should familiarize himself with samples having known particle size composition. If this approach is used, it should take approximately one-half day to learn the technique (D. Gallup, pers. comm.). It is helpful to have an experienced field soil scientist to assist.

3.34.6 Cost

Fifteen minutes per sample (D. Gallup, pers. comm.).

3.34.7 References

Sabey 1969; Donahue et al. 1971.

## 3.35 FLOATING BODY

3.35.1 Variable Estimated

Surface Water Velocity (p. 13).

3.35.2 Description

In summary, velocity is calculated by measurement of the time taken for a marker to travel a known distance down the stream.

A stretch of stream should be selected which is approximately straight. The compass direction of this stretch of stream should be measured. Using the compass direction, a 90° angle is laid out so it crosses the stream. This is most conveniently done by locating a landmark on the distant side of the stream, and moving up or down stream to locate (and mark) the point at which a 90° angle exists. A distance should then be measured downstream to the other end of the straight stretch, and a similar 90° angle laid out. The marker or dye is tossed into the stream above the initial point, and then timed to see how long it takes to get from one point to the other. If dye is used, the time is measured until the front part of the dye stain arrives. Velocity is calculated as distance divided by time.

When the velocity measured is the peak velocity of the stream (usually at the surface in the center), it is possible to calculate an approximate average for velocity for the stream, assuming typical cross section. A common average is 85% of the maximum current velocity (Avery 1975:270).

3.35.3 Accuracy

This technique can be moderately accurate. The major sources of error are caused by the marker floating out of the desired path. If the maximum current velocity is desired, the marker may tend to end up in eddies along the way, rather than staying in the maximum velocity portion of the stream. This source of error can be reduced by making repeated measurements or by using dye as the marker. Calculations of average stream velocity from a measured maximum velocity are in error if the correction factor is inappropriate. Deviations from the 85% factor mentioned above are common.

3.35.4 Application Notes

This technique is inexpensive. A crew size of one is suitable for slow moving streams, but a crew size of two is necessary to signal when the marker has passed the ending point if the stream moves too fast for one crew member to move from the starting point to the ending point. It is most appropriate where streams are relatively large and have a smooth slope.

3.35.5 Training

Minimal.

3.35.6 Equipment

Marker, e.g., an orange from the grocery store for a surface float, or any obvious dye such as potassium permanganate, or ink. Clay, chalk, mud, or flour may also be used. A watch with a second hand.

3.35.7 Cost

One-quarter crew hour per measurement.

3.35.8 References

Corbett 1943; Avery 1975.

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## APPENDIX A. LOCATING RANDOM SAMPLE POINTS, LINE TRANSECTS, INDIVIDUAL PLANTS, AND GROUPS OF PLANTS

### RANDOM POINTS

#### Grid

Two lines are laid out perpendicular to each other (Fig. 26). They should run the length and width of the site, and are usually most easily located at the sides of the plot. Each line is measured. Enough precision (decimal places) should be used so that if you ignore the decimal point, the measurement for each line is between 50 and 1000 (e.g., 18.1 and 92). The numbers of digits in these measurements of each line are counted (e.g., 3 and 2). This number of random digits in the length is selected from a random number table. If the random number selected is larger than the length, other sets of random digits are taken until one is selected that is equal to or smaller than the length. This process is repeated for the width. Each set of random digits is used as coordinates to locate the random point (Fig. 26).

For large sites, it is best to draw the lines on a map and locate all the random points before leaving the office. The field crew can then start at one corner and sample each point in a systematic pattern to avoid unnecessary walking.

This technique is preferred in dense vegetation or where the vegetation is obviously different near the margins than in the center. It selects truly random points, so it is suitable for high accuracy inventories. It is better than a line transect in plots that are not long and narrow. It can be easier to apply than the dropped pointer if few obvious landmarks are present.

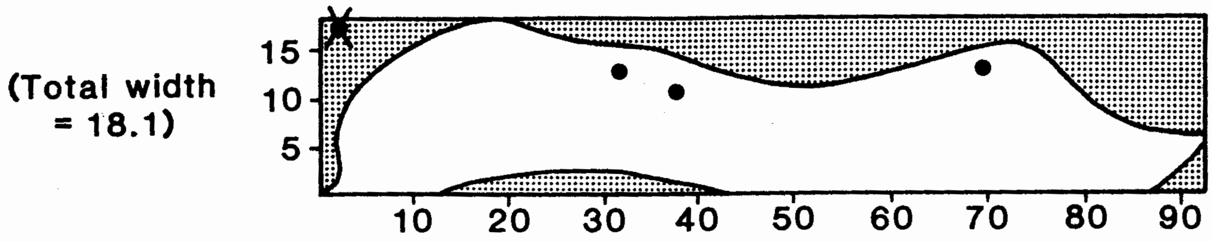
#### Thrown Marker

The crew walks to a convenient point near the center of the site. One member closes his eyes, spins around several times, then tosses a marker (e.g., a rock) over his shoulder. The random point is where the marker lands. The next random point is selected using the same process while standing at the first random point. If the marker lands outside the site, the process should be repeated using the last random point inside the site.

Note that this approach actually identifies points in a haphazard manner. The deviation from the randomness has a tendency to over sample the center of the site. Consequently, it is not suitable for high accuracy inventories. It can be difficult to apply if the vegetation is dense enough to make it hard to find the marker.

#### Line Transect

A line transect is laid out using one of the techniques described under LINE TRANSECTS below. Pairs of random digits are selected from a random numbers table. An observer moves along the line a distance corresponding to the pair of random digits to locate the random point. The next point can be located by repeating the process starting from the point just located.




Map of study area
(Total length = 92)

| Point No. | Length | Width | |
|---|---|---|---|
| 1 | 31 | 13.0 | |
| 2 | 69 | 13.2 | |
| ~~3~~ | ~~1~~ | ~~17.9~~ | (outside) |
| 3 | 37 | 10.4 | |

| | Length | Width | Width (continued) |
|---|---|---|---|
| | 340 | 159 | 830 |
| | 477 | 885 | 104 |
| | 945 | 094 | 683 |
| | 527 | 002 | 147 |
| | 230 | 540 | 170 |
| | 678 | 261 | 597 |
| | 234 | 449 | 333 |
| start | 318 | 292 | 678 |
| | 691 | 356 | 416 |
| | 013 | 190 | 917 |
| | 370 | 978 | 294 |
| | 817 | 266 | 092 |
| | 282 | 316 | 636 |
| | 366 | 130 | 572 |
| | 248 | 132 | 986 |
| | 274 | 557 | 070 |
| | 793 | 818 | 260 |
| | 481 | 179 | 180 |
| | 016 | 485 | 938 |
| | 304 | 910 | 924 |

Figure 26. Locating random points with the grid technique. The starting point in the random number table was selected by dropping a pencil point down on the page.

This technique is best applied using a meter tape as the line. It is preferred in long narrow sites where the vegetation is open enough to permit walking in a straight line.

Dropped Pointer

A pencil is held point down over a map or photo with one's eyes closed. It is then dropped. The mark left by the point is used. Note that this approach selects points haphazardly and may oversample some portion of the study area. It is most applicable in plots with many good landmarks, such as open woodland.

## LINE TRANSECTS

### Starting Point

The Grid or Thrown Marker techniques (above) can be used for establishing random points. Alternatively, a baseline can be established along one side of the site. Starting points for line transects can be selected at random or regular intervals along the baseline. Multiple transects can be run from the baseline. If this is done, it is best to run them all parallel to one another.

### Direction

Spinning "pointer". This technique involves spinning a "pointer" until it stops. The most convenient "pointer" is a pencil. One tosses the pencil up in the air so it is spinning in a horizontal plane (like a baton). After the pencil comes to rest, its direction is used. This technique can be somewhat biased, and should not be used in high accuracy inventories.

Random angle. A 3-digit random number less than 360 is selected from a random numbers table. This is used as the bearing on a compass. This technique takes longer to use than the spinning pointer, but is truly random. Hence, it is preferred for high accuracy inventories.

Laying out the line. This is most conveniently done using one edge of a stretched tape measure as the line. One crew member stands at the start of the transect and holds the free end of the tape. The other member moves off with the bulk of the tape in the direction selected. The moving member should select a distant landmark in the appropriate direction. He should then select another landmark at about 5 m distance (or the first barrier, if closer). Next, he should walk toward the close landmark. When it is reached, he should stop and select another close landmark in line with the distant one (for barriers, see below). The person holding the end of the tape should direct corrections if the walking person deviates out of line. When the end is reached, the line should be raised above the surface and stretched, if possible, before laying it down.

For highest accuracy, the tape should be anchored in place straight and stretched. The free end of the tape (or a loop of cord attached to it) can sometimes be held adequately by pushing a small stick through the loop. The reel case's weight will sometimes hold it well enough. Often, however, both ends should be tied to plants or stakes driven into the ground.

### Barriers

If the line transect passes out of the site, or crosses an impenetrable barrier, it should be terminated at that point. Either a new starting point or the termination point can be used to lay out the next transect. If the termination point is used, a new direction can be selected using the Spinning Pointer or Random Angle technique (above), which will avoid the boundary or barrier.

## INDIVIDUAL PLANTS

### Nearest Neighbor

Select a random point using one of the techniques described above. The plant closest to this point is used. This technique is usually preferred in inventories of multiple variables. It can be biased if a haphazard method is used to select the point. Often the density of plants is patchy, and plant characteristics, e.g., size, are correlated with density. Using this technique in this situation will give a biased sample because sampling is more likely to select a plant in the low density areas. In this case, the following technique may be used. Alternatively, high and low density areas can be sampled separately (Greig-Smith 1964:47).

### Assigned Label

Identify and number every plant of the type to be sampled in the site. Draw a group of random digits (from a random numbers table) that lie within this range (see the Grid technique discussion above) to identify the plant to be used. This technique is preferred in plots with few plants to be sampled.

## GROUP OF PLANTS

### Quadrat

Determine a quadrat size that will encompass approximately the number of plants desired in the group. Next, decide on a convenient shape (see p. 65). If this shape is not a long narrow strip, locate a random point (see above). This is the center of a round quadrat or a corner of a square or rectangular one. If the quadrat is not round, select a random direction (see the Direction discussion under LINE TRANSECTS, above). This determines where a side of the quadrat goes. The side to be used should be determined ahead of time. All plants lying inside the quadrat are used.

If a strip or belt quadrat is used, lay out a transect line (see LINE TRANSECTS, above). Next, determine the width to be used. All plants falling within this width from the transect line (usually on one side only) are used. This technique is preferred if a quadrat or line transect is to be laid out for sampling other variables.

Nearest Neighbors

Use the Nearest Neighbor technique under INDIVIDUAL PLANTS above, except determine the size of group desired. One then selects, successively, the nearest plants to the random point until the desired group size is reached. This technique is preferred if random points are being used for sampling other variables. It is also convenient if the plant density is low.

# APPENDIX B. INTRODUCTION TO AERIAL PHOTOGRAPH APPLICATION TO HABITAT VARIABLE ESTIMATION

## PURPOSE

Several of the techniques can make use of aerial photos. This appendix discusses briefly a few selected aspects of what is a complex and specialized technology: remote sensing. The reader is encouraged to become familiar with at least one book on the general field, before attempting much use of remote sensing methods. Avery (1978) is recommended highly. This discussion is limited to supplementing Avery (1978) for a few topics.

This appendix discusses some of the types of aerial photos available, what types are recommended for using techniques included in this manual, where they can be acquired, and the process of mapping cover types. No discussion is included of nonphotographic remote sensing, or photos taken other than vertically. Several minor sources of error are not addressed because such high accuracy is assumed to be unnecessary for habitat analyses.

## TYPES OF AERIAL PHOTOS

A variety of "platforms" (i.e., vehicles) are used to carry the camera. Usually, fixed wing aircraft or helicopters are used for taking photos at low altitudes (150 to 3,659 m) to high altitudes (9,000 to 24,390 m) (Aldrich 1979:22). Spacecraft are used to take photos (and other types of images) from distances of 190 km and greater.

Scale is an important criterion in measuring certain habitat parameters on aerial photo and satellite images (LANDSAT). Large scale photos range in scale from 1:600 to 1:10,000 and are useful for applications requiring ground resolution of 0.1 m and smaller (Aldrich 1979:vii). Resolution distance is the minimum distance between two adjacent objects, or the minimum size of a feature which can be detected by a photographic system (Smelser and Patterson 1975:xxviii). Medium scale photos of 1:12,000 to 1:30,000 provide ground resolution larger than 0.3 and 1.5 m, respectively. Small scale photos taken from aircraft and satellites provide ground resolutions between 1 and 4 m.

Conventional cameras are available for film formats from 35 mm (e.g., single lens reflex cameras) to 10 x 10 in. There are also high altitude reconnaissance cameras with formats of 9 x 18 in and panoramic cameras with formats of 5 x 48 in that are gaining greater use in natural resource surveys. The larger formats provide for more rapid photo interpretation (Cuplin 1978:2). Usually, it is the film and the camera optics that restrict ground resolutions obtained by photographic systems (Aldrich 1979:15).

Two black and white (BxW) and two color films are used in aerial photography. The BxW films are panchromatic and infrared (IR). The color films include the normal color film (e.g., Ektachrome and Kodachrome) and color infrared (CIR). Panchromatic and normal color film respond to the visible range of the electromagnetic spectrum [0.4 μm (blue) to 0.7 μm (red)] and the infrared films extend this range of sensitivity to 0.9 μm while still encompassing the normal range.

## RECOMMENDED PHOTO TYPES AND SCALES

Table 7 lists recommended aerial photo film types and scales for selected purposes.

## MAPPING

Classification and mapping involves drawing boundaries around areas considered homogeneous for habitat analysis. A minimum mapping area unit must be specified to avoid trying to map more detail than can be dealt with in inventory. Usually areas smaller than 1-2% of the total study area to be evaluated should be ignored by including them with an adjacent type.

Mapping should be done using a surface cover type classification. If this is not prescribed by standard procedures, it should be developed by the crew after comparing what is visible on the photos to what is needed during analysis. Usually 10 or so catagories present on a project area are adequate. Lines should be drawn with a soft pencil directly on the photo, or on a sheet of frosted acetate overlayed on it. Field checking of the delineations is essential to ensure accurate mapping of types.

## SOURCE OF PHOTOS

We found Richardson's (1978) appendix "Sources of Remote Sensing Imagery" (below) to be a relatively comprehensive guide to sources of available photos. There are some general sources that may be helpful to field biologists doing vegetation analysis. In many instances, the local office of the Agriculture Stabilization and Conservation Service (ASCS) or U.S. Soil Conservation Service (SCS) have complete stereo BxW coverage of their area of jurisdiction. These photos can be used only in the office and are not intended for field use. Copies can be ordered in several forms including waterproof laminates. Much time can be saved by knowing at least what photos to order. The U.S. Bureau of Land Management and U.S. Forest Service district offices usually have stereo BxW (sometimes color) coverage of their districts. These photos can be loaned out, but usually for short time periods when slack field activity occurs. The scale of these photos is generally adequate for vegetation mapping. Sometimes the U.S. Bureau of Reclamation (BR) or U.S. Army Corps of Engineers (CE) has photo coverage of areas proposed for water development projects. As a rule, the BR and CE obtain the photos too late in the planning process to be helpful in FWS habitat evaluations. If timely specialized coverage is needed, it may be necessary to contract with private firms to procure the photos. A word of caution: writing contract specifications to get the photos you need requires technical assistance. FWS personnel can obtain assistance in writing contract specifications from Remote Sensing Coordinator, U.S. Fish and Wildlife Service, Dept. of the Interior, Washington, D.C. 20240.

Successful interpretation of aerial photos, especially color and CIR, may depend upon the season of the year the images were taken (Driscoll 1971:8). This is especially true in vegetation studies where stage of plant development, plant size, associated vegetation, and stand density may be critical in the interpretation of photographic images. Because of the complex range of

Table 7. Recommended aerial photo film type and scale (from Aldrich 1979)

| Data requirement | Required magnification | Preferred film type | Resolution (M) | Smallest scale | Platform |
|---|---|---|---|---|---|
| I. Mapping sites | | | | | |
| A. Forest stands | 26 | CIR | 30 | 1:750,000 | SAT[a] |
| B. Nonforest | 8.5 | CIR | 3 | 1:184,000 | HAA[b] |
| II. Measurements of resource variables | | | | | |
| A. Tree height | 1.5 | CIR | 0.3 | 1:9,600 | MAA[c], LAA[d] |
| B. Canopy cover by species group | 1.5 | CIR | 0.3 | 1:9,600 | MAA[c], LAA[d] |
| C. Tree density | 1.5 | CIR | 0.3 | 1:9,600 | MAA[c], LAA[d] |

[a]Satelite (over 190 km altitude)
[b]High altitude aircraft (>9,150 m)
[c]Medium altitude aircraft (3,660-9,150 m)
[d]Low altitude aircraft (150-3,660 m)

environmental parameters, there is no single optimum time to procure photos for interpretation.

SOURCES OF REMOTE SENSING IMAGERY (Modified from Richardson 1978)

Manned spacecraft photography, Skylab photography, all LANDSAT standard products, computer enhanced LANDSAT images, NASA aircraft photography, U.S. Department of Interior photography, black and white aerial mapping photography, and Apollo and Gemini photography can be purchased from:

EROS Data Center
Sioux Falls, SD 57198

The EROS Data Center provides geographic computer searches for LANDSAT, Skylab, NASA aircraft, and aerial mapping photography at no charge. To obtain this information, send the latitude and longitude of a point, or the latitudes and longitudes of the corners of a selected area to the EROS Data Center. If the geographic coordinates of a point or area are unknown, a geographic computer search will be made from other information, such as geographic names, locations, or a map. When a computer search is requested, such additional information as time of year, minimum imagery quality, maximum cloud cover acceptable, and type of product (black and white, color, or color infrared) should be forwarded to the EROS Data Center.

Imagery which is archived at the EROS Center may be reviewed at any one of the EROS Data Reference Files. These are located at:

Alaska

Public Inquiries Office
U. S. Geological Survey
108 Skyline Building
508 Second Street
Anchorage, AK 99501

California

Public Inquiries Office
U. S. Geological Survey
Room 7638, Federal Building
300 North Los Angeles Street
Los Angeles, CA 90012

Hawaii

University of Hawaii
Department of Geography
Room 313C, Physical Science Building
Honolulu, HI 96825

Massachusetts

U. S. Geological Survey
5th Floor
80 Broad Street
Boston, MA 02110

Missouri

Topographic Office
U. S. Geological Survey
900 Pine Street
Rolla, MO 65401

New York

Water Resources Division
U. S. Geological Survey
Room 343, Post Office and Court House Building
Albany, NY 12201

Ohio

Water Resources Division
975 West Third Street
Columbus, OH 43212

Tennessee

Maps and Survey Branch
Tennessee Valley Authority
20 Haney Building
311 Broad Street
Chattanooga, TN 37401

Oregon

Bureau of Land Management
729 NE Oregon Street
Portland, OR 97208

Washington

U. S. Geological Survey
Public Inquiries Office
Room 678, U. S. Court House
West 920 Riverside Avenue
Spokane, Washington 99201

The EROS Data Center is part of the National Cartographic Information Center (NCIC). The NCIC provides information concerning cartographic data, aerial photography, and space imagery. NCIC offices are located at:

Map and Air Photo Sales
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

National Center, Stop 507
12201 Sunrise Valley Drive
Reston, VA 22092

Air Photo Sales
U. S. Geological Survey
Federal Center, Building 25
Denver, CO 80225

Information concerning LANDSAT and Skylab imagery, as well as data from Tiros and Nimbus weather satellites, ATS geostationary satellite imagery, and full disc and section images of the earth from ESSA, NOAA, and SMS geosynchronous satellites is available at:

NOAA Satellite Data Services
Information Services Division
National Climatic Center
World Weather Building
Suitland, MD 20233

LANDSAT imagery can be inspected before ordering at numerous NOAA Browse Files. These are located at:

Alaska

University of Alaska
Arctic Environmental Information and Data Center
142 East Third Avenue
Anchorage, AK 99501

California

Inter-American Tropical Tuna Commission
Scripps Institute of Oceanography
Post Office Box 109
LaJolla, CA 92037

Colorado

National Geophysical and Solar
Terrestrial Data Center
Solid Earth Data Service Branch
Boulder, CO 80302

District of Columbia

National Oceanographic Data Center
Environmental Data Service
2001 Wisconsin Avenue
Washington, DC 20235

Florida

Atlantic Oceanographic and
Meteorological Laboratories
15 Rickenbacker Causeway,
Virginia Key
Miami, FL 33149

Hawaii

National Weather Service
Pacific Region
Bethel-Pauaha Building, WFP 3
1149 Bethel Street
Honolulu, HI 96811

Maryland

National Ocean Survey - C3415
Building No. 1, Room 526
6001 Executive Boulevard
Rockville, MD 20852

Atmospheric Sciences Library - D821
Gramax Building, Room 526
8060 13th Street
Silver Spring, MD 20910

National Environmental Satellite
Service
Environmental Sciences Group
Suitland, MD 20233

Massachusetts

Northeast Fisheries Center
Post Office Box 6
Woods Hole, MA 02543

Michigan

Lake Survey Center - CLx13
630 Federal Bldg. and
U. S. Courthouse
Detroit, MI 48226

Missouri

National Weather Service
Central Region
601 East 12th Street
Kansas City, MO 64106

New York

National Weather Service
Eastern Region
585 Stewart Avenue
Garden City, NY 11530

North Carolina

National Climatic Center
Federal Building
Asheville, NC 28801

Oklahoma

National Severe Storms Lab
1313 Halley Circle
Norman, OK 73069

Texas

Remote Sensing Center
Texas A and M University
College Station, TX 77843

National Weather Service
Southern Region
819 Taylor Street
Fort Worth, TX 76102

Utah

National Weather Service
Western Region
125 South State Street
Salt Lake City, UT 84111

Virginia

Atlantic Marine Center - CAM02
439 West York Street
Norfolk, VA 23510

Washington

Northwest Marine Fisheries Center
2725 Montlake Boulevard East
Seattle, WA 98112

Wisconsin

University of Wisconsin
Office of Sea Grant
610 North Walnut Street
Madison, WI 53705

LANDSAT photo mosaic maps of the conterminous United States and Alaska can be purchased from:

Aerial Photography Field Office
U.S. Department of Agriculture
Agricultural Stabilization and Conservation Service
222 West 2300 South
P.O. Box 30010
Salt Lake City, UT 84125

Skylab, Gemini, Apollo, and Apollo-Soyuz photographs, along with a LANDSAT mosaic of New Mexico (black and white 1:1,000,000), can be purchased from:

Technology Application Center
The University of New Mexico
Albuquerque, NM 87131

Audio visual slide programs of space photographs can be purchased from:

Audio-Visual Institute
6839 Guadalupe Trail N. W.
Albuquerque, NM 87107

Annotated slide sets of space photographs from Skylab, Gemini, and Apollo can be purchased from:

Pilot Rock, Inc.
P. O. Box 470
Arcata, CA 95521

Satellite images of weather systems can be purchased from:

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite Service
Washington, DC 20233

National Environmental Satellite Service
Satellite Field Services Station
601 East 12th Street, Room 1724D
Kansas City, MO 64106

16 mm time lapse motion pictures of clouds imaged by satellite over the western hemisphere may be purchased from:

California Institute of Earth, Planetary and Life Sciences
1525 37th Avenue
Seattle, WA 98122

Aerial photographs of various areas can be ordered from:

<u>California</u>

Stratex Instrument Company
Box 27677
Los Angeles, CA 90027

<u>Colorado</u>

Western Distribution Center
U. S. Geological Survey
Federal Center
Denver, CO 80225

<u>District of Columbia</u>

U. S. Forest Service
Department of Agriculture
Washington, DC 20250

Map Information Office
U. S. Department of the Interior
Geological Survey
Washington, DC 20240

<u>Maryland</u>

U. S. Department of Agriculture
Soil Conservation Service
Federal Center Building
East-West Highway and Belcrest Road
Hyattsville, MD 20781

U. S. Coast and Geodetic Survey
Department of Commerce, ESSA
Washington Service Center
Rockville, MD 20852

<u>Michigan</u>

Abrams Aerial Surveys
124 North Larch Street
Lansing, MI 48823

<u>Minnesota</u>

Mark Hurd, Inc.
345 Pennsylvania Avenue, S
Minneapolis, MN 55426

<u>North Carolina</u>

Eastern Laboratory (for areas east of the Mississippi River)
Aerial Photography Division
Agricultural Stabilization and Conservation Service
45 South French Broad Avenue
Asheville, NC 28802

<u>Tennessee</u>

Tennessee Valley Aurhority
Maps and Survey Branch
311 Broad Street
Chattanooga, TN 37401

<u>Virginia</u>

Eastern Distribution Center
U. S. Geological Survey
1200 South Eads Street
Arlington, VA 22202

<u>UTAH</u>

Western Laboratory (for areas west of the Mississippi River)
Aerial Photography Division
Agricultural Stabilization and Conservation Service
2505 Parley's Way
Salt Lake City, UT 84109

Professor Gary Whiteford supplied the following sources from which Canadian space imagery can be obtained:

Integrated Satellite Information Services, Ltd.
P. O. Box 1630
Prince Albert, Saskatchewan, Canada S6V 5T2

National Air Photo Library
615 Booth Street
Ottawa, Ontario, Canada K1A 0E9

Addresses of Aerial Photograph Libraries in Canada for oblique and vertical aerial photographs are:

Alberta

Director Technical Division
Alberta Lands and Forest
National Resources Bldg.
Room 325
109th Street and 99th Avenue
Edmonton, Alberta T5K 1H4

British Columbia

Director of Surveys and Mapping Branch
Department of Lands, Forests and Water Resources
Victoria, B.C. V8V 1X5

Manitoba

Director of Surveys
Department of Mines, Resources and Environmental Management
1007 Century Street
Winnipeg, Manitoba R3H 0W4

Maritimes

New Brunswick, Nova Scotia, Prince Edward Island
Mr. Neale Lefler
Maritime Resource Management Service
Box 310
Amherst, Nova Scotia B4H 325

Newfoundland

Department of Forestry and Agriculture
Building 810
Pleasantville
St. John's, Newfoundland A1A 1P9

Ontario

Photo Library
Administrative Services Branch
Whitney Block, Room 3501
Queen's Park
Toronto, Ontario M5S 2C6

Quebec

Ministere des Terres et Forets
Service de la Cartographie
1995 Quest, Boul. Charest
Quebec, Quebec GIN 4H9

Saskatchewan

Lands and Surveys Branch
1260-8th Avenue
Regina, Saskatchewan S4R 1C9

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* Colorado Cooperative Wildlife Research Unit

16. Abstract (Limit: 200 words)

Thirty five techniques for estimating variables commonly used as input to habitat models for terrestrial wildlife species are described. Each description includes explicit directions for use, and information about required equipment, cost to apply, accuracy, and conditions under which it is appropriate to be used. A glossary of variables is included, and crossreferenced to the appropriate techniques. Directions are also included for randomly locating sample points and line transects, and for selecting random individual plants, and groups of plants. No remote sensing techniques are included, but some information is provided about sources and types of images, and where to go for a discussion of remote sensing techniques.

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Denver, Colorado 80225
FTS: 234-5586
COMM: (303) 234-5586

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## Fish and Wildlife Service

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