# Measurements for Terrestrial Vegetation

CHARLES D. BONHAM

# MEASUREMENTS FOR TERRESTRIAL VEGETATION

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*To Dr. F. M. Churchill*

# PREFACE

This book was developed from experiences gained over a 20-year period of vegetation measurements. Additional appreciation for the need of these measurements and insight on their quantitative characteristics were developed from courses taught by the author to both undergraduate and graduate students at Colorado State University. The book introduces the four commonly used measures of vegetation and associated units used to obtain such measures. Furthermore, a basis is provided to develop this understanding from a statistical variability viewpoint.

In general, plant community ecology has emphasized two broad categories: functional processes in plants and structural characteristics of plants. The structural approach to plant ecological studies emphasizes the form and arrangements of plants within the community and assumes that functional processes account for physical characteristics of plants. That is, the weight of individual plants, plant size and shape, leaf arrangements, and numbers of individuals all result from physiochemical processes of plants.

No attempt has been made to give more concise meanings of words and terms than those already employed for up to a half-century. These include the use of production for standing crop, double sampling for regression equations, quadrat for plot, and line transects for a measurement tape, to mention a few. The book deals with principles and procedures used to obtain structural measurements of terrestrial vegetation communities. Emphasis is placed on frequency, cover, density, and biomass as commonly defined in the preponderance of literature on such measures. A special case for measures of vegetation characteristics resides in double sampling. While any measure not obtained directly by contact with vegetation has been "double sampled," the most commonly used definition is retained in the book.

Efforts were made to balance conceptual as well as practical characteristics of measurement procedures and techniques presented. Yet, an abundance of studies are referenced whereby individual units of measures were made. A number of references are also used to illustrate differences in estimates of individual measures, such as density, obtained by various techniques and units.

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# 1 INTRODUCTION

Variation in the morphology of plants resulted in the grouping of plants into broad categories on the basis of life-forms. Major life-forms are represented by terms such as "tree," "shrub," "grass," and "forb." These life-forms often provide a basis to describe major terrestrial plant communities (Odum 1971). Life-forms of plants or plant species can be described by a number of characteristics such as biomass, frequency, cover, and density. Some life-forms or plant species are perhaps better described by certain characteristics of measure than are others. A combination of objectives of a study and species involved will determine what characteristics are to be measured for an effective description of vegetation. To see this more clearly, consider the measurements of cover, which are estimates of relative areas that a plant controls to receive sunlight. In comparison, biomass directly indicates how much vegetation is present, and particular species indicate the amount of forage available to herbivores in the area. Density describes how many individual stems or plants occur per unit ground area, while frequency describes the dispersal or distribution of a species over the landscape. Each of these species characteristics has a distinct use in vegetation characterization and description. Often, several measures are used in combination for an in-depth description of vegetation (Bonham 1983).

A distinction is made between a unit and a technique, as used here, to discuss vegetation measures. The unit is a distinct measure of an individual component. Since frequency, cover, density, and biomass are expressed in quantities per unit of area, these are units associated with equipment. Points, plots, and tape measures are often used to obtain these units of measure. On the other hand, a technique includes the process used to obtain the unit of measure, specifically: location of the observation, clipping, observing a hit by a point, and summarization of the unit data. Thus, methods used in measurement are not units but, rather, are ways of doing things to obtain the unit of measure. Often the terms "methods" and "techniques" are used synonymously in the vegetation literature to include pieces of equipment. Thus, one reads phrases such as "the method used was a 0.5-$m^2$ quadrat." No distinction is made here between techniques and methods because both describe or imply a process used in obtaining a measure of given vegetation characteristics. In any case, methods or techniques involve the use of units, equipment, and field procedures to make a measurement.

Measurements of vegetation characteristics have been made for more than a century, and techniques developed to obtain these measurements are numerous. Few units and techniques are comparable, even for measuring the same characteristic of vegetation, such as cover. This is true because objectives to obtain the measure differ. Yet, comparisons of vegetation characteristics over time and space are often necessary. If comparisons are to be made, comparable methods must be used to obtain measurements.

There are basically two objectives to be considered in the selection of measurements and techniques used to obtain measurements. One objective is to assess effects of a perturbation applied to vegetation. For example, the objective may be to describe the characteristics of the native vegetation at a given time, and then again at a later date, to assess changes. Clearly, the rule of least costs will often dominate the method of evaluation and comparison of vegetation characteristics.

The second objective is to describe vegetation characteristics so that the measurement can be used as a standard or a baseline. Otherwise, all descriptions of the vegetation would be relative and not subject to valid comparisons. The two objectives are compatible and should not be considered as competing for resources, especially monetary, in order to be attained.

The purpose in a study of units and techniques to obtain vegetation measurements is twofold in nature: (1) to make proper choices of appropriate units used to estimate a characteristic of vegetation, that is, frequency, cover, density, and biomass, and (2) to properly select and utilize a sample design that will provide unbiased estimates of the characteristic measured. One will gain efficiency in carrying out both of these objectives simultaneously only through proper use of methods in the field, followed by effective data analysis procedures.

No known set of techniques is free of disadvantages for any measurement or set of measurements. Rather, selection of a technique should be made with perhaps an understanding that certain modifications may be needed to optimize its use. Modifications of techniques to reduce effects of biased estimates or to limit disadvantages are frequently described in the literature. In general, however, all techniques used to measure vegetation are related to land areas. That is, frequency, cover, density, and biomass amounts are correlated not only for certain species but also by the fact that each is estimated with reference to a land area and, in some cases, volume occupied.

## 1.1 HISTORICAL BRIEF

Measurements of vegetation date to antiquity. In the third century B.C., Theophrastus observed that certain relationships existed between plants and their environment. Thus, he was an early contributor to plant ecology in the quantitative sense. Still, centuries passed with qualitative assessments dominating vegetation descriptions, and plant species in particular. Geographic descriptions of vegetation occupied the interest of many naturalists in Europe, where only listings of species dominated their efforts. Indeed, lists of plants provided the beginning of vegetation characterization as a true quantitative approach. Emphasis was placed on such lists throughout the eighteenth and nineteenth centuries on the European continent. It was in Europe that Raunkiaer (ca. 1900) used the first known plot to obtain a quantitative measure of plant species: that of frequency, although the work was still to describe geography of plants (Raunkiaer 1934).

The work of F. E. Clements in the United States increased precision in vegetation measurements. Clements, in 1905, coined the word "quadrat" for use in vegetation data collection. While the term technically defines a four-sided plot, its usage over time has been adulterated to include any plot shape, even a circle.

Gleason (1920) further advanced the concept of quantitative measurements. He described applications of the quadrat method in description of vegetation characteristics. In particular, Gleason (1922, 1925) developed a thorough explanation of species and area (or space) relationships. His concepts led to the notion that sample adequacy could be determined from the relationship between the number of species encountered as a plot area increases. The well-known species–area curve is still used at present to determine relative sample adequacy.

Measurements and analysis of vegetation characteristics during the 1920s led to statistical applications to plant ecology. Kylin (1926) introduced the concept of "mean area" and defined it to be the inverse of density, that is, the number of individuals per unit of area. He was also among the first to present explanations for the relationship between density and frequency, which is of a logarithmic nature, not linear. Kylin's work followed that of Svedberg (1922) in Europe, and their approach to measures of vegetation was of a statistical nature that encouraged many others to examine vegetation characteristics from a quantitative point of view.

Cain (1934) and Hanson (1934) compared quadrat sizes, while Ashby (1935) gave an early introduction for the use of quantitative methods in vegetation descriptions and (Ashby 1936) published on the topic of statistical ecology. Bartlett (1936) gave examples of statistical methods for use in agriculture and applied biology, but Blackman (1935) had previously introduced statistical methodology to describe the distribution of grassland species. These early studies in vegetation measurements emphasized the dispersion of individuals in plant communities. Thus, patterns of dispersal were very much in the forefront of most quantitative assessments of vegetation characteristics.

How plants are arranged spatially implies distance measures and, subsequently, pattern. This emphasis on pattern analysis began in earnest in

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the 1920s and reached a peak in the late 1940s and early 1950s (Greig-Smith 1964). Interest in species patterns was briefly rekindled in the 1970s as distance measures were again used for density estimates (Green 1966, Beasom and Houcke 1975). Many distance measures in plant patterns use a single, linear dimension and are, thus, referred to as "plotless" methods. The return to plotless methods in the United States was essentially driven by time–cost considerations needed for large-scale inventories of forests and rangeland resources.

Since distance measurements included rigid assumptions about the distribution of individual plants, an understanding of patterns found in natural plant populations was necessary. Therefore, a great deal of effort was expended to develop acceptable modifications to plotless methods for use in the estimation of frequency, cover, density, and biomass. Thus, measurements of vegetation actually began to find a place in the work of professional plant ecologists from the 1920s onward. Very few professionals in vegetation ecology, however, mastered the seemingly more difficult merger of this discipline with that of statistics. Very few specialists study statistical plant ecology, especially with emphasis on native vegetation characteristics.

## 1.2 UNITS OF MEASURE

The science of measurement, which is called *metrology*, has been a vital part of science, especially the physical sciences, for centuries. The science of metrology was given much attention during the nineteenth century because a better system of units and standards for measurements is needed to assist the field of physics (Pipkin and Ritter 1983).

The metrology of vegetation itself, however, is of even more recent origin. Only within the decade 1970–1979 was there major progress on the determination of fundamental constants needed to relate measured vegetation characteristics displayed by density, cover, and so forth to biological and ecological theory.

The initiation of the International Biological Program (IBP) to study the interrelationships of organisms and their environment that operated in an ecosystem pursued the integrated systems approach. Mathematical and statistical models formulated during this time provided some fundamental insight as to how such systems of organisms functioned individually and collectively. Thus, for example, constants for energy and nutrient transfer through a system were provided, which resulted in a clearer understanding of how measured characteristics described plant–environment relationships. For example, the amount of biomass accumulation by an individual species can be used to assess that species role in nutrient utilization and recycling within the vegetation system as a whole.

Most vegetation measurements are now made in metric notation, which is used throughout this book. Table 1.1 provides a definition of the relationship that exists among linear, area, volume, and weight measures from the metric system. The volume measure is given in this form because some measures of weight of vegetation biomass may be reported as per unit volume occupied. Essential or fundamental constants used in measure-

**TABLE 1.1 Metric Weights and Measures**

| | |
|---|---|
| *Linear Measure* | |
| 10 millimeters (mm) | = 1 centimeter (cm) |
| 10 centimeters | = 1 decimeter (dm) |
| | = 100 millimeters |
| 10 decimeters | = 1 meter (m) |
| | = 1000 millimeters |
| 10 meters | = 1 dekameter (dam) |
| 10 dekameters | = 1 hectometer (hm) |
| | = 100 meters |
| 10 hectometers | = 1 kilometer (km) |
| | = 1000 meters |
| *Area Measure* | |
| 100 square millimeters ($mm^2$) | = 1 square centimeter ($cm^2$) |
| 10,000 square centimeters | = 1 square meter ($m^2$) |
| 100 square meters | = 1 are (a) |
| 100 ares | = 1 hectare (ha) |
| | = 10,000 ($m^2$) |
| 100 hectares | = 1 square kilometer ($km^2$) |
| | = 1,000,000 ($m^2$) |
| *Volume Measure* | |
| 1000 cubic millimeters ($mm^3$) | = 1 cubic centimeter ($cm^3$) |
| 1000 cubic centimeters | = 1 cubic decimeter ($dm^3$) |
| | = 1,000,000 ($mm^3$) |
| 1000 cubic decimeters | = 1 cubic meter ($m^3$) |
| 1,000,000 cubic centimeters | = 1,000,000 ($mm^3$) |
| *Weight* | |
| 10 milligrams (mg) | = 1 centigram (cg) |
| 10 decigrams | = 1 gram (g) |
| | = 1000 (mg) |
| 10 dekagrams | = hectogram (hg) |
| | = 100 (g) |
| 10 hectograms | = kilogram (kg) |
| | = 1000 (g) |
| 1000 kilograms | = 1 metric ton (t) |

ments of vegetation may include conversion from one system to another. For example, in order to interchange units from the metric to the English system, constants are needed. Approximation values for some of these constants are given in appendix Table A.1 (appendix at end of the book).

Additional constants to those in Table 1.1 are often needed in vegetation measurement work. Such constants are given in appendix Table A.2 since these small areas are often used to estimate weight of plant biomass, especially that of forage, in much of the world. Some public land agencies in the United States still use "lb/acre" for management of forage resources, yet use metric dimensions for obtaining these estimates. Therefore, conversions are given for the most commonly used plot areas.

Calculation of a constant for any given area to a larger area is as follows:

$$\text{unit of wt(1)/large area} = \frac{\text{one unit of wt(2)/large area}}{\text{(units of wt(2)/unit wt(1) (small area)}} \tag{1.1}$$

That is, for a 0.25-m$^2$ plot (appendix Table A.2),

$$\text{kg/ha} = \frac{\text{g}/10{,}000\ \text{m}^2}{(1{,}000\ \text{g/kg})(0.25\ \text{m}^2)} = \frac{10}{0.25} = 40$$

Still other constants may be useful for conversion of one or more measures into another measure. For example, cover percentage of a species may be used to estimate biomass weight (grams) of the species, in which case the constant is estimated by least squares procedures of regression analysis. The general form of the equation is usually

$$\text{Biomass (g/area)} = f\left[\sum_{i=1}^{k} (\text{measure } i)\right] \tag{1.2}$$

where $i$ is one or more independent measures such as cover, stem diameter, and so on, and $k$ is the number of independent measures made on the plant. The function $f$ also includes measurements in the equation as given in appropriate chapters of the book.

## 1.3 CHOICE OF TECHNIQUE

Selection of an appropriate technique to use for obtaining a measure is based on several criteria. Emphasis in this chapter is based on two major characteristics: (1) those involving the physical aspects of vegetation and (2) those involving biometrics and econometrics of the techniques.

### 1.3.1 Vegetation Characteristics

Selection of proper units and measurement techniques to use requires a knowledge of floristic composition of the vegetation type. That is, units to estimate density, biomass, and cover are determined by the plant community life-forms. The abundance of these measures determines the size of quadrat, the specific distance measure, and the number of sampling points needed. In general, dense vegetation, which usually implies higher density of individual plants, larger plants, or both, can be measured with fewer large plots or fewer points than a sparsely occupied area. The latter areas often require more points, plots, and so on because the variation is larger for the measure, such as cover or biomass.

Life-forms present in a vegetation type are suggested as a consideration in selection of technique. But sometimes a given form, such as the shrub or tree form, will have more variation in size over species than will grasses or forbs in a vegetation type. The same can be true for forbs compared to grasses. That is, size variation among species within a life-form can suggest the use of a technique such as the size of a quadrat for individual plant counts or biomass determination. If a large plant is abundant and may fully occupy the quadrat when encountered, then spatial exclusion occurs for all other species in that case; in other words, no other individual can occur in a quadrat occupied by another large individual. In such cases, underestimates of a measure for some species may result, while other species, especially large ones, may be overestimated.

Patterns of distribution for individuals within a species, and patterns for species, are of major concern in technique selection and use. If all distributions were random, or very nearly so, then measurements would not yield biased results in most cases. Random distributions imply that no pattern is present in the measure obtained and that such measures can be obtained from a random sampling process to provide unbiased estimates of the measure. In vegetation measurements, the presence of patterns in the measure causes the greatest biometric concern, which, in turn, influences the economics of measurements.

### 1.3.2 Biometrics and Econometrics

Biometrics (the science of statistics applied to biological observations) and econometrics (the science of statistics applied to economic data) are useful in the selection of appropriate measurement techniques. Statistics provide estimates of the population mean and an estimate of its variance with assignable probabilities for confidence limits. When the data distribution form (e.g., normal or binomial) is known or assumed for a measure, a technique that provides the smallest value of an estimate of the variance of the mean is the best estimate of the mean. Furthermore, such a technique provides the minimum number of observations to be taken for that given measure of biomass, cover, density.

Obviously, the foregoing discussion implies that certain techniques will also be more efficient from the economic viewpoint. A technique that requires more observations than another to obtain the same precision is not as cost-effective if the cost is the same for each observation. Additionally, accuracy of the estimates is to be considered. In some cases, a technique may be precise, that is, gives repeatable results. However, it may not be accurate, which means that the technique does not estimate the true population value very well.

Emphasis should be placed on the sample error of a technique. This error is not a mistake or an oversight, but rather involves the variation present in actual measures (cover, density, and biomass). An estimate of this error is usually defined by the "standard error" of the mean. The magnitude of the sampling error depends on the (1) number of observations, (2) inherent variability of the measure, and (3) method of selecting a sample. That is, location of units in the field is made according to random or other methods. All of these aspects of the sample error will affect the cost of sampling.

## 1.4 VARIATION IN VEGETATION

Sources of variation in measures of vegetation characteristics are many. Vegetation characteristics of frequency, cover, density, and biomass are affected by species life-form; species composition; seasonality; previous use by humans and animals; and edaphic and climatic characteristics. Already, life-forms have been suggested as a variable that affects the selection of a technique used for a measure. Life-form (tree, shrub, herb) is a source of variation in vegetation in terms of its relationship to frequency, amounts of cover, number of individual plants possible in an area, and effects on biomass of a plant.

Precipitation, air and soil temperature, soil moisture, and time in relation to initiation and cessation of plant growth all affect the measure of a characteristic for a certain species. More importantly, however, they contribute significantly to variation of the measure when made over all species present. For example, total biomass of an area depends on the phenological stages of the species present. Variations among time intervals over a growing season or years, then, will depend on the development stage of both major and minor species. Previous use of, or destruction of, vegetation is often reflected in the variation found in vegetation characteristics. Previous harvesting of trees, heavy grazing by large herbivores, periodic infestation of insects, and disease are significant sources of variation in measures of vegetation. Variations are often noted also by species composition, which indicates a secondary or greater successional stage of the plant community. Edaphic (soil) sources, as contributors to variation in vegetation, include parent material, stage of soil development, and physical and chemical properties of the present soil.

While weather is a measure of present events such as air temperature, wind, and precipitation, climate is a long-term phenomenon. Weather, in general, affects the measure of vegetation cover more so than it does density for perennial species. However, annual and ephemeral species are affected through expressions of frequency, density, cover, and biomass by weather events occurring within a few days. Climate, on the other hand, introduces variation in vegetation through its determination of species composition and reproduction in perennial species.

These sources of variation should be used to stratify for sampling purposes to enhance efficiency in the sampling process. A "stratum" is a unit of vegetation that is homogeneous with respect to species composition, soil type, and so on. Or a combination of vegetation and environmental characteristics are used to form strata. Strata should be used to classify measurements to ensure minimum variability within a stratum and maximum variability among strata for measures of interest. Vegetation typing accomplishes stratification on a large scale, but much more efficiency in sampling is gained within a stratum found in the type that is more homogeneous. Then, statistical procedures provide a more efficient estimate, both statistical and economical, of the measure. Measures of vegetation will have less variation if like life-forms are placed into strata according to trees, shrubs, and herbaceous plants. Season of growth for herbaceous plants should be stratified into early, mid, and late season, while kinds of past use and intensity of use also provide strata. Table 1.2 provides a schematic diagram for relationships among vegetation variability and general effects on measurement attributes.

**TABLE 1.2 Relations of Vegetation Characteristic Variability and Measurements of Cover, Density, and Biomass**

| To Large | Variability | From Small |
|---|---|---|
| ← | Sample size increases | |
| ← | Plot size increases | |
| ← | Need for stratification increases | |
| ← | Effectiveness of double sampling increases | |

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