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 and Barrett 2005). 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).

Frequency, cover, density, and biomass are expressed in quantities per unit of area and these are units associated with equipment. Points, plots, and tape measures are often used to obtain these quantities of measure. On the other hand, a measurement technique includes the process used to obtain the measure, specifically location of the observation, clipping, observing a hit by a point, and summarization of the data. Thus, methods used in measurement are ways of doing things to obtain the 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.

Measurements of vegetation characteristics have been made for more than a century, and methods developed to obtain these measurements are numerous. Few

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methods 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, then comparable sampling methods must be used to obtain the measure. For instance, if 100 plots of 0.1 m^2 area are measured for cover, then 10 m^2 of area have been measured. To compare these results to the use of a 50 m length fine point transect, the number of transects measured has to be associated with an area of 10 m^2. The same area measured would then be comparable (Bonham and Clark 2005). More on this is presented in the individual chapters on measures.

There are basically two objectives to be considered in the selection of measurements and methods used to obtain measurements. For example, one objective may be to describe the characteristics of the native vegetation at a given time period, and then again at a later date, to assess changes. The second objective is to describe vegetation characteristics so that the measurement can be used as a standard or a baseline. Sampling intensity has to be the same for both time periods; that is the sampling process has to sample the same area although the equipment area has changed. Otherwise, all descriptions of the vegetation would be relative to different areas measured 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 methods to obtain vegetation measurements is twofold in nature: (1) to make proper choices of appropriate methods 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 equipment to reduce effects of biased estimates or to limit disadvantages are frequently described in the literature. In general, however, all methods 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 (1912) used the first known plot (0.1 m^2) to obtain a quantitative measure of plant species 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 idea that sample adequacy could be determined from 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. There are limitations to this method of determination of proper plot size; namely, each species would have a different size of plot.

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. Furthermore, species absence, not presence, determines density. 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 the 1920s and reached a peak in the late 1940s and early 1950s (Greig-Smith 1983). Interest in species patterns was briefly rekindled in the 1960s 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 distance measures have been 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. Recently, these methods have been referred to as "variable area" methods and this description for these methods is used here because, indeed, "area" is involved in all of them.

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 variable area 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. Today, many professionals in vegetation ecology have mastered the seemingly more difficult merger of this discipline with that of statistics.

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 was needed to assist the field of physics (Pipkin and Ritter 1983).

The metrology of vegetation itself, however, is of even more recent origin. In the decade 1970–1979 there was 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.

In the decade of the 1960s, the International Biological Program (IBP) introduced the integrated systems approach to study the interrelationships of organisms and their environment that operated in an ecosystem. Mathematical and statistical models formulated up to the present time have provided 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

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	= 1dekameter (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)
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	= 1 kilogram (kg)
	= 1000 (g)
1000 kilograms	= 1 metric ton (t)

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 should be reported as per unit volume occupied. Essential or fundamental constants used in measurements 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. Vegetation workers on rangelands of the United States and other places often use pounds of forage per acre (lb/acre) to manage 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:

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

That is, for a 0.25 m^2 plot (Appendix Table A.2),

$$\text{kg/ha} = \frac{\text{g}/10\,000\,\text{m}^2}{(1000\,\text{g/kg})\left(0.25\,\text{m}^2\right)} = \frac{10}{0.25} = 40$$

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 equals 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 method

Selection of the proper method to obtain a measure is based on several criteria. Emphasis is based on two major characteristics: (1) those involving the physical aspects of vegetation, and (2) those involving biometrics and econometrics of the methods.

1.3.1 Vegetation characteristics

Selection of proper measurement methods to use requires knowledge of the floristic composition of the vegetation type. That is, equipment to estimate density, biomass, and cover is determined by the plant community life-forms. The abundance of these measures determines, for example, 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 a method. 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 method such as the size of a quadrat for individual plant counts or biomass determination.

Spatial exclusion, by large plants, or other species from a given size of plot area, might be overcome by increasing the sample size, in which case, sampling design should be considered in an application of adaptive sampling (Chapter 4). Patterns of distribution for individuals within a species, and patterns for species, are of major concern in method 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 methods. 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 method that provides the smallest value of an estimate of the variance of the mean is the best estimate of the mean. Furthermore, such a method provides the minimum number of observations to be taken for that given measure of biomass, cover, and density.

Obviously, the foregoing discussion implies that certain methods will also be more efficient from the economic viewpoint. Any method 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, precision of the estimates is to be considered. In some cases, a method may be precise, that is, gives repeatable sampling results. However, it may not be accurate, which means that the method does not estimate the true population value very well.

Emphasis should be placed on the sampling error of a method. 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: (1) the number of observations, (2) the inherent variability of the measure, and (3) the method of selecting a sample. That is, location of sampling units in the field is made according to random or other methods. All of these aspects of the sampling 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 (soil) and climatic characteristics. Already, life-forms have been suggested as a variable that affects the selection of a method used for a measure. Life-form (tree, shrub, and 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 during sampling. 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. Prior 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 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. This is true for established individual plants of a species. In the case that one is interested in variation in life cycles of one or more species, density counts should be made on an annual basis to document life stages of the species from germination to maturation over the growth season. 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

Table 1.2 Relations of vegetation characteristic variability and measurements of cover, density, and biomass

From small	Variability	To large
	Sample size increases →	
	Plot size increases →	
	Need for stratification increases →	
	Effectiveness of double sampling increases →	

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 should be used in the sampling design to classify measurements to ensure minimum variability within a stratum and maximum variability among strata for measures of interest. Vegetation typing into plant communities provides a more efficient estimate, both statistical and economical, of the measure. 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 illustrates some general effects that variation in vegetation characteristics have on sampling the measures.

1.5 Observational units

A unit is a distinct, discrete member of a population that can be analyzed in an aggregate or as a whole. It is any quantity (weight, percentage, length) used as a measurement and is representative of the population as a whole. Then, amount of plant biomass in an area of a plot is a single unit, just as a point touching a leaf is a unit of cover. Thus, some literature references prefer to use the term "sampling units" that is used in this book.

1.6 Sampling

Sampling is best understood when compared to a complete enumeration or census. Both of the latter refer to measurements of every individual unit in a population. For example, every possible quadrat or distance between plants constitutes a population. It is well known that a sample from a population of measurable units will essentially contain the same information as a complete enumeration, yet will cost far less than the census. What is less well known, though, is the fact that sample-based data may be more reliable than a 100% inventory. This follows from the fact that samples are often taken with greater care than can be used in a complete census because more expertise can be used in sampling. Sample-based data also can be collected and processed in a small fraction of the time required for a complete census. Even in a census, there are, in fact, non-sampling errors occurring. These include missing observational units, double-counting, etc. that can make the census less accurate than a sample. The objective for sampling is to obtain an unbiased estimate of the population parameters, namely, the mean and its variance. Samples are made up of a number of observations. Each sample is of size n, the number of observations made for the measure of interest. Then, each sample has a set of observations specific to it. Therefore, the word "sample," in the statistical sense, refers to a set of observations, not a single observation. An observation, in contrast, is a single measurement made from a sampling "unit" defined in Section 1.5 and Chapter 4. This definition should be used to prevent misinterpretation of sample size information.

An understanding of basic statistical concepts should be developed before fieldwork is begun, regardless of the reason for obtaining measurements. For this purpose, principles of statistics are given in elementary detail in Chapter 3. Of particular importance is the relationship of variation and sample size needed to adequately describe population measures.

Concepts of accuracy and precision are important in the selection of a measurement unit. For example, some sampling units may be precise (results are repeatable) but not necessarily accurate (providing true population value). The difference between the two emphasizes the sample estimate (precision) while "accuracy" refers to the true population measure that cannot be known for a sample.

Sampling units used to measure characteristics of vegetation influence the data distribution. For example, the size of a plot determines the number of individuals that can occur within the plot boundaries. Then, the Poisson distribution can be derived from consideration of plot area relative to the total area sampled. No derivations are given in Chapter 3, only explanations of the relationships of measurements to distributions and relationships among distributions. The Bernoulli distribution is discussed to develop an intuitive basis for occurrence of four binomial distributions. These distributions can be useful in studies of individual species such as threatened and endangered species, invasive species, and indicator species. The point-and-count binomial distributions are given with parameters and associated sample size adequacy as estimated from an equation based on the normal distribution.

1.7 Frequency

Frequency is the percentage of a species present in a sampling unit and, therefore, it is influenced by size and shape of sampling units. Frequency can be estimated by plots only because the measure is based on occurrence per unit area and by definition, the point eliminates area dimensions (Chapter 5). Frequency is a useful index for monitoring changes in vegetation over time and comparing different plant communities. Mathematical relationships may be used to estimate plant density and cover from frequency data. The index is also highly sensitive to abundance and pattern of plant growth. Selection of an appropriate plot size and shape requires preliminary study of the vegetation type. Some plant ecologists recommend plots of certain size on the basis of experience, while others calculate plot sizes from mathematical relationships between some vegetation characteristics for statistical considerations. The scope of frequency and details for calculation of plot size, plus other considerations are discussed in Chapter 5.

1.8 Cover

Cover can be measured for vegetation in contact with the ground (basal area) or by projected aerial parts of vegetation onto the ground (foliage cover). All methods of measuring cover depend on occurrence of a plant part within a quadrat or by contact with a pin, the area of which may be very close to zero (0). In fact, all methods give cover estimates on a two- or three-dimensional basis. Yet, a line is often erroneously assumed to be one-dimensional when, in fact, its width is very narrow, while its length is very long relative to this width (Bonham and Clark 2005). It is important, as stated above, to realize that all measures are in units of area sampled; cover estimates from point or line intercepts are no exceptions.

Points have been used singly, as in the step-point method, or in frames, as in the point-frame method. Spacing of pins within a frame is, in general, closer for intensive studies, and farther apart for general surveys. This is so because individual species are of more interest in the former, while a general cover estimate will suffice in the latter. Cross-hairs in telescopic sights are used for sighting the points rather than the lowering of a pin. The line-point method involves point readings spaced along a line-transect; spacing of points depends on the size of the study area and density of ground cover. In no case should there be more than 100 points for a sampling unit. The difficulty with a biological-ecological interpretation of species cover values less than 1.0% is obvious. Furthermore, individual line-point transects to obtain estimates of basal cover of plant species have been shown to be unreliable and produce biased results because individual transects cannot be precisely relocated in the exact position with no deflection angle from that point (Bonham and Reich 2009).

Line-intercept often uses a tape measure as a line-transect through a plant community of interest and measuring the length of a species basal or foliage area intersected. Line-intercept methods give values closer to true cover as calculated from ellipse formulas than with variable area plot methods. Line-intercept data are more precise, and data are obtained more rapidly than by the use of quadrats in communities with different-sized individuals of plant species. It is a good method only for a few types of situations, e.g., measuring the canopies of shrubs or mat-forming plants, or measuring the area covered by different plant communities. Relocation of line-intercept transects for monitoring plant species changes suffer from the same errors as the line-point transect does and should follow recommendations provided for latter methods to avoid bias or at least minimize it.

Quadrats of varying sizes have also been used to measure cover. The most often used quadrat methods involve ocular estimates of percentage cover by species. Cover classes and use of the mid-point value of the cover class for data analysis usually accomplish this. Use of cover classes enables repeatable estimates to be made by different observers and the data cannot be analyzed by standard statistical methods. Some simulation studies on mid-points of cover classes have shown that there is small bias in means of these mid-points over a study area compared to means estimated by standard statistical methods. However, non-sampling errors by observers can be large for cover class methods or by methods to obtain estimates to the nearest 1.0%.

Variable area plot techniques have been used to estimate shrub cover, but not extensively – specifically, because most methods are more difficult to use as shrub cover increases. Variable area plot techniques include distance measures and other unbounded units. On the other hand, variable plot techniques might be more efficient than other methods (bounded as a quadrat) in open shrub and forested communities. Yet there is another method to obtain unbiased estimates of shrub cover given in Chapter 6 and is referred to as the line shadow transect (LST) (Thompson 1992). In essence it is an intercept transect, but differs in the method of obtaining estimates of the canopy cover. The method uses the placement of several line transects (sampling units) within a plant community of dominant shrub species. Measurements of the major and minor axes of an ellipse-shaped area of canopy are made on intercepted shrubs and these canopy areas are projected onto a baseline transect from which sample transects originate. Equations to obtain unbiased estimates of the mean and variance of areas covered by shrubs within the plant community are provided.

1.9 Density

Density measurements require that a defined individual unit of a plant be countable. Density, historically, has been an important measurement for trees and shrubs, and somewhat less important for bunchgrasses and forbs. Essentially, the counting process is slow and tedious for herbs and is questionable for use with sod-forming grasses and other growth-forms where the identity of an individual plant may be difficult to establish. However, density can be estimated if a standard counting unit is defined properly. Plots of various bounded areas and variable area methods to estimate density include: plots of various shapes and areas, point-centered quarter

(PCQ), wandering quarter, line transect, random pairs, nearest neighbor, and closest individual. These latter variable area plots are considered to be minimally biased, if not unbiased. Other often used methods to obtain estimates of density provide biased estimates.

1.10 Biomass

Biomass is another primary vegetation measure because it indicates the quantity of resources, such as water, used by plant species in the community. Biomass is a relative measure of a community's resources bound up in different species. The primary method used to measure herbaceous biomass is to clip biomass in quadrats. Tree and/or shrub biomass is usually estimated from dimensional analysis. That is, other measures, such as plant height and crown diameter, are made and used to predict biomass from regression equations.

Historically, long narrow plots, placed across the direction of change, were generally considered the most efficient, but recent studies contradict this view. It can be shown that proper sample design and number of sampling units provides unbiased estimates of biomass (or other measure), irrespective of spatial patterns.

Optimum plot sizes may differ for determination of biomass of plant species. Additionally, optimum size and shape of plot will differ among vegetation types. Furthermore, sample adequacy, in terms of observations needed, also varies according to the size and shape of the quadrat, species combination, and vegetation type. To appreciate why this is true, recall the sources of variation in vegetation characteristics presented in Section 1.4.

Biomass of shrubs is usually measured with two major components in mind: total biomass and forage for animals. If the objective of a project is an ecological characterization of the vegetation, then only total biomass need be considered. Otherwise, if large herbivores are present and feed on shrubs, then forage (or "browse" as it is often termed) is measured. Shrub and tree biomass and/or current annual growth are determined by indirect methods using dimensional analysis. As previously suggested, the most frequently used dimensions include crown diameter, crown area, height, and basal stem diameter.

Shrub foliage estimates and browse are based on twig diameter, length, and count measurements. Then, regression equations are computed by size classes for shrubs and vegetation types. In fact, very few studies have shown meaningful relationships between tree and shrub size and biomass unless plant size classes by site are considered. Site differences probably account for growth differences and express environmental differences directly. Suggested measurements for double sampling of shrubs and trees are crown length and width, plant height, basal stem diameter, and percentage of live crown cover. The percentage cover may not be useful for indirect estimation of total biomass, but in species with large patches of dead crown, cover provides an acceptable estimate of biomass when used in regression equations. Chapter 8, on biomass, provides more details.

1.11 Measurements with remote sensing

Earth-imagery satellites have not yet provided methods to obtain the precise vegetation species measurements needed in most plant ecological projects. However, spectral imagery from aerial and satellite platforms can be used effectively to describe vegetation-environmental systems as a combination within pixels produced by the spectral imagery. Such systems can be related to ground surface areas via pixels generated with their coordinates. These pixels can be ground located within a reasonable precision level, sampled by use of quadrats, lines, and/or points to obtain a description of species composition, biomass, density, and/or ground cover. The plant ecological emphasis is on the pixel area and the vegetation-environment of that 900 m^2 area (less than 0.25 acre). Relocation of an individual pixel with a given precision level depends on the quality of the GPS used. Often there is a group of pixels having the same combination of spectral bands and, in such a case, plant communities can be mapped within the group.

There is considerable literature on forested vegetation types where satellite imagery has been used to map tree crown cover in general and in relation to insect and fire damage incurred over large areas of forests. Aerial and satellite remote sensing have been used to map rangeland types and to detect and monitor some invasive plant species. But information on plant species cover, density and biomass has continued to be collected by traditional “on-ground” methods.

There is some discussion on sampling designs to locate similar combinations of spectral imageries in pixel size (30×30 m) areas. Field designs to collect detailed information on vegetation-environmental combinations within these pixels are easy to implement and relocate for monitoring changes over time. Emphasis might be on a total assessment of species combinations and their environmental factors (topography, soil, climate, past use history, etc.) present in association with individual pixels of a scene or partial scene.

Methods of measures using remote sensing and spatial sampling designs are presented in the chapters on cover, density, and biomass. Uses of these general methods are also presented in the chapter on monitoring and evaluation.

1.12 Monitoring and evaluation

Objectives of vegetation measurements differ with respect to various project goals. One may be interested in mapping plant communities and studying changing patterns in dominant species as they interact with changes in soil–water relationships. The objectives and methods of vegetation measurement may be different, but the plant characteristics to be measured remain the same: frequency, cover, density, and biomass. Once information is available on these characteristics, data can be synthesized and analyzed in a manner that best suits the objectives of the study.

A prerequisite of any vegetation measurement for inventory purposes is general familiarity with the area and recognition of general physiognomy of the vegetation. This can be achieved through a reconnaissance survey of the area. Topographic maps, soil survey maps, and aerial photographs are very helpful in such a survey. These maps can be overlaid to study topographic and soil influences on plant characteristics and species composition. It is, therefore, possible to map plant communities and their descriptions on survey maps. Once these communities or ecological units are delineated, the next step is to choose a sampling design and a measure of plant characteristics. A summary of the sampling statistics should be used in a narrative description of the ecological sites. These statistics should include spatial terms to account for autocorrelation of individual species of importance.

There are few areas not grazed by domestic or wild animals. In fact, competition between domestic and wild animals is significant in many parts of the world. Moreover, herbivorous insect populations sometimes reach epidemic proportions that have detrimental effects on native vegetation. Even at normal population levels, small herbivores such as insects, although sometimes not visible, consume substantial quantities of forage that would otherwise be available for large herbivores (Capinera 1987).

Methods of determining carrying capacity for herbivores range from general reconnaissance to detailed surveys. The choice depends on objectives and resources available to undertake such a survey. Simple information on herbage biomass is not a sufficient basis for decision-making in regards to number and kinds of herbivores that might graze on a given ecological site or plant community type. Such a decision depends on the condition (health) of the vegetation relative to a natural environment. The objective is usually to maintain vegetation resources in at least a sustainable condition for grazing of large herbivores. Therefore, monitoring to detect any change of plant species composition enables adjustment of land use practices when necessary. Planning and management decisions for vegetation use by humans and animals should be based on precise assessments of the vegetation resources, and these assessments should be regularly updated to detect trends and revise the management plans accordingly.

1.13 Overview and summary

Processes involved in measurements of vegetation characteristics and associated uses with environmental data are given in Figure 1.1. Variability encountered in measurements should not be determined solely after data have been collected. Even casual observations, made visually, reveal sources of variability likely to influence the measures made. The most obvious sources of variation are usually

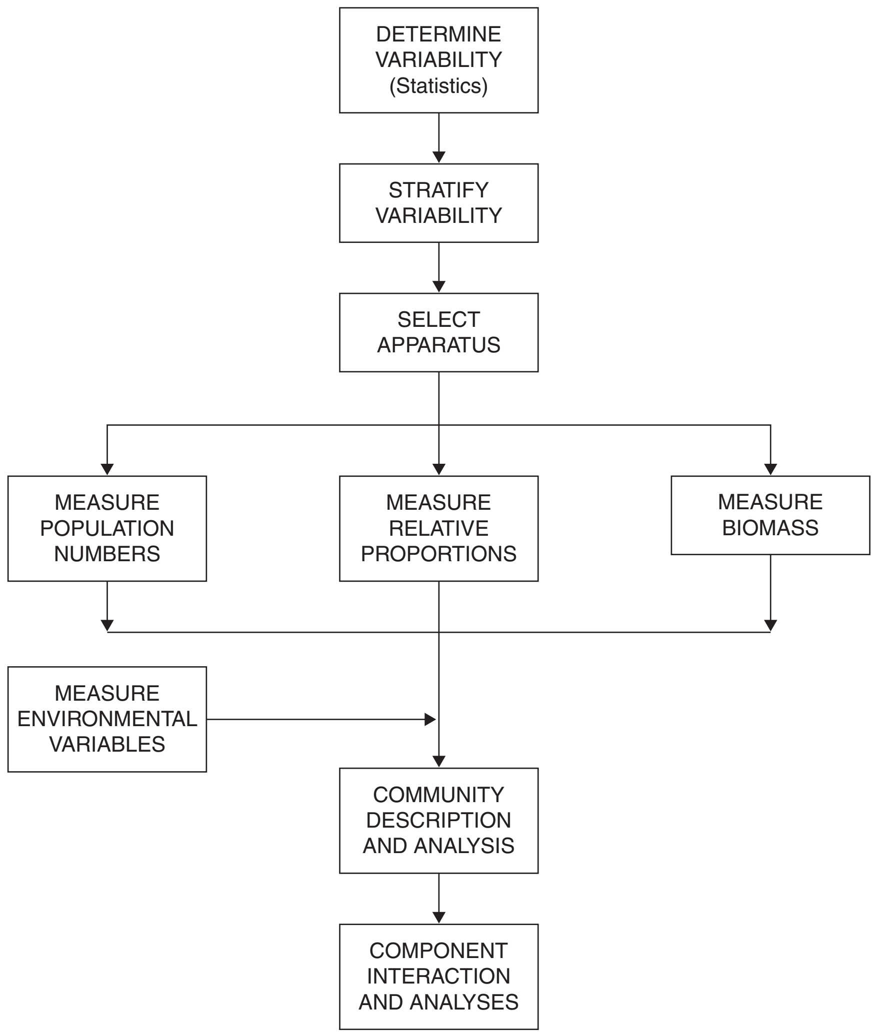

Figure 1.1 A flow diagram of processes involved in vegetation measurement and data analysis.

those influences on vegetation caused by topographic, edaphic, and elevation differences among vegetation types. These same influences are also found in a micro manner within a vegetation type, such as that of individuals of species aggregating into clumps. Thus, one recognizes micro-topographic influences, and micro-relief differences, as well as associated soil differences. All three characteristics of vegetation structure, cover, density, and biomass of species should be used to describe the vegetation of an area. As implied in Figure 1.1, proportions include both cover and frequency. These measures are then used to develop plant community descriptions when environmental data are also available. Basic soil descriptions, along with general meteorological data for the area, are sufficient to provide an analysis of general interactions occurring in vegetation environment of an area. In which case, a vegetation-environmental systems analysis can be used to develop an interpretation for general uses or perturbations that might occur to the vegetation.

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