CHAPTER 9
METHODS OF SAMPLING
THE PLANT COMMUNITY

Vegetation scientists would like to understand the degree of species interdependence within communities, how the distribution of communities depends upon past and present environmental factors, and what the role of communities is in such ecosystem activities as energy transfer, nutrient cycling, and succession. However, communities must first be measured and summarized in some effective way before these questions can be addressed. The ongoing attempt to inventory the world's vegetation is based on a small sample of the total vegetation cover because of limitations in people, time, and resources. These samples must be taken very carefully to ensure that the resulting estimates will be accurate and useful.

In this chapter, we will summarize only a few sampling methods; not a very complete review but enough to get a taste of the diversity among the methods. In Chapter 10, we will discuss data analysis methods that can be used to convey the essence of a vegetation type to others who may be half a world away and have never seen the type, yet wish to compare it to types with which they are familiar.

Overview of Sampling Methods

For sampling to be done rationally and efficiently, the continuum of vegetation that covers the earth must be divided into discrete, describable community or vegetation types, just as the taxonomic continuum of individual plants has been divided into species. Most of the world's vegetation is known to science, but at a relatively simplistic level. It has been broadly classified, mapped for large areas, and photographed from the air or from space. The dominant species and physiog-
Overview of Sampling Methods

Even to describe a particular plant community in a relatively circumscribed region, scientists usually do not make a complete census of the community but instead take measurements on perhaps only 1% of the total land on which the community exists. If the samples are chosen carefully, the investigators feel confident in extrapolating from their sample data to estimate the true values or the parameters for the entire community. If the samples are not chosen carefully, the samples will not be representative of the true community parameters and are said to be biased.

There are five approaches to locating representative samples. One approach is complete subjectivity. A seasoned field-worker who has traveled extensively in a region first formulates a concept of a particular community type. Representative stands of that type are found in the field, and one or more sample quadrats are placed so that each quadrat encloses the essence of that stand. This is the relevé method.

The other approaches involve either random or regular placement of samples. A completely random approach would randomly choose stands of vegetation and then randomly locate replicate subsamples (quadrats) within each stand. Such a complete random design is statistically desirable because it removes all bias. In practice, however, there are several limitations to this approach: (a) Random selection of stands may place some in difficult-to-reach locations and the small amount of information they provide would not compensate for the investment in time it takes to reach them. In any event, the field time required to visit randomly located samples is large and will probably be inappropriately large for surveys of more than several thousand hectares. (b) Random selection of either stands or subsamples within stands may—by chance—result in the location of samples in clumps, leaving large sections of the survey area unsampled and failing to include all possible variation. (c) Completely random sampling will inevitably undersample rare but ecologically informative patches of vegetation, which would be sampled in a subjective design.

A stratified random design allows the field-worker to subdivide the survey area—or any given stand—into several homogeneous regions, then to locate the stands or samples randomly within each homogeneous region. This design ensures that samples will be dispersed throughout the entire survey area and throughout each stand (Figure 9-1b), and it does not compromise the concept of random sampling (Avery 1964).

A complete systematic design locates stands and subsamples within stands by reference to a grid superimposed over the survey area (Figure 9-1c). Intersections of north-south and east-west lines at one scale define stands to be sampled and intersections at a finer scale define sample points within stands. This design has some of the same limitations that a complete random design has. It is rarely used, although Sequoia–Kings Canyon National Park in California has been using this method to document its vegetation for nearly a decade. Ecologists have argued with statisticians for half a century about the wisdom of applying paramet-
Methods of Sampling the Plant Community

Figure 9-1 Basic sampling designs. (a) Completely random, (b) stratified random, (c) completely systematic, (d) random-systematic. [* = sample point]

Ric statistics to data collected systematically, rather than randomly. Most ecologists would argue that statistical analyses require independence of data points and that randomization neither guarantees this nor is the only way to achieve it. That is, regularly placed samples along a transect line should be appropriate for statistical analysis unless that placement just happens to coincide with some underlying environmental periodicity, such as a topographic pattern.

The most frequently used design employs both random (or stratified random) and systematic aspects. We will call this compromise the random-systematic design. We may first select stands by either a random or a stratified random plan. We then locate the starting point—and direction—of a transect within a stand by
some random or stratified random plan (Figure 9-1d). Finally, along that starting point we will take samples according to some systematic plan. This compromise design is probably the most frequently chosen design by field ecologists. It incorporates some degree of randomness, yet it is efficient of field time because the ultimate stand samples lie along convenient transects. Later in the chapter we will discuss the gradsect method, which is a variant of this random-systematic design.

The Relevé Method

The relevé method was largely codified, if not developed, by Josias Braun-Blanquet, an energetic Swiss ecologist who helped classify much of Europe's vegetation, wrote an impressive text on plant ecology in 1928, founded and directed a center of synecology at Montpellier, France, called SIGMA (Station Internationale de Géobotanique Méditerranéene et Alpine), and was an active editor of the technical journal *Vegetatio* until he was 90. His methods of sampling and classification are sometimes called the *relevé*, SIGMA, Braun-Blanquet, or Zurich-Montpellier (Z-M) school.

Our description of the relevé method will be brief. Expanded discussions can be found in van der Maarel et al. (1980), Mueller-Dombois and Ellenberg (1974), Shimwell (1971), Becking (1957), Küchler (1967), and Poore (1955a,b). The Braun-Blanquet method is extensively used throughout the world—with the exception of North America. Until the end of the twentieth century, the relevé method was seldom applied to North American vegetation. Henry Conard (1935)—who helped translate Braun-Blanquet's book into English—was one of the first Americans to use the method. Vera Komarkova (1978, 1979) was another early user, applying the relevé technique to Colorado alpine vegetation. Professor Jack Major at the University of California supervised several master's and doctoral candidates in the use of Braun-Blanquet's method for various California vegetation types in the 1960s through the 1980s, but their results went unpublished except as dissertations with limited distribution.

During the 1990s, the relevé approach found wide use with government agencies, nonprofit conservation organizations, and academic vegetation scientists. The Nature Conservancy adopted the relevé approach in its project to survey, classify, and map all national park vegetation in the United States. The California Department of Fish and Game regularly employs the relevé approach to document threatened vegetation types ranging from riparian forest to desert scrub. Plant ecologists in the U.S. Fish and Wildlife Service have used the method on vast acreages of Alaskan tundra (e.g., Talbot and Talbot 1994). Academic ecologists have classified North American deserts (Peinado et al. 1995), western woody vegetation (Peinado 1997, Rivas-Martinez 1997), eastern deciduous forests (Miyawaki et al. 1994), and Pacific Northwest conifer forests (Krajina 1965, Strong et al. 1990, Klinka et al. 1996).

In the relevé method, an investigator familiar with the vegetation of a region begins to develop concepts about the existence of certain community types that ap-
pear to repeat themselves in similar habitats. A number of stands that represent a given community are subjectively chosen. The investigator walks through as much of each stand as possible, compiling a list of all species encountered. Next, an area that best represents the community is located. It is then necessary to determine the minimal area—the smallest area within which the species of the community are adequately represented. The minimal area may be determined by a species-area curve. The resulting sample quadrat, based on the concept of minimal area, is called a relevé.

A species-area curve is compiled by placing larger and larger quadrats on the ground in such a way that each larger quadrat encompasses all the smaller ones, an arrangement called nested quadrats (Figure 9-2a). As each larger quadrat is located, a list is kept of additional species encountered. A point of diminishing return is eventually reached, beyond which increasing the quadrat area results in the addition of only a very few more species. The point on the curve where the slope most rapidly approaches the horizontal is called the minimal area (Figure 9-2b–d). Because this definition of minimal area is subjective, some define it instead as that area which contains some standard fraction of the total flora of the stand, for example, 95%. Problems in defining minimal area have been discussed by Rice and Kelting (1955). The most recently proposed solution (Dietvorst et al. 1982) is to plot the mean similarity among all samples as the cumulative area sampled increases. Beyond some critical area, similarity remains relatively constant, and this critical area is the minimal area. Experienced phytosociologists do not usually conduct a minimal area exercise every time they take a relevé, instead employing widely agreed-upon rules of thumb that suggest an adequate relevé size for herbaceous vegetation would be <10 m², for a shrubland <25 m², and for forests <1000 m² (though another rule of thumb for forests is to use an area equivalent to the square of the height of the overstory canopy).

Whatever the method, the actual relevé area is somewhat larger than that which gives the graphical minimal area, for the sake of being conservative. For this reason, it might be more appropriate to call the relevé area “appropriate” rather than “minimal.” The appropriate/minimal area is thought by some ecologists to be an important community trait, just as characteristic of a community type as the species that make it up. Table 9-1 shows minimal areas associated with various vegetation types.

In the relevé method, each species’ cover is recorded. Cover is not measured precisely but is placed in one of seven categories by a visual estimate (Table 9-2). Braun-Blanquet and others, such as Rexford Daubenmire (1968a), recognize that plant cover is very heterogeneous from point to point and from time to time even within a small stand. They believe that an exact estimate at one place gives an aura of precision to community description that is not warranted. As another ecologist said, “The ecological world is a sloppy place” (Slobodkin 1974).

Another argument against overly precise cover estimates is that there is a differential bias from one individual to another; it is unlikely that any two estimates would agree closely (Sykes et al. 1983). Schultz et al. (1961) dramatically demonstrated this bias by bringing an artificial quadrat (a 1 m² board with plants represented by discs of different size and color) to a national meeting of professional range management people and asking 100 of them to estimate the total cover of all the “plants” to 62%. Just 33% in error class, such estimates will fall in the investigator server’s devi
Figure 9-2 The species-area curve. (a) Nested plots for determining minimal area. (b) Minimal area for dune grassland in North Carolina is about 0.13 m². (c) Minimal area for an English woodland is about 100 m². (d) Minimal area for two stands of tropical rain forest in Brunei are 1000 m² on a dry ridge and >20,000 m² in a mesic valley bottom. (a) and (d) From Aims and Methods of Vegetation Ecology. Mueller-Dombois and Ellenberg. Copyright © 1974 John Wiley and Sons, Inc. Reprinted by permission. (b) From “A discussion of the application of a climatological diagram, the hythergraph, to the distribution of natural vegetation types,” by A. D. Smith, Ecology 21:184–191. Copyright © 1940 by the Ecological Society of America. Reprinted by permission. (c) From Hopkins. 1957. By permission of the British Ecological Society.

the “plants” on the board. The resulting range of estimates was impressive: from 6 to 62%. Just as impressive was the fact that the average estimate (27% cover) was 33% in error of the true cover (20%). If each percentage estimate is converted to a class, such as those in Table 9-2, however, more than half of the percentage estimates will fall into the correct class. Seven classes do not provide as much precision as 100 percentage points, but using classes results in greater agreement among investigators. The range of percentage points within each class allows for each observer’s deviance from the correct cover percentage.

<table>
<thead>
<tr>
<th>Type</th>
<th>Minimal area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical rain forest</td>
<td>1000–50,000</td>
</tr>
<tr>
<td>Temperate forest:</td>
<td></td>
</tr>
<tr>
<td>Overstory</td>
<td>200–500</td>
</tr>
<tr>
<td>Undergrowth</td>
<td>50–200</td>
</tr>
<tr>
<td>Dry temperate grassland</td>
<td>50–100</td>
</tr>
<tr>
<td>Heath</td>
<td>10–25</td>
</tr>
<tr>
<td>Wet meadow</td>
<td>5–10</td>
</tr>
<tr>
<td>Moss and lichen communities</td>
<td>0.1–4</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Braun-Blanquet</th>
<th>Domin-Krajina</th>
<th>Daubenmire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Range of cover (%)</td>
<td>Mean</td>
</tr>
<tr>
<td>5</td>
<td>75–100</td>
<td>87.5</td>
</tr>
<tr>
<td>4</td>
<td>50–75</td>
<td>62.5</td>
</tr>
<tr>
<td>3</td>
<td>25–50</td>
<td>37.5</td>
</tr>
<tr>
<td>2</td>
<td>5–25</td>
<td>15.0</td>
</tr>
<tr>
<td>1</td>
<td>1–5</td>
<td>2.5</td>
</tr>
<tr>
<td>†</td>
<td>&lt;1</td>
<td>0.1</td>
</tr>
<tr>
<td>†</td>
<td>&lt;1</td>
<td>*</td>
</tr>
<tr>
<td>†</td>
<td>&lt;1</td>
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<tr>
<td>†</td>
<td>&lt;1</td>
<td>0.5</td>
</tr>
<tr>
<td>†</td>
<td>&lt;1</td>
<td>*</td>
</tr>
</tbody>
</table>

*Individuals occurring seldom or only once; cover ignored and assumed to be insignificant.

When all stands have been visited, a summary table of species and stands is prepared; this table will be discussed in Chapter 10. The summary table reveals synthetic traits, which are traits of a community rather than of a single stand. Two synthetic traits are presence and constance. Presence is the percentage of all stands that contain a given species. If species A occurs in 8 of 10 stands, the species has 80% presence based on a random sample of 10 stands. Constance is the percentage of all stands that contain given species. If species A is seen in 8 of 10 stands, the species has 80% constance based on a random sample of 10 stands. General patterns and terms, and the patterns and terms, and the patterns and terms, will be included with actual data for accurate estimation.
80% presence. Presence is calculated from the presence lists that were generated as the investigator walked through the stands. **Constance**, in contrast, is based on species encountered in relevés. One relevé, recall, is placed in each stand, and those relevés are all of equal area (though not necessarily of equal shape). Generally, presence is higher than constance. Species A may have been present in 8 stands, but in only 6 of the 10 relevés, thus having 60% constance (sometimes called constancy).

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**Quadrat Methods**

Care must be taken in selecting the shape, size, and number of quadrats. A considerable body of literature developed on these subjects in the 1940s and 1950s. Some of that research was done on scale drawings of plots of real vegetation as seen from above, with miniature quadrats of various sizes and shapes placed randomly over the drawings. Some of these maps have been published (e.g., Curtis and Cottam 1962). Other research was done on maplike models of artificial vegetation, generally by placing discs of different size and color in random or other patterns, and then sampling these models with miniature quadrats.

In any case, whether the maps represent real or artificial vegetation, the point is that one knows the true number of plants and the true cover. Sample estimates of these parameters can then be compared for accuracy. The best sampling method will be both accurate and precise. **Accuracy** is close agreement of sample means with actual parameter means. In Figure 9-3, method A gives values that are very accurate, within 10–20% of the true mean. **Precision** is close agreement of sample means.

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**Figure 9-3** Accuracy and precision of sampling. The center of the target represents the true cover for a stand of vegetation, and the radiating circles represent departures from accuracy of up to 40% error. Means estimated by sampling methods A, B, and C are shown. Methods A and B are both precise (the points are in tight clusters), but method A is the more accurate. Method C has both poor precision and accuracy.
means to each other, without reference to the true mean. In Figure 9-3, methods A and B are equally precise because their sample means cluster equally tightly. Method B, however, is much less accurate, sample means being within 30% of the true mean. Method C is neither precise nor accurate.

Precision can be measured without knowing the true mean; it is equal to 1 divided by the variance of sample means. Accuracy, however, can only be measured when the actual parameters are known, and in vegetation sampling this is never the case.

Quadrat Shape, Size, and Number

By sampling a map of forest vegetation in North Carolina, Bourdeau (1953) and Bormann (1953) concluded that precision is best when quadrats are long, narrow rectangles that tend to cross contour lines. Square and round quadrats are often less precise because each one encompasses less heterogeneity within it than a long, narrow plot placed parallel to the major environmental gradient (see also Clapham 1932 and Lindsey et al. 1958).

Accuracy, however, may decline as the plot lengthens because of the edge effect. The more perimeter there is to a quadrat, the more often an investigator will have to make subjective decisions as to whether a plant near the edge is "in" or "out," and these decisions are likely to be biased by the taxonomic knowledge of the investigator, how alert the investigator is that day, and how close it is to dinner-time. In this respect, round quadrats are the most accurate because they have the smallest perimeter for a given area. They are also easier to define in the field with a tape measure and center stake, and so the perimeter of a large quadrat need not be marked first. Obviously, compromise choices on quadrat shape are often made.

The best quadrat size to use depends on the items to be measured. If cover alone is important, then size is not a factor. In fact, the quadrat may be shrunk to a line of one dimension or to a point of no dimension and cover can still be measured, as described later in this chapter. But if plant numbers per unit area, frequency, or pattern of dispersal are to be measured, then quadrat size is critical. One rule of thumb is to use a quadrat at least twice as large as the average canopy spread of the largest species (Greig-Smith 1964); another is to use a quadrat size that permits only one or two species to occur in all quadrats (Daubenmire 1968a); another is to use a quadrat size that permits the most common species to occur in 63–86% of all quadrats (Bonham 1989, Blackman 1935). Quadrats should also be large enough to capture a wide range of density, so that the data can be considered to be continuous. There are no fixed rules, however, and the choice is often made by combining intuition and convenience. One person working alone in a desert scrub might choose a quadrat area 2 m long on each side because the area can all be seen from one point, whereas a team of two to three people in the same vegetation might choose a quadrat area twice that size.

The number of quadrats to use can be determined empirically by plotting the data for any given feature, using different numbers of quadrats, and picking the number of quadrats that corresponds to a point where fluctuations become damped. For example, cover has been tallied in this way in Figure 9-4. Some spe-
Fluctuations in cover are damped out as the number of quadrats increases. In this example from a sagebrush/grassland in the eastern Washington area, 40 quadrats might be sufficient to conduct the study, with diminishing reward for added effort beyond that point. Reprinted by permission from Daubenmire (1959).

The number of quadrats necessary to reach even this modest accuracy can be enormous if variance among quadrats is high. Standard statistical formulae are available to predict quadrat numbers required for selected degrees of accuracy (Bonham 1989, Hayek and Buzas 1997, Krebs 1989). Warning: these formulae presume a normal, continuous density distribution.

Suppose, for example, we sample a grassland with five quadrats, and we count the number of individuals of species A in each quadrat. Our objective is to determine how many quadrats will be necessary, based on this initial sample, to come within 10% of the real average density of species A with 95% probability. Our
five density measures for species A are 2, 3, 6, 8, and 11. The mean density for A, from this initial sample of five quadrats, is 6. The formula for the number of desired quadrats (Q) is

$$Q = \frac{(t \text{ value for 95% confidence and 4 degrees of freedom})^2 \times (\text{coefficient of variation})^2}{(\text{percentage accuracy desired})^2}$$

The coefficient of variation (CV) in the formula is \((100 \times \text{standard deviation})/\text{mean}\). Solving for CV first, \((100 \times 3.67)/6.0 = 61\). Substituting this value in the Q formula, and substituting 2.78 for the \(t\) value, we have

$$Q = 2.78^2 \times 61^2 / 10^2 = 288 \text{ quadrats}$$

Note that as the percent accuracy gets smaller by half, the number of quadrats desired will quadruple. In the face of such sampling intensity, it is not surprising that most vegetation estimates are only within 25% of the true mean because only about 1% of a stand is included in the cumulative quadrat area.

**Cover, Density, Frequency, Dominance, and Importance**

**Cover** (also called coverage) is the percentage of quadrat area beneath the canopy of a given species. The canopy of an overstory species creates a microenvironment that smaller, associated species must contend with. The overstory canopy, therefore, exerts a biotic control over the microclimate of the site. No doubt the root system of the overstory species extends beneath the ground out to a perimeter corresponding with the canopy edge or even further, so the soil microenvironment is also under the biotic influence of the overstory species. It is assumed that a comparison of cover for each species in a given canopy layer will reveal the relative control or dominance that each species exerts on the community as a whole, such as the relative amount of nutrients or other resources each species commands.

For the practical measurement of cover, holes in the canopy may be viewed as nonexistent, and the canopy edge can be mentally “rounded out,” the rationale being that such space is still under the root or shoot influence of the plant in question. The canopy of a plant rooted outside the quadrat is tallied to the extent that the canopy projects into the quadrat space. Thus, in Figure 9-5 and Table 9-3, shrub E does extend into the quadrat space when its canopy is rounded out (dashed lines), and it contributes 7.9% cover. Similarly, the radiating, basal leaves of B that project into the canopy space are tallied by rounding out the edges and estimating each plant separately, but the overlap is not counted twice. The D plants, some small herbs, are mentally grouped together and their cover is estimated separately from the overtopping B plants. In some vegetation, with many overlapping canopies, total cover could exceed 100% and there could still be bare ground. For this reason, bare ground cannot be estimated by subtracting total plant cover from 100%. Some ecologists, however, do not round out the canopies to the extent shown in Figure 9-5; they would award 0% cover for shrub E. Also, some ecologists do count overlapping canopy areas in the same stratum twice.

**Relative cover** is the cover of a particular species as a percentage of total plant cover. This is quite low. Cover hours of...
Figure 9-5  Estimation of cover. As seen from above, two members of species B contribute the most cover within the quadrat. The leaf tips describe the perimeter of a circle, and cover is estimated as though the circle were completely covered with leaves. Shrub E has a canopy that does not actually penetrate into the quadrat, yet if one fills in the canopy holes with an imaginary circle, then there is cover. Cover values are shown in Table 9-3. Reprinted by permission from Daubenmire (1959).

Table 9-3 Absolute and relative cover and density, based on the 0.1 m² quadrat shown in Figure 9-5.

<table>
<thead>
<tr>
<th>Species</th>
<th>Absolute cover (%)</th>
<th>Relative cover (%)</th>
<th>Absolute density</th>
<th>Relative density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per quadrat</td>
<td>Per ha</td>
</tr>
<tr>
<td>A</td>
<td>0.2</td>
<td>0.4</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>B</td>
<td>33.2</td>
<td>63.6</td>
<td>1</td>
<td>100,000</td>
</tr>
<tr>
<td>C</td>
<td>4.7</td>
<td>9.0</td>
<td>9</td>
<td>900,000</td>
</tr>
<tr>
<td>D</td>
<td>6.2</td>
<td>11.9</td>
<td>14</td>
<td>1,400,000</td>
</tr>
<tr>
<td>E</td>
<td>7.9</td>
<td>15.1</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total</td>
<td>52.2</td>
<td>100.0</td>
<td>24</td>
<td>2,400,000</td>
</tr>
<tr>
<td>Overlap</td>
<td>5.3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Bare ground</td>
<td>53.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Cover. Thus, relative cover will always total 100%, even when total absolute cover is quite low, as in the case of Figure 9-5 and Table 9-3.

Cover of tree canopies can be difficult to estimate, as well as painful after a few hours of neck bending. One solution is to use a "moosehorn" crown-closure esti-
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A periscope-like device is attached to a staff so that the eye-piece is easy to use for viewing while standing; the view of the canopy is seen superimposed on a template of dots (Figure 9-6). The percentage of dots “covered” by canopies is equivalent to percent cover. These readings could be taken at one location in each quadrat. Other versions of the same approach include densiometers and densitometers. A densitometer is an L-shaped tube that reflects one’s vision into the field of view. Coverers that are used:

1. Per centage of dots “covered” by canopies is equivalent to percent cover.
2. Densiometers and densitometers are used.
3. Densiometers and densitometers are used:

   a) Crown-closure estimator (moosehorn) with a grid of dots in the view.
   b) Densitometer with a single point created by two cross-hairs in the field of view.
   c) Spherical densitometer with 24 squares etched into the reflective surface.

![Figure 9-6](image)

**Figure 9-6** Several devices for estimated overstory tree cover. (a) Crown-closure estimator (moosehorn) with a grid of dots in the view. (b) Densitometer with a single point created by two cross-hairs in the field of view. (c) Spherical densitometer with 24 squares etched into the reflective surface.
directly upward (Figure 9-6b). A bull’s-eye type level—visible in the field of view—directs the person holding the densitometer to hold it in an unbiased way. Cover is then recorded as either yes or no, depending on whether tree canopy covers the intersecting point of two hairs that cross in the center of the field of view. If readings are taken at 100 positions along a transect route and “yes” is noted 85 times, then there is an average of 85% cover along the transect for the canopy of all species.

A densiometer is a hemispherical mirror about 6 cm in diameter and mounted on a wooden platform held in one’s palm parallel with the ground and about 20 cm in front of one’s chest. The mirror reflects a large segment of overstory canopy, much like what would be seen through a fish-eye lens. The mirror is marked off into 24 squares (Figure 9-6c) and the recorder tallies cover in each. Readings are repeated at regular intervals along a transect to gain an estimate of cover throughout the vegetation type. A more elegant method is to take a picture of the canopy with a fish-eye lens from one location in each quadrat, then to analyze the photographs later for percent cover.

Typically, however, canopy cover of trees is assumed to correlate with trunk cross-sectional area (basal area, BA) or with trunk diameter at breast height (dbh). To obtain the basal area, the tree is usually measured with a special diameter tape that converts circumference to diameter units. Sometimes relative dominance is used as a synonym for relative basal area or relative cover. In this book, we prefer not to equate dominance with BA or any single measure, but to use it as a sum of several measures (see below).

Cover of shrubs and herbs is usually estimated to the nearest whole number or put into cover categories, but if greater detail is required the quadrats may be photographed from above or a scale drawing can be made. Cover of grasses—especially bunchgrasses—is often assessed by estimating the area that a group of tillers occupy at the ground surface, rather than tediously trying to estimate cover of all the grass blades. One can quickly capture the perimeter’s shape and its enclosed area by bending a piece of wire around the cluster of tillers. The wire forms can be saved for repeated sampling over time, to determine shape as well as area changes.

Density is the number of plants rooted within each quadrat. The average density per quadrat of each species can be extrapolated to any convenient unit area. For example, Figure 9-5 and Table 9-3 show that herb D had a density of 14 plants per 0.1 m² quadrat, which converts to 1.4 million plants per hectare. Relative density is the density of one species as a percent of total plant density. Mean area is plot area/density; it is the area per plant. Density may not be proportional to cover. For example, many young, slender trees may have a higher density but a lower cover than a few older, branching trees. Abundance is a rather nebulous term, but often it is used as a synonym for density.

Frequency is the percentage of total quadrats that contains at least one rooted individual of a given species. Rarely, frequency is expressed on a cover basis: any plant, whether rooted in the quadrat or not, which contributes cover for species A is tallied as “present,” and frequency becomes the percent of all quadrats in which the canopy of A was “present.” Relative frequency is the frequency of one species
as a percentage of total plant frequency. Frequency is highly dependent on quadrat size, and in this respect it is a more artificial statistic than cover or density.

Frequency and density are often independent of each other. A clumped species may have a high density but a low frequency, whereas a much less abundant species distributed singly and regularly throughout a stand will have a low density but a high frequency.

It is unfortunate that such an important ecological term as dominance is still ambiguously defined by many ecologists. Generally, the dominant species of a community is that overstory species that contributes the most cover or basal area to the community, compared to other overstory species. This definition is based on physiognomy. If oak has the highest relative cover in an eastern deciduous forest with oak, hickory, and elm in the overstory, then oak is said to be the dominant species. If all three species contribute about the same amount of cover, or if the balance shifts from one to the other depending on the stand, then the three species are codominants. In a savanna or a semidesert woodland, where tree canopies may contribute only 10–30% cover and understory plants such as grasses or shrubs contribute more, then some grass or shrub species will usually be considered the dominant species.

Another view of dominance is sociologic dominance (Kershaw 1973). Sociologic dominants control the reproduction and continued existence of a community, and they may be understory species. For example, the regeneration of ponderosa pine saplings in some ponderosa pine forests is inhibited by root competition for moisture by the understory grass Festuca arizonica, but not by another grass, Muhlenbergia montana (Pearson 1942). The grasses are the sociologic dominants of the ponderosa pine community, even though ponderosa pine is the physiognomic dominant. For this reason, some methods of community description name communities by both overstory and understory species and separate the two species by a slash, for example, the Pinus ponderosa/Muhlenbergia montana community, or the P. ponderosa/Purshia tridentata community (Daubenmire 1952).

Foresters and tropical ecologists call any individual overtopping tree whose canopy is more than half exposed to full sun a dominant, even though it may not be a member of a species that is a physiognomic or sociologic dominant of that community. In this sense, dominant is a synonym for emergent, and the latter term should be used. In some other forest studies, dominance is equivalent to trunk basal area. The species with the most basal area per hectare is called the dominant. This use of the term dominant is similar to our definition.

Finally, the term aspect dominance is applied to species that are very noticeable and at first glance appear to dominate a community by cover. Careful sampling would reveal, however, that other, less conspicuous species in the same canopy layer contribute more cover and are the actual dominants. Aspect dominance is most common in herbaceous communities, such as grasslands or meadows, where all members of one species will flower synchronously and in this way stand out from the rest of the vegetation at certain times of the year.

Throughout this text, we will use the term dominant in the physiognomic sense.

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Table 9-4: Elevation summarized in Methods of Sampling the Plant Community

<table>
<thead>
<tr>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koa tree</td>
</tr>
<tr>
<td>(Acacia koa)</td>
</tr>
<tr>
<td>Ohia lehua</td>
</tr>
<tr>
<td>(Metrosideros</td>
</tr>
<tr>
<td>Ohia</td>
</tr>
<tr>
<td>(M. tremuloides)</td>
</tr>
<tr>
<td>Guava</td>
</tr>
<tr>
<td>(Psidium guajava)</td>
</tr>
</tbody>
</table>
Importance refers to the relative contribution of a species to the entire community. It can be used in a very nebulous, almost intuitive, informal sense, or it can be calculated in a precise way. At the investigator's pleasure, importance may be synonymous with any one measure—for example, density. Originally, however, importance was defined as the sum of relative cover, relative density, and relative frequency (Curtis and McIntosh 1951). In the latter case, the importance value (IV) of any species in a community ranges between 0 and 300. Table 9-4 illustrates the calculation of IVs for all overstory trees in a Hawaiian rain forest. Notice that two species with similar IVs could have entirely different values for relative cover, density, and frequency; any differences are submerged in the addition process, and the one number that results is a synthetic index of importance. Other formulas for IV calculation have been developed; they may sum only two relative values rather than three (Bray and Curtis 1957, Ayyad and Dix 1964), or sum more than three values (Lindsey 1956). To avoid confusion, all IVs should be made relative to a 0–100 unit scale and called an importance percentage (Bonham 1992).

Biomass and Productivity

Biomass is the weight of vegetation per unit area; synonyms are standing crop and phytomass. The dominance or importance of any species can be expressed as its percentage of total biomass. For small quadrats in herbaceous vegetation, biomass may be measured by clipping all aboveground matter, drying it in an oven, and weighing it. Ideally, roots are also excavated, but they are often ignored; consequently, most biomass data represent only aboveground plant matter.

The clearing of large plots in woody vegetation is not practical. Instead, relatively few individuals of different age or size classes are harvested, and a regres-

<table>
<thead>
<tr>
<th>Species</th>
<th>Relative density</th>
<th>Relative cover</th>
<th>Relative frequency</th>
<th>IV</th>
<th>IV rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koa tree (Acacia koa)</td>
<td>30.0</td>
<td>78.4</td>
<td>30.8</td>
<td>139.2</td>
<td>1</td>
</tr>
<tr>
<td>Ohia lehua (Metrosideros collina)</td>
<td>20.0</td>
<td>13.9</td>
<td>23.1</td>
<td>57.0</td>
<td>3</td>
</tr>
<tr>
<td>Ohia (M. tremuloides)</td>
<td>5.0</td>
<td>5.8</td>
<td>7.7</td>
<td>18.5</td>
<td>4</td>
</tr>
<tr>
<td>Guava (Psidium guajava)</td>
<td>45.0</td>
<td>1.9</td>
<td>38.5</td>
<td>85.4</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 9-4  Calculation of importance value (IV) for an open tropical rain forest at 450 m elevation near Honolulu, Hawaii. Only the four most abundant overstory trees are summarized below. “Cover” here is the total basal area of all stems >3 cm dbh. From Aims and Methods of Vegetation Ecology. Mueller-Dombois and Ellenberg. Copyright © 1974 John Wiley and Sons, Inc. Reprinted by permission.
Species Richness and Diversity

Avi Shmida (1984) has proposed that a quadrat technique developed and widely used by Robert Whittaker until his death in 1980 be adopted worldwide as a standard method to take data for species richness and the calculation of species diversity.

In this method, a $20 \times 50$ m plot (0.1 ha) of homogeneous vegetation is subjectively chosen as representative of a community by the investigator. A 50 m tape is stretched across the plot to serve as a central axis (Figure 9-7a). A central 10 m portion is selected, and ten contiguous $1 \text{ m}^2$ quadrats are marked along one side of the tape. Species presence is noted for each of these ten quadrats. Two $1 \times 5$ m quadrats on the other side of the tape are then searched for species not already noted in the ten small quadrats, and these are added separately to the list. A single $10 \times 10$ m quadrat is then searched for new species, and so, finally, is the entire $20 \times 50$ m plot. Canopy cover for each species can be noted, and additional measures or notes on growth forms, vertical foliage profile, tree and shrub density, and distribution patterns can be taken. Two individuals can complete one plot in as little as one hour (desert vegetation) or as many as four hours (tropical vegetation).

Two important comparative values can then be calculated. If cumulative number of species is plotted against increasing area on semilog paper, a best-fit linear relationship can be formulated. The slope of that line is a convenient measure of habitat and biotic diversity and can readily be compared to other habitats and communities. Species diversity can also be calculated for the 0.1 ha plot, weighted by cover rather than density.

Tom Stohlgren and others (1995) have pointed out that the Whittaker method has two design flaws: the nested quadrats do not all have the same general shape, and the dispersal of the plots overemphasizes the central portion of the 0.1 ha area. They then modified the design, making all plots rectangular and scattering them throughout the 0.1 ha sample (Figure 9-7b). Tests demonstrated that the new design was strikingly more accurate in capturing species richness in the 1–100 m$^2$ range. The Whittaker design consistently underestimated species richness by about one-third compared to the modified design.
Gradient-oriented transect (gradsect) sampling was developed in the 1980s to solve the problem of sampling large areas (>10,000 ha) within narrow constraints of limited time, staff, and budgets (Gillison and Anderson 1981, Gillison and Brewer 1985, Austin and Heyligers 1989). Transects that follow the steepest gradients of environment and vegetation are subjectively selected to maximize sampling efficiency and minimize travel time. Once a transect is chosen, homogeneous pieces (vegetation types or topographic positions) within it are sampled with quadrats or relevés in a stratified random design. Sampling intensity for each vegetation type is proportional to the fraction of the landscape that it occupies. Thus, if 10,000 ha of land is to be sampled and aerial photographs indicate that 6000 ha are covered by many patches of relatively open savanna, 3000 ha are cu-
mulatively covered by patches of denser forest, and the remaining 1000 ha are covered by patches of grassland, then 60% of the quadrats will be randomly scattered within the 6000 ha of savanna, 30% within the forest, and 10% within the grassland. Field trials and computer simulations (e.g., Austin and Adomeit 1991) have revealed that gradsect sampling detected more species and vegetation units at lower cost than more complete restricted random sampling.

Gradsect sampling is a natural outgrowth of a quadrat placement technique first used by Robert Whittaker (1956) when he sampled vegetation in the Great Smoky Mountains. He subjectively chose transects that progressed up in elevation along major slope faces (e.g., north-facing, south-facing, west-facing), beginning in mesic valleys or coves and ending on xeric ridges. At regular intervals of elevation change along each transect he placed quadrats to sample the vegetation. Thus there was no element of random quadrat placement at all. Whittaker applied this technique later to mountain slopes in the Pacific Northwest (1960) and in the warm deserts (1975). In each location he assumed that the environmental gradients were complex combinations of temperature, precipitation, soil moisture storage, and exposure to drying winds, but he did not take microenvironmental measurements to quantify those gradients.

Whittaker's nonrandom sampling technique has been called direct gradient analysis (see Chapter 10). Mohler (1983) later analyzed the effectiveness of Whittaker's regular placement of quadrats in comparison with various other patterns, including random. He concluded that regular placement was very effective but it could be even more so if the intensity of sampling was greater toward the ends of the transects. That is, if quadrats were placed every 100 m change in elevation along most of the transect, they should be placed every 50–25 m near the ends.

**Line Intercept, Strip Transect, and Bisect Methods**

R. H. Canfield (1941) and H. L. Bauer (1943) developed the line intercept method for dense, shrub-dominated vegetation. They found it to be as accurate as traditional quadrat methods but less time-consuming. If a quadrat is reduced to a single dimension, it becomes a line. The line may be thought of as representing one edge of a vertical plane that is perpendicular to the ground; all plant canopies projecting through that plane, over the line, are tallied. The total decimal fraction of the line covered by each species, multiplied by 100, is equal to its percent cover. Just as with quadrats, total cover can be more than 100%. Disadvantages of the method are the loss of density and frequency measures because there is no area involved (although frequency can be expressed on a cover basis if the line is broken up into segments).

Often, a lengthy line intercept is combined with quadrats that run alongside it. Cover is measured along the line, and density or frequency is noted in the

...
quadrats. If the quadrats run continuously along the line, the method is called the *belt transect, strip transect, or line strip method*. These methods have been most often applied to forest vegetation (Lindsey 1955).

**Bisects** are scale drawings of the vegetation within line strips. The idea was originally applied to tropical forests (David and Richards 1933, Richards 1936, Beard 1946); Figure 9-8 is an example from the British West Indies. All plants in a strip approximately 60 m long and 8 m wide are shown, drawn as accurately as possible. For those who are not good artists, bisects can be drawn in highly diagrammatic fashion using symbols (see Dansereau 1951). Other bisect studies have used areas of size $10 \times 10$ m, $10 \times 50$ m, and $8 \times 40$ m (Ashton and Hall 1992, Iremonger 1990, Peters and Ohkubo 1990, Swaine 1992).

These three methods can record cover as a function of height above the ground, if the sampling is done carefully enough. When the data are summarized in bar graphs, such as the ones in Figure 9-9, striking differences between vegetation types become apparent. The eastern deciduous forest is seen to be composed of four canopy layers, with the most cover being contributed by the overstory tree layer. In contrast, the boreal forest has three canopy layers, with the trees and ground (herbaceous) layers providing nearly continuous cover.

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**The Point Method**

If a quadrat is reduced to no dimension, it becomes an infinitely small point. In practice, metal pins with sharp tips serve as the points, and cover is equal to the fraction of total pins that touch any plant part as the pin is lowered. Typically the pins are arranged in frames that rigidly limit the pin to a vertical path perpendicular to the ground (Figure 9-10). The frame may be located at several random places in a stand, and one to ten pins can be lowered at each place. For the best precision of estimated cover, lowering only one pin at each place is better than lowering several (Goodall 1957). To measure cover up to 1.5 m tall, modifications in frame construction permit rapid placement of as many as 100 pins and projection of pins upward as well as downward (Baker and Thomas 1983, Taha et al. 1983).

As the pin is lowered, the first plant it touches is recorded, then the pin is lowered more until it touches another leaf (of the same or a different plant than the first touch), and so on until bare ground is reached. If no plant is hit, then the point is tallied as bare ground. These data permit two calculations. One is percent cover:

$$\% \text{ cover} = \frac{\text{no. of pins that hit species A at least once}}{\text{total no. of pins}} \times 100$$

The other calculation is percent of sward, which weights each species by its canopy thickness, or cover repetition, at each point:

$$\% \text{ sward} = \frac{\text{no. of contacts with species A}}{\text{total no. of contacts}} \times 100$$
Figure 9-8  Bisects of tropical rain forest. (a) Trinidad, British West Indies. (b) Borneo. Both bisects represent all woody vegetation within a strip 61 m long and 7.6 m wide. (a) From Beard (1946). By permission of the British Ecological Society. (b) From Richards (1936). By permission of the British Ecological Society.
Disadvantages of the point method are that density cannot be measured (although cover frequency can), and the method is limited to low vegetation, such as grassland, for obvious reasons. But for measuring cover of low vegetation, it may be the most trustworthy and objective method available (Goodall 1957). Modifica-
tions of the method have included decisions to drop the pins at some angle, rather than perpendicular to the ground (vertical pins tend to weight broad-leaved herbs more than grasses); to nest the pins in a circular arrangement rather than a linear one (Baker and Thomas 1983); to insert pins upside down so that they can be used to touch shrub cover above the point frame, in addition to herb cover beneath it (Floyd and Anderson 1982); and to refine the diameter of the sample point by replacing the pins with sighting devices that use crosshairs (Bonham 1989) or a laser beam deflected by a mirror (Eek and Zobel 1997).

**Distance Methods**

**Distance methods** do not use quadrats, lines, or point frames. Only distances (from a random point to the nearest plant, or from plant to plant) are tallied. Average distance, multiplied by an empirically determined correction factor, becomes density. The basic distance methods were developed by Grant Cottam and John Curtis at the University of Wisconsin in the 1950s and were tested and refined on maps of real and artificial forest vegetation. The five methods briefly described here have been best summarized and compared by Cottam and Curtis (1956), Lindsey et al. (1958), Mueller-Dombois and Ellenberg (1974), and Bonham (1989). Four methods are illustrated in Figure 9-11. These methods have been used with many different types of plants, but most often with trees.
**Nearest Individual Method**

Random or regular points are located in a stand. At each point, the distance to the nearest tree of any species is recorded, the species is identified, and its basal area is measured. Only one measurement is made from each random point. All distances for all species are summed and divided to yield one average distance. Density per hectare \( (10,000 \text{ m}^2) \) for all trees is then

\[
\text{Density} = \frac{10,000}{2 \text{ (average distance, in meters)}^2}
\]
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(If distance is measured in feet, then the numerator is 43,560, the number of square feet in an acre.) The 2 in the denominator is a constant correction factor. Absolute density of each species is

$$\text{Absolute density of species A} = \frac{\text{no. of trees of species A encountered}}{\text{no. of all trees encountered}} \times \frac{\text{density for all trees}}{\text{trees encountered}}$$

Cover or dominance of each species can then be calculated as its relative density times its average basal area.

Point-Centered Quarter Method

Again, random or regular points are located. The area around each point is divided into four 90° quarters of the compass, and the nearest tree in each quarter is sought. Each tree is identified, its basal area is measured, and its distance from the random point is measured. Again, average distance for all trees taken together is computed, and this is converted to total density by the formula given for the nearest individual method, except that the correction factor vanishes. (The correction factor is 1, not 2.) Because more information is gained at each point than in the nearest individual method, the point-centered quarter method is more efficient, requiring one-fourth the number of points to achieve the same level of accuracy and precision. This method has also been used in grasslands (Dix 1961, Risser and Zedler 1968).

Problems with accuracy for the point-centered quarter (PCQ) method revolve around steepness of the terrain and nonrandom dispersion of trees. The distance measured from point to tree must be along a horizontal surface; if instead the distance is measured parallel to steeply sloping ground, it will be greater than the true (horizontal) distance and tree density will be underestimated. If trees are clumped rather than random, the PCQ method underestimates density; if trees are regularly distributed, PCQ will overestimate density (Bonham 1989, Mueller-Dombois and Ellenberg 1974). Consequently, a test for random tree dispersion should be conducted wherever the PCQ method is used (Ludwig and Reynolds 1968).

An alternative distance method specifically for use with clumped populations is the wandering quarter method (Figure 9-12; Catana 1963, Bonham 1989). A transect is taken along a compass line, and at the first point the distance to the nearest tree within a 90° quadrant (bisected by the compass line) is measured. From that tree a new line parallel to the original is erected, a 90° quadrant is established, and again the distance to the nearest tree is measured, and so on. Several transects per forest stand are recommended. Ultimately, the distance data can be analyzed to reveal mean clump radius, mean distance between clumps, and overall tree density.

A thorough comparison of these and other distance methods was conducted by Richard Engeman and others (1994). They concluded that the most accurate, efficient, and computationally straightforward method is a modification of the
nearest individual method, where up to three individuals are measured: the nearest, next nearest, and second next nearest. They reported that the PCQ method required too much time in the field determining the boundaries of each quarter.

Nearest Neighbor Method

Random or regular points are located in a stand, and the nearest plant is located. The distance measured in this case is from that plant to its nearest neighbor (of any species). Total density is calculated as for the nearest individual method,
except that the correction factor is 1.67. This nearest neighbor method has also been used to determine whether trees of the same species are distributed at random, are clumped, or are regular (Clark and Evans 1954, Pielou 1961).

**Random Pairs Method**

In the random pairs method, the nearest plant to a point is located. A line from point to plant is imagined. Perpendicular to the line and passing through the point is an exclusion line. In Figure 9-11d, the exclusion line happens to correspond with the transect. A nearest neighbor is now searched for, but it cannot be on the same side of this exclusion line as the first tree. The constant correction factor in the density formula is 0.8.

**Bitterlich Variable Plot Method**

A final distance method can be used to calculate basal area only, but basal area is important in calculating board feet of lumber, and the method is extremely fast and has been widely adopted by foresters. It yields more reliable data for less field time than quadrat methods or other distance methods (Lindsey et al. 1958). The method is named after its German inventor (see Grosenbaugh 1952), who originally used a sighting stick 100 cm long with a crosspiece at one end that was 1.4 cm across (Figure 9-13a). The stick was held horizontally with the plain end at one eye, and the viewer would slowly turn in a complete circle. Every tree whose trunk was seen in the line of sight on the circuit was tallied and identified as to species if its trunk appeared to exceed the width of the crosspiece; all other trees were ignored. Using a stick of these dimensions, and based on geometric principles, the total basal area in m² ha⁻¹ for any species is equivalent to the number of trees of that species tallied, divided by 2. (If English units are preferred, then a stick 33 inches long with a crosspiece 1 inch across will give basal area in ft² acre⁻¹ if the trees tallied are multiplied by 10.)

As shown in Figure 9-13b, an angle is being projected—an angle whose size depends on the relative lengths of the stick and the crosspiece. For example, the 33 inches × 1 inch arrangement produces an angle of 1°45' and an English units basal area factor (BAF) of 10. BAF is the number that is multiplied by the number of tallies to obtain basal area (in ft² acre⁻¹). If the angle becomes smaller, more trees will be tallied and the BAF will become smaller; for example, an angle of 0°33' has an English units BAF of 1. If the angle becomes larger, then fewer trees are tallied and the BAF will become larger; this is useful in a dense forest to avoid miscalculating. In the United States, angles that give BAFs of 5–20 are commonly used.

More recently, small hand held prisms or sophisticated viewing scopes have replaced sighting sticks (Figure 9-13c). Looking both through and over the top of a prism, the lower trunk will appear to be offset partially or completely from the upper trunk; if it is not completely offset, the tree is tallied.

Note that plot size is variable in this method. Plot radius is not fixed but extends as far as the largest tree with an apparent diameter big enough to be tallied.
Figure 9-13  The Bitterlich variable plot method for calculation of basal area. (a) The original Bitterlich stick sighting device. This particular one will give total basal area in square feet per acre if the number of trees tallied is multiplied by 10. (b) A bird's-eye view of trees that would be tallied as an observer at the center point turns in a complete circle. Trunk X (shaded) is tallied because its trunk diameter exceeds the angle projected by the sighting device, but trees Y and Z (not shaded) are not tallied. In one complete circle, the observer would tally four trees (all shaded). (c) The prism type of sighting device. In this case, the lower trunk is not completely displaced from the upper trunk, therefore the tree would be tallied.
A rather complete analysis of the geometric rationale at the base of this method has been compiled by Dilworth and Bell (1978). The method has also been applied to shrubland (Cooper 1957).

Summary

A major objective of vegetation scientists is to complete an inventory of the earth's plant resources—not an inventory of individual species, but an inventory of communities and vegetation types. The results of such an inventory have application to applied and basic science and to autecology as well, for the environment of a plant includes adjacent organisms as well as the physical factors of climate and soil. The inventory is far from complete because of limitations in researchers, scientific interest, and accessibility of some areas. Conclusions will have to be based on samples representing 1% or less of the earth's surface vegetation. If the estimates are to be accurate and precise, the samples must be chosen carefully. This chapter described procedures for choosing and measuring those samples.

The relevé method uses a more subjective choice of sample locations than any other mentioned, but the process of recording data is relatively rapid and non-mathematical, and its widespread use in the non-English-speaking world makes it an attractive sampling method. Each stand is represented by one large quadrat, whose size must meet minimal area requirements. Data are recorded by cover class. Important synthetic values are presence and constance.

Quadrat methods involve fewer subjective decisions than the relevé method. Questions that have to do with the size, shape, number, and placement of quadrats are time-consuming to answer, and there is no one best solution to them. A statistical level of confidence can be applied only to data from random quadrats. Such data can include absolute and relative cover, density, frequency, and biomass. Generally, these four measurements are unrelated. (If plants are distributed randomly, density and frequency are related, but plants are usually not distributed randomly.) Cover may be the most meaningful of the four. It can be estimated as actual crown cover, but for trees it is assumed to correlate with trunk basal area. Cover and basal area are both aspects of size. Frequency is the most artificial of the four, being highly dependent on quadrat size.

Two synthetic values from quadrat data are dominance and importance. A single definition of dominance has not yet been accepted. Most often, however, dominance is related to the cover of overstory species, but in some cases density is also considered. Typically, importance is a summation of relative cover or basal area, density, and frequency, but the summation may involve one more or one less component, and it can be expressed as a phytograph.

Restricted random quadrat placement is generally preferred over complete random. Gradsect sampling is a combination of subjective and restricted random quadrat placement.

The line intercept sampling method reduces quadrats to a single dimension;
consequently, only cover can be measured. Line intercepts may be combined with quadrats, as in strip transect and bisect methods. The point method reduces quadrats to no dimension; it is most useful for estimating cover in short vegetation types.

Distance methods measure distances from random points to nearest plants or distances between plants. The data can be converted to plant density, and in some cases the data can reveal whether plants are randomly or nonrandomly distributed. The most efficient distance method is the nearest individual method. The Bitterlich variable plot method was treated as a distance method, even though distances are not measured, because the geometric assumptions behind it relate to distance from observer to tree and to tree diameter.