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INTRODUCTION

WHAT IS THE UTILITY of vegetation measurements for wildlife managers? In the prairie, savanna, tundra, forest, steppe, and wetland regions of the world, mixtures of plant species provide wildlife with food, cover, and in some circumstances, water; the 3 essential habitat elements necessary to sustain viable wildlife populations. **Habitat** refers to use of a vegetation type by an animal (e.g., deer habitat), and **vegetation type** refers to differences in vegetation stands (e.g., marsh vegetation type versus tall grass prairie vegetation type; Hall et al. 1997). The variety of wildlife using plants ranges from snails and voles to bison (*Bison bison*) and elephants (*Loxodonta* spp.) in uplands and from mosquitoes and ducks to muskrats (*Ondatra zibethicus*) and manatees (*Trichechus manatus*) in wetlands. Through evolutionary processes, some wildlife species are totally dependent on vegetation for all annual life requirements, whereas other species use vegetation only for cover or food. Regardless of the role of vegetation in the sustenance of wildlife, any management or research project that requires evaluation of wildlife and vegetation type relationships on a unit of land will necessitate some form of vegetation measurement.

The term **vegetation** can refer to a single plant or species on a specific site or a community in the landscape. Vegetation may occur naturally or be introduced, and it may be live or dead. Uses of vegetation measurements are many: (1) evaluation of vegetation response to management, (2) estimation of carrying capacity, (3) characterization of cover and habitat components for an endangered species, or (4) long-term monitoring of the general trend of plant vigor or vegetation type condition.

Surveying and measuring **quantity** and **quality** of vegetation in habitats are basic to wildlife research and management. Grassland, shrubland, and woodland vegetation types are comprised of populations in which individual plants are usually too numerous to inventory completely. Consequently, wildlife biologists usually use sampling techniques to make inferences about the total plant population in a given vegetation type.

Vegetation sampling methodologies have evolved in several ecological disciplines (e.g., plant ecology, forestry, and range science) and for a variety of management or research objectives (e.g., estimating forage for ungulates and describing habitat use by passerine birds). Description of every method that has been used to sample vegetation is beyond the scope of this chapter. We describe how to measure **vegetation structure,** which Dansereau (1957) defined as the spatial organization (distribution) of individuals that form a stand. We have organized this chapter into

a description of basic methods of vegetation sampling, with examples of how those methods have been applied or modified in wildlife research and management. We assume the investigator has adequate knowledge of the concepts of wildlife ecology, primary habitat requirements of wildlife species under study, and ability to systematically identify the species of wildlife and vascular plants in the geographic area of the investigation.

INITIAL STEPS IN SAMPLING VEGETATION

Development of Objectives

The critical element of any project, whether management or research, is **defining objectives.** Data should not be collected if a project has neither an objective for vegetative measurements nor a defined use for each type of measurement. Collecting vegetation data is time consuming and often difficult, and that time should be used to meet well-defined objectives. It is important to review management or research plans to ensure the information being collected fulfills the objectives and that critical information is not neglected.

Objectives must be specific. They should include what will be sampled, when it will be sampled, and where it will be sampled. Although these factors often are taken for granted, their identification requires the investigator to make a thorough analysis of the biology of the wildlife species to be studied, factors that relate to the study, and management or research needs. Elzinga et al. (1998) elaborate on components of vegetation sampling objectives and provide examples of effective measurement objectives.

General Aspects of Vegetation

After listing the objectives of the study and primary habitat requirements of the wildlife species under study, one then may identify which aspects of the vegetation to sample. Some or all of the following may be important in describing primary wildlife habitat requirements:

1. species composition,
2. vertical and/or horizontal spatial distribution,
3. temporal variation in structure,
4. biomass,
5. overall stand structure, and
6. surrounding environment (landscape structure).

A **reconnaissance survey** of an area is usually sufficient to provide the investigator with an overview of vegetation structure. Reconnaissance can be done on the ground or with aerial photography. In either instance, the objective of a preliminary survey is to decide **whether** to sample, identify **what** to sample, and determine which environmental factors will influence **how** and **when** to sample.

Consider the following example. Suppose the goal of a study is to inventory potential natural nesting sites for wood ducks (*Aix sponsa*). The wood duck nests only in cavities in trees. Because nesting cavities within a reasonable distance of water are a primary habitat requirement of wood ducks, 3 objectives are to

1. quantify the number of wood duck nesting cavities,
2. identify the species of trees containing the cavities, and
3. calculate the age-distribution of trees with cavities.

Assume that a reconnaissance survey has revealed the study area is a riparian system with a permanent stream, riparian vegetation bordering the stream, and farmland bordering the riparian vegetation. Because wood ducks nest in trees, one would not sample the area with crops, but would sample the riparian vegetation. A sample would be designed to randomly select a number of trees for examination. The objectives require identifying the species of trees in which wood duck cavities occur. Because we are interested in estimating the number of potential nest cavities, our sample will need to provide an estimate of tree density, one aspect of horizontal spatial distribution. We are not, however, interested in heights of cavities; thus, vertical distribution will not be of interest. Cavities often are present in older and larger trees and in dead trees, and the age distribution of trees is important. In addition, dead trees are likely to be blown over in windstorms, and we may decide to mark cavity trees and follow them over time to measure the rate of loss. Biomass of trees is not of interest; however, if a mast crop is produced by the trees, we would be interested in biomass of mast, a food item of wood ducks.

Study Site Selection

Study site selection is a critical phase of any vegetation study and is directly related to the objectives. If the objective is to describe vegetation conditions in relation to patterns of animal distribution or abundance, location of vegetation plots may be influenced by locations of animal observations or by wildlife population sampling objectives. If the objective is to describe vegetation conditions of selected habitats, the first issue is to define the targeted sample population and develop an appropriate sampling frame, following sampling principles described by Garton et al. (2005). Elzinga et al. (1998) provide a thorough overview of the step-by-step procedures for vegetation surveys.

A variety of factors influence selection of study sites (e.g., topography, elevation, slope, aspect, soil type, management history, distance to human-caused disturbances, and vegetation). Generally, one is interested in selecting sites that are similar to one another, and care must be taken to select sites so the intersite variation is natural and not affected by some factor not accounted for in the objectives and design of the study. This step may require **mapping** of the project area, so that all vegetation types, their locations, and their sizes are enumerated. The objectives may require that samples be

taken in all or in only several sites containing a certain habitat type.

The size of the study site must be sufficiently large, so that vegetation characteristics being measured are not influenced by adjacent habitat types (often called **edge effect**). Edge effect may increase the variation in the sample. Unless such variation is explained by the sampling design (Garton et al. 2005), the results of the sample will be biased with regard to the objectives of the study. For example, if one were to sample browse production in a 100-ha stand of upland willow (*Salix* spp.), one would avoid sampling adjacent to the edge of a vegetation type that offered resting cover for moose (*Alces alces*), because those plants measured in close proximity of resting cover likely would have higher use (and perhaps lower levels of production) than plants measured in the middle of the willow stand.

Visualizing how vegetation sampling plots, or plots along a transect, will appear in field applications can be difficult. Many layout designs are possible (Figs. 16.1–16.3), and the final choice of a design also will depend on the objectives and requirements of the statistical analysis. For those not familiar with statistical principles of sampling, it is important to consult a biometrician before committing project resources to vegetation sampling.

PREPARATIONS AND GETTING STARTED

Leadership

Vegetation sampling is time consuming and demanding (Table 16.1). Good **leadership** is essential to maintaining enthusiasm and quality of data collection. The principal investigator can demonstrate leadership by (1) being enthusiastic and knowledgeable about the study area, research design, equipment, plant identification, and data collection; (2) being organized and efficient during all aspects of vegetation sampling; (3) explaining to other team members how the data will be used to make decisions on resource management; and (4) doing his or her share of the data collection. The principal investigator also should listen to suggestions from team members. They often have ideas that make data collection more efficient. Explaining the entire project, answering questions, and incorporating appropriate sugges-

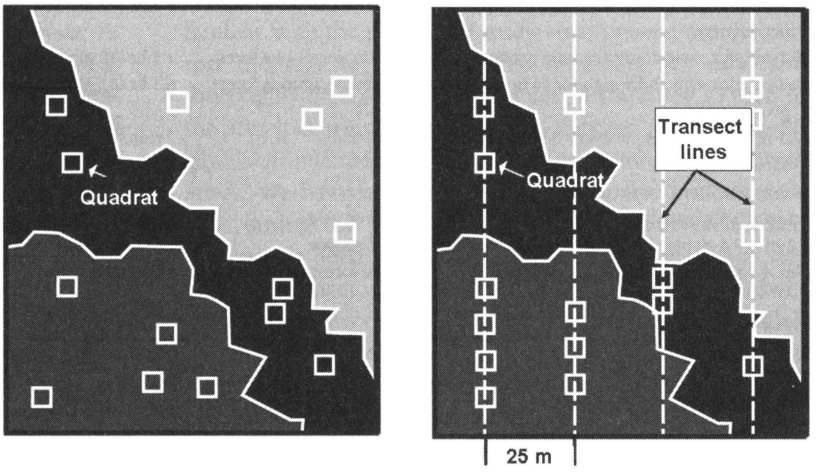

Fig. 16.1. Random (left) and systematic (right) distribution of quadrats with and without use of transect lines on a site with 3 different vegetative cover types.

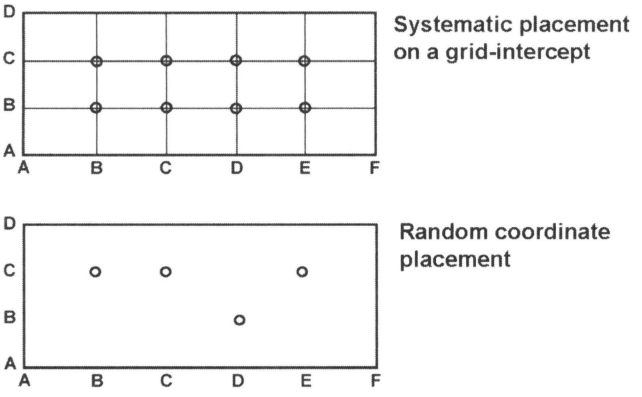

Fig. 16.2. Systematic and random placement of quadrats with grid coordinates.

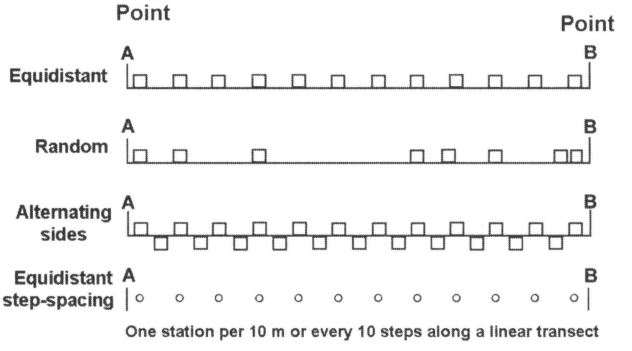

Fig. 16.3. Examples of patterns of quadrat placement along permanent transect lines.

Table 16.1. Representative times to complete a transect or a number of plots for different vegetative sampling techniques in various habitats or for different purposes. The numbers are relative, so they may not apply to a specific project; however, they should help the investigator during initial planning. The times were derived from published literature, personal communication, and personal experience.

Sampling technique	Vegetation type	Estimated time[a]	Number[b]	Reference
Grassland				
30.5-m transect, line intercept method for basal area		1.8–2.5 hr/transect[c]		Johnston 1957
30.5-m transect, point quadrat for basal area		0.5–0.8 hr/transect[c]		Johnston 1957
30.5-m transect, loop method for basal area		0.3–0.4 hr/transect[c]		Johnston 1957
0.30-m^2 clipped plots	California annual grasses	7 min/plot		Reppert et al. 1962
2.9-m^2 circular plots, clipped all species	Southeastern U.S.	32 min/plot, one person		Hilmon 1959
Single-point basal hit sampling	Tallgrass prairie	7 hr/3,000–4,000 points/3 persons	~25 ha	Owensby 1973
Foliage density readings (Robel et al. 1970)	Any grassland	8 hr/1,000 readings/2 persons	10 sites	J. M. Callow[d]
Nudds-board foliage density readings (Nudds 1977)	Any grassland	8 hr/100–200 readings/2 persons		L. D. Flake[d]
10-pin point frame (Smith 1959)	Mixed and tallgrass	8 hr/4,000–6,000 points/2 persons		L. L. Manske[d]
10-pin point frame (Smith 1959)	Wet meadow wetland	8 hr/2,000–3,000 points/2 persons		L. L. Manske[d]
Shrubs				
Shrub dimension/production estimates	Boreal forest	2 hr/25 plants/2 persons		Peek 1970
3-m × 5-m clipped plots	Boreal forest	24.7 hr/17 plots[c]		Bobek and Bergstrom 1978
Height × diameter measurements in 3-m × 5-m plots	Boreal forest	2.3 hr/21 plots[c]		Bobek and Bergstrom 1978
Clipped plots	Southern forest	10–50 plots/2 person-days	28–158/site	Harlow 1977
Twig length method to measure browse use	Montane shrub	50 min/50 plants/2 persons	50/site	Jensen and Scotter 1977
30.5-m^2 plot, weight estimation for twig production	Eastern deciduous forest	1.5 hr/41 plots/2 persons		Shafer 1963
30.5-m^2 plot, twig count for twig production	Eastern deciduous forest	1.5 hr/39 plots/2 persons		Shafer 1963
30.5-m^2 plot, clip and weigh for twig production	Eastern deciduous forest	6.5 hr/37 plots/2 persons		Shafer 1963
30.5-m transect, sample every 0.30 m for shrub cover	Chaparral	7 min/transect[c]	4–26/site	Heady et al. 1959
30.5-m line intercept for shrub cover	Chaparral	16 min/transect[c]	9–13/site	Heady et al. 1959
0.1-m × 0.5-m quadrats for shrub cover	Shrub steppe	15–30 min/80 quadrats/2 persons		Hanley 1978
1.2-m × 7.6-m plot for shrub cover mapping	Shrub steppe	12 plots/day/2 persons		Pickford and Stewart 1935
1-m × 5-m quadrats for shrub density	Boreal forest (postburn)	50 quadrats/day[c]		Oldemeyer and Regelin 1980
Trees				
0.1-ha circular plots	Upland forest	10–15/day[c]	5–20/site	Lindsey et al. 1958, James and Shugart 1970
Point-centered quarter method	Upland forest	20–50/day	10–50/site	Lindsey et al. 1958, James and Shugart 1970
Bitterlich variable radius sampling	Upland forest	40–75/day[c]	10–50/site	Lindsey et al. 1958, James and Shugart 1970
Camera on stick to analyze cover from 33-mm slides	Grassland	36 scanned images in 2.5 hours		Bennett et al. 2000
Visual obstruction readings	Grassland	20 stations/transect in 25 minutes		Benkobi et al. 2000
Clipped quadrats	Grassland	6 (0.25-m^2 circular) in 45 minutes		Benkobi et al. 2000

[a] Estimated time necessary to complete a plot, a practicable number of sample plots, or a transect by 1–3 persons.

[b] Minimum number or range of plots usually necessary to characterize the community's vegetative structure.

[c] One or two persons were used to collect data in specified time.

[d] Personal communication; J. M. Callow is biologist with U.S. Fish and Wildlife Service, Woodworth, North Dakota; L. D. Flake was former biologist with South Dakota Fish and Game Department; and L. L. Manske is with North Dakota State University, Dickinson.

tions will make team members feel they are an integral part of the project (and they are!).

Initial Planning and Preparation

Considerable **office preparation** is required before the team goes into the field to conduct a vegetation study. The development of a **list of supplies** and equipment necessary to complete the task (Table 16.2) is an important first step. Equipment lists will vary, depending on sampling objectives and whether sampling is in grasslands, wetlands, shrublands, or woodlands. These lists should be all-inclusive and should include everything from the number of pencils, color of data sheets and plot markers, and size and shape of the sampling frame to calipers, photometers, seed traps, and field vehicles.

Data Forms

Develop **forms** for recording the field data. Major advances have been made with entry of field data directly into laptop computers at the time of sampling. Remember to electronically download and store information daily and backup digital data to avoid costly loss of information. Alternately, field data forms can be developed to facilitate simple mathematical analysis with conventional calculators or entry onto a personal computer for detailed and complex analysis. In either situation, a set of instruction codes defining what is represented by each number or letter entry should accompany each field data form. Team members must understand the meaning of **zeros** and **blank spaces.** Although a blank space usually means no value was available to measure or no attempt was made to make a measurement, we have found that a hash mark rather than a blank space reduces confusion about whether the blanks were accidental or intentional. We suggest use of different color forms for different sampling tasks to aid organization and recording efficiency. For example, one color might be used for sampling shrub density and another for herbaceous cover when both were measured at a site and required use of 2 different sampling techniques. White paper reflects direct sunlight, and the investigator may want to use colored paper to reduce eyestrain. Waterproof or water-legible paper is more convenient and reliable than regular bond in regions with frequent rainfall or snow.

Table 16.2. Supplies and equipment needed in the field for vegetation sampling

Data forms and notebooks	Camera and film or digital camera
Pencils and ink pens	Hammer, hatchet, and knife
Rulers and tape measures	Transect markers
Plant identification guides	Shovel and hand trowel
Plant press	Global Positioning System unit
Tags and plastic bags	Metal tags and wire
Quadrat frames	Sunscreen lotion
Cover board or poles	Insect repellent
Point frame	Hand gloves
Hand magnifying lens	Backpack on frame
Maps and aerial photos	Compass
Laptop computer or data logger	Batteries and chargers

Preliminary Field Test

It is important and useful to conduct a small-scale preliminary **field test** of a site before initiating full-scale sampling with the entire team. This field test provides the investigator with an opportunity to identify and collect plants for field mounts (Burleson 1975) for technician use, evaluate and test equipment and sampling methods, evaluate and adjust experimental design, and make final estimates of the time required to complete the work. Many research projects and surveys that were designed in the office have been completely abandoned after the first day of fieldwork, because the investigator failed to test the procedures and equipment under field conditions.

Training the Field Crew

An important step to maximize field efficiency is to properly **train** field assistants. Field assistants should have a thorough understanding of the safe and proper use of equipment, be familiar with the plants and study area, understand the correct methods for collecting and recording the data, and thoroughly understand the rationale of the study so that, in the principal investigator's absence, they can make an intelligent and informed decision when an unforeseen situation arises. We have found that several questions and concerns arise during the first week of data collection even when the crew is adequately trained. We suggest that each day end with a short meeting of the entire field crew to answer questions, inspect data forms for completeness and legibility, and discuss problems encountered in collecting data. We suggest that experienced members be teamed with those less experienced and that membership rotate daily if the field crew is divided into smaller teams for collecting data. Daily rotation of field teams increases the number of questions that arise early in the project, and the prompt settlement of problems results in more uniform collection of data and builds better rapport among crew members.

The principal investigator or field team leader is responsible for quality control of the project. We recommend the principal investigator spend at least one day working with each crew member early in the field season. This practice provides the opportunity to discuss the project more fully, provide assistance and guidance in field methodologies, demonstrate enthusiasm about the project, and learn more about the background and interests of the individual crew members. These recommendations all contribute to building a quality field team and improving the quality of data collected. An important point is to make sure all crew mem-

bers have a personal stake in the quality of data collected. Emphasize creating a sense of ownership in the outcome of the project.

TECHNIQUES FOR SAMPLING VEGETATION

Frequency of Occurrence

Frequency is the proportion of sample units in which a species occurs (Bonham 1989). If, for example, 50 small plots were examined in a study site and bitterbrush (*Purshia tridentata*) occurred in 20 of those plots, the frequency of bitterbrush would be $20/50 \times 100$, or 40%. Frequency is an easy attribute to estimate, because the plant either occurs in the sample unit or it does not (Fig. 16.4). Frequency is a useful characteristic for describing distribution of plants in a community, and it is a measure that is related to plant density (Mueller-Dombois and Ellenberg 1974). It also is useful for monitoring changes in the plant community over time or comparing different communities (Bonham 1989). If frequency is low (15%), plants have an **aggregated distribution** (occur in clumps) in the community. When frequency is high (>90%), plants are **uniformly distributed.** Most statistical procedures rely on plants being **randomly distributed,** (i.e., having a frequency of 63–86%; Bonham 1989:92). Wild plants generally have an aggregated distribution that is related to the morphological characteristics of the species in the community, the extent and nature of competitive interaction among individuals and species, and environmental patterns (e.g., differences in soil characteristics, fire history, or herbivory; West 1989). Thus, each species may have its own distributional pattern, and the pattern of the plant community may be different from those of component species. Sampling methods to deal with complex plant distribution patterns are not adequately developed (West 1989). In an attempt to identify a best method for sampling complex communities, Etchberger and Krausman (1997) evaluated 5 methods for measuring plant species occurrence in complex desert vegetation communities, where they had a complete census of the vegetation. They found that using a **line-intercept** method, whereby the plants that intercept the line are counted as hits rather than measuring the length of vegetation canopy intercepting the line, most closely estimated the true vegetation census.

Frequency varies with size and shape of the sample unit when compared over time or among communities. Consequently, sample unit size and shape must remain constant, because it is difficult, if not impossible, to compare frequency data among sampling sites when different sizes and shapes of quadrats have been used. The size and shape of the sample unit is a function of whether one is sampling herbaceous vegetation, shrubs, or trees. Cain and Castro (1959:146) recommended **sample unit sizes** for herbaceous vegetation (1–2 m^2), tall herbs and low shrubs (4 m^2), tall shrubs and low trees (10 m^2), and trees (100 m^2)

When the total vegetation of a community is sampled, one size of sample unit will not adequately sample frequency for each form of vegetation. The mean frequency of the several species in a given vegetation form should not be 5% or >95% (Hyder et al. 1965). Nesting plots of different sizes within each other can solve this problem. Preliminary surveys of vegetation may be made using the size recommendations of Cain and Castro (1959). Further refinements of sample unit size may then be made by use of the relationship between density and frequency suggested by Hyder et al. (1965).

Plots may be square, rectangular, or round. Ordinarily, plot boundaries are either marked or measured to size with a ruler or tape measure, or they are defined by the inside dimensions of a frame (Fig 16.4). Frames may be of permanent shape and made of welded steel rod or some other rigid material, or they may be collapsible and made with hinged wood products or jointed polyvinyl chloride (PVC)

Fig. 16.4. Color demarcation and subplot frame attachments (bottom) also are used to provide quick representation of percentage of frame coverage by vegetation.

pipe. Collapsible frames are useful when they enhance efficiency of placement on the ground or travel to remote areas that are inaccessible to vehicle use. We have found that frames with one open end are useful for placing the plot around shrubs or other obstructions in shrubby terrain.

Frequency also may be measured with **points.** A pin (knitting needle or pointed, small-diameter steel rod) is lowered to the ground over herbaceous cover and will either hit or miss a plant part (Fig. 16.5). The percentage of hits gives an estimate of the frequency of a species. A single pin may be used to measure frequency (or cover; Owensby 1973), or commonly, a frame containing several (usually 10) pins is used, and pins may be positioned vertically or at an inclined angle. Spacing of the pins in the frame is dependent on the vegetative type, but it is commonly 4–15 cm (Hays et al. 1981). Although the **point frame** can be placed in random locations, pins are usually spaced systematically. Single point sampling is self-descriptive. Cook and Stubbendieck (1986) provided useful suggestions for making a 10-pin frame. Along a 10-pin frame (Fig. 16.5), the same plant may be intercepted more than once in communities with large or clumped plants. This duplication can result in overestimates of cover for those species (Bonham 1989).

Sample size is a consideration when frequency is estimated. Frequency data have a **binomial distribution,** and confidence limits are wide for small samples. Grieg-Smith (1964:39) recommended that >100 sample units be read to obtain estimates that provide reliable comparisons from one community to another or over time. With a 10-point frame, data from 1,000 (100 frames) points (hits) are usually sufficient to describe grassland vegetation at one location, whereas fewer points (200–500; 20–50 frames) usually will provide data similar to those from a single-point method (Goodall 1952).

Density

Density is the total number of objects (e.g., individual plants or seeds) per unit area. One advantage of the density parameter is that **count data** are straightforward to obtain and interpret, and results obtained from different methods are directly comparable (Gysel and Lyon 1980). A disadvantage of measuring shrub density is that data are tedious to obtain and often are excessively variable. Such variability requires an often prohibitively large sample size for statistical reliability. Density is a useful and often important measurement for evaluation of wildlife habitat for bunchgrasses, annual grasses and forbs, some shrubs, and trees. However, by itself, density is not an adequate descriptor of a plant community, because it does not provide information about how plants are distributed in the community. Combined with frequency, density provides a good description of a plant community. Combined with biomass of individual plants, density may provide estimates of total biomass in a plant community.

Fig. 16.5. An inclined 10-pin frame for frequency estimates.

The definition of an individual plant poses a problem when density is sampled. For perennial grasses and forbs, and shrubs that produce several stems from below ground, definition of an individual plant may be impossible or not sufficiently important to warrant the effort or the potential error. However, individual plant identity may be necessary in studies of plant succession, whereas counting the number of stems, etc., may be sufficient when the objective is to quantify cover or food availability. In these situations, frequency combined with some other measurement, such as cover, may provide more useful descriptions of the plant community. For shrubs, the problem is best resolved either by counting stems at ground level, thereby eliminating the need to define an individual shrub, or by establishing a distance criterion to define individuals arbitrarily. For example, Lyon (1968*a*) considered stems rooted ≤15 cm of one another to represent a single shrub, whereas those sprouting ≥15 cm apart were counted as separate individuals.

Quadrat Methods

Density can be measured with either **quadrats** or **plotless** methods. Quadrats are frames made of materials with fixed boundaries and are placed over vegetation to demarcate an area in which plants are counted, whereas plotless methods make use of ocular estimates. If quadrats are used, the investigator must distribute quadrats of uniform size representatively throughout each experimental unit and then count each individual in each quadrat. Quadrats require that 3 characteristics be considered (Bonham 1989): (1) distribution of the plants, (2) size and shape of the quadrat, and (3) number of observations needed to obtain adequate estimates of frequency and density.

Sample frames typically are rectangular, square, or circular. **Rectangular plots** have the largest perimeter per unit area and hence the most edge, where decisions must be made about including or excluding a plant. **Circular quadrats** often are more efficient to use than square or rectangular

quadrats. Sampling in circular quadrats also is effective for characterizing the vicinity around a point of interest, such as a nest, a den location, or a feeding or resting site. A review of recent wildlife habitat studies reveals frequent use of circular quadrats, that are typically in the range of 0.01–0.1 ha (e.g., Hirst 1975, Pierce and Peek 1984, Ratti et al. 1984, Wiggers and Beasom 1986, DeGraaf and Chadwick 1987, Edge et al. 1987, Bentz and Woodard 1988). For these areas, the radius of a quadrat would range from 5.6 to 17.8 m. Increasing the size of a quadrat generally results in lower variance and reduces the perimeter:area ratio (Bonham 1989). Numerous studies have evaluated quadrat size, and no consistent recommendation has been made about the size to use for herbaceous vegetation, shrubs, or trees.

For herbaceous vegetation, 1-m × 1-m quadrats frequently are used (Bonham 1989). However, in dense vegetation, smaller quadrats, such as 20 cm × 50 cm, may be appropriate (Daubenmire 1959). Eddleman et al. (1964) compared quadrats of 4 sizes and several shapes in alpine vegetation. They recommended against using 100-cm^2 plots because of high standard deviations and highest frequencies of 50%. Even though plot sizes >400 cm^2 provided similar estimates of density, they favored 400-cm^2 rectangular plots, because the chance for counting error was reduced and fewer rectangular plots were required (compared to square plots of the same area) to obtain a 10% standard error of the mean.

Quadrats sufficiently large to contain an average of 4 individuals have been recommended in shrub communities (Curtis and McIntosh 1950, Cottam and Curtis 1956). Although quadrats as small as 1 m^2 have been used to measure shrub density (Alaback 1982), 4–10-m^2 plots are more commonly selected (Irwin and Peek 1979). Oldemeyer and Regelin (1980) recommended a 1-m × 5-m quadrat over a 2-m × 5-m quadrat in an Alaskan shrub community, because the smaller one provided nearly the same precision and required only one-half the sampling time as the larger quadrat. Rectangular plots have advantages over square and circular plots in aggregated shrub communities, because they have the greatest chance of overlapping individual clusters of shrubs. A rectangular quadrat 1-m wide of any length may be delineated easily by marking one long side of the rectangle with 2 chaining pins and a chain, and using a meter stick to define the remaining boundaries while one counts shrubs along the strip as the meter stick passes over them.

Quadrats must be quite large when trees are sampled, typically in the range of 0.01–0.1 ha. Curtis (1959) used square quadrats 10 m on a side (0.01 ha) in deciduous and coniferous forests of Wisconsin. Mueller-Dombois and Ellenberg (1974) concluded that forest quadrats typically should be squares of 10 m or 20 m on a side (0.01 ha or 0.04 ha). Quadrats can be positioned with tape measures or other measuring devices and surveyor's pins after sampling points are located. This measurement might require considerable time and effort in dense vegetation or in some types of terrain. To reduce that time, Penfound and Rice (1957) proposed using an elongated 0.0004-ha quadrat established by measuring the width of one's outstretched arms and then, knowing the average pace length, walking the appropriate number of paces along a compass line and recording the trees within reach. It is important to realize that, although this method is faster to implement under natural forest conditions, the area sampled is approximate, and accuracy is sacrificed without careful attention. Further, the advent of **laser rangefinders** now favors use of circular plots as an alternative, relatively quick method of estimating tree density. From any established plot center, the field biologist using a laser rangefinder may quickly estimate distances of trees from plot center. Thus, the biologist may quickly count all trees present within a predetermined fixed radius. The method has the added advantage of minimizing the perimeter:area ratio of the sample plot, but care must be exercised to ensure the laser rangefinder being used is both accurate and precise.

The **number of samples** measured varies from community to community and among the different vegetation forms in a community. Because many species are not randomly distributed, variation normally is quite high, and number of samples required is quite large. To calculate **sample size,** one can use results from the preliminary field test to obtain an estimate of the variance for use in the sample size equation (Garton et al. 2005). Frequently, less common species require a larger number of samples than do the more common species. For example, to obtain a 10% standard error of the mean in a 10-cm × 40-cm plot, Eddleman et al. (1964) concluded that 816 plots would be required for a species with a density of 0.13 (no area units given), whereas 69 plots would be required for a species with a density of 5.6. Oldemeyer and Regelin (1980) reported that 50 1-m × 5-m quadrats produced estimates of shrub density within 2 standard errors of actual (counted) shrub densities. Lyon (1968*a*), however, reported that >400 1.5-m × 6.1-m quadrat samples would be necessary to obtain an estimate of shrub density within 10% of the true mean 95% of the time. Sample sizes in the hundreds are not an uncommon result. As an alternative, one may plot the running mean density against the number of samples taken (Kershaw 1964). One may stop sampling when the density of the target, or more abundant, species does not significantly change with additional quadrats. Mueller-Dombois and Ellenberg (1974:77) suggested that sampling stop when the running mean of a sample is within 5–10% of a "maximum" sample. Clearly, one must critically evaluate the objectives of a project and the end product of the data when designing a study of plant density. It may not be necessary to have the density (or frequency or cover) estimate be within 5% of the true value; however, it is a waste of time and effort to undersample a community and obtain totally unreliable estimates.

Plotless Methods

Plotless methods of sampling density have been in use since the 1950s. These methods do not use boundaries and are based on the premise that density may be estimated from the mean area occupied per tree; that is, density (trees/m^2) = 1/mean area (m^2/tree). The challenge then becomes estimating the area occupied per tree from distance measurements that can be obtained in the field.

Cottam and associates (Cottam and Curtis 1949, 1956; Cottam et al. 1953) pioneered research on plotless methods. These methods included the **closest individual method, nearest-neighbor method, random-pairs method,** and **point-centered-quarter method.** Of these, the point-centered-quarter method has been widely used in many vegetation types throughout North America. Using this method, one randomly or systematically selects a number of points in a community and measures the distance to the nearest plant in each of 4 quadrants around the point (Fig. 16.6). Mean area is calculated by squaring the mean distance d between points and individual stems: density = $1/d^2$.

This method may be used to calculate density of all species collectively. Or, density of individual species can be estimated by measuring distances to each species in every quadrant around each point. A reliable estimate of an individual species' density cannot be obtained by using only those distances for an individual of the species that was the closest plant in a sample and the distance was measured to the nearest plant regardless of species. That is, if 25 points were sampled, and distances to 100 plants of several species were measured, the density of all plants can be estimated based on the 100 distances. The density of one of the several species from the sample cannot be estimated reliably, because the distance measured to the plant when it was the closest plant in a particular quadrant may not be the least distance when all plants of that species within the entire circle around the point are considered (e.g., species A in Fig. 16.6).

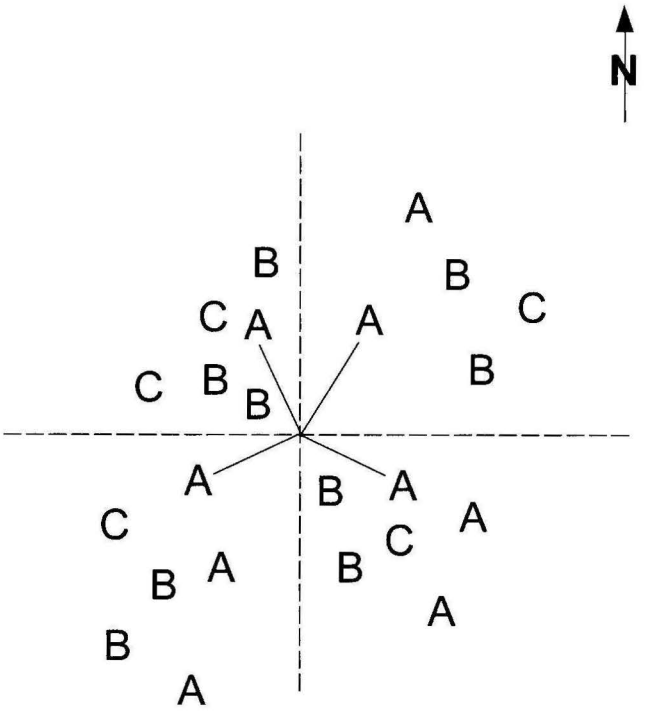

Fig. 16.6. Point-centered quadrat sampling: the point-to-plant distance is measured for the individual of each species nearest the point in each of the 90° quadrants around the point. Species A is being sampled in this figure.

The point-centered-quarter method has been criticized, because it provides reliable estimates of density only when plants are distributed randomly and not when plants are clumped or uniformly distributed. Studying stands of known density, Oldemeyer and Regelin (1980) concluded this method accurately estimated density of white spruce (*Picea glauca*) saplings, which were more randomly distributed, but underestimated density of paper birch (*Betula papyrifera*) and aspen (*Populus tremuloides*) saplings, which had clumped distributions. The point-centered-quarter method overestimates density in communities with regularly distributed plants (Mueller-Dombois and Ellenberg 1974). This method likely provides reliable estimates of density when total plant density in a community is the only concern. However, Laycock and Batcheler (1975) reported that evaluating composition from the proportion of times each species occurred in the total measurements resulted in biased composition estimates.

Methods have been developed to correct for density estimates in nonrandom plant populations (Morisita 1957, Batcheler 1973). The **angle-order method** (Morisita 1957) measures the distance from the point to the center of the third nearest plant in each quadrant around the point. This method is based on the assumption the area may be divided into several smaller units in which the plants will be distributed randomly or uniformly, even though they are distributed nonrandomly over the larger area. The method was tested on known populations of grasses, forbs, and shrubs (Laycock and Batcheler 1975, Oldemeyer and Regelin 1980) and provided estimates of density that were more accurate than those of the point-centered-quarter method. Oldemeyer and Regelin (1980) reported the method provided density estimates closest to the true density in shrub stands and that its coefficient of variation was lower than other accurate estimators. However, because of the time required, Laycock (1965) recommended against using the angle-order method when density is measured for each species in a community. Bonham (1989) provided a detailed description of the procedures for calculating density and the variance when the angle-order method is used.

The **corrected-point-distance** (Batcheler 1973) is a modification of the point-centered-quarter method that uses measurements to the second and third nearest plants to correct for nonrandomness. That is, from a sample point, one

measures the distance to the nearest plant, the distance from that plant to its nearest neighbor, and the distance from the nearest neighbor to its nearest neighbor, exclusive of the first plant measured. In aggregated populations, the distance between the nearest plant and its nearest neighbor is generally less than the distance from the point to the nearest plant. Density is calculated by the equation

$$m = \frac{a}{\pi[\Sigma r_i^2 + (N-1)R^2]},$$

where N is sample size or number of points used, m is density, R is the maximum distance over which a search is made for a plant at any point, a is the number of points at which a plant is found at a distance $\leq R$, and r_i is the ith distance measured. As R decreases, m approaches the true density; however, variance generally will increase, because fewer measurements are included (Bonham 1989). Although this equation is designed for random and nonrandom distributions, densities will be biased in nonrandom populations (Bonham 1989). This problem may be corrected by using a factor based on distances from the nearest plant to its nearest neighbor. Laycock and Batcheler (1975) recommended use of the corrected-point-distance method over other distance methods, because the density estimate was within 12% of the true density, and the method is relatively fast and easy to use.

Engeman et al. (1994) reviewed 24 plotless density estimators and compared the relative biases among methods in relation to simulated differences in plant aggregation patterns. These simulated results verified field results described above, indicating that when plant distributions are clumped, the point-centered-quarter method produces biased results compared to angle-order methods. The authors observe, however, the added effort of measuring several plants per quarter complicates the method and results in fewer sample points. Generally, for any fixed amount of effort, it is better to sample more independent points than to invest more effort at individual points. Based on this practical consideration and the evaluation of bias under simulated conditions, Engeman et al. (1994) recommend using ordered-distance (Morisita 1957, Pollard 1971) or variable area transect (Parker 1979) sampling methods for estimating density. The ordered-distance estimator involves measuring distance to the third closest tree to sampling points. The variable area transect involves measuring the distance along a fixed-width strip transect (generally, 1–2 m in most field applications) until the gth individual tree is encountered (usually, $g = 3$). The review paper by Engeman et al. (1994) or the original authors cited above should be consulted for the analytical formulas.

The choice of using a plotless method over a quadrat method will depend on the objectives of the study. If the density of 1 or 2 species is required, plotless methods appear to be faster than quadrat methods. If the density of all species in the community is desired, the quadrat method is recommended.

Cover

Cover is defined as the vertical projection of the crown or stem of a plant onto the ground surface. **Canopy cover** serves as a criterion for relative dominance in a community and is of practical importance because of its influence on interception of light or precipitation and on soil temperature (Hanley 1978). It may be used by plant ecologists to describe total vegetation cover, by range managers to define cover of forage for livestock, or by foresters to describe **basal area** of merchantable timber. Cover can be an estimator of biomass when height structure of a community is known. Daubenmire (1959) suggested that canopy cover is the surface area over which a plant has influence; thus, cover provided by seedlings and seed stalks might not be measured, because they have little influence in the ecosystem. Although canopy or crown cover may vary in a season or over years, basal cover is relatively stable. **Basal cover** is a reliable measurement for bunchgrasses, tussocks, and trees. Cover is frequently measured at a height of about 2 cm on bunchgrasses and tussocks (Bonham 1989:98), whereas on single-stemmed trees, it is measured at 1.5 m above ground (Mueller-Dombois and Ellenberg 1974:88). This latter measurement is referred to as **diameter at breast height** (DBH). Basal cover is measured at the ground surface on trees with multiple stems or on trees with buttressed trunks. Cover often is expressed as a percentage, and in a dense or multilayered community, total vegetation cover may exceed 100%. Cover can be measured directly with quadrat-charting (Gibbens and Beck 1988) or pantographic methods (Mueller-Dombois and Ellenberg 1974, Fehmi and Bartolome 2001), an ocular estimation technique (Daubenmire 1959, Mueller-Dombois and Ellenberg 1974), or line-intercept (Canfield 1941) and point-intercept methods (Levy and Madden 1933, Owensby 1973).

Quadrat-Charting Method

This method has its greatest utility in low herbaceous vegetation, where one can stand and look over the vegetation. Cover is mapped to scale on graph paper from a small quadrat (e.g., $1 m^2$). The idea is to map the crown area or the basal area onto the graph paper. This process may be facilitated by subdividing the larger quadrats into smaller ones. Quadrat charting is useful generally only in long-term studies, when quadrats are permanently marked at each corner and can be exactly relocated for each measurement (Gibbens and Beck 1988). Rather than charting indirectly from what the observer sees on the ground, the observer may use a pantograph (Mueller-Dombois and Ellenberg 1974) or take photographs (Wimbush et al. 1967).

Ocular Estimate Method

Ocular estimates of basal and canopy cover can be obtained with relative ease in grasslands because of their low profile and height. However, the task becomes more difficult in wetland vegetation because of the combination of water depth and plant height, often requiring use of scuba equipment or a ladder.

Cover can be estimated to the nearest percentage point, or to the nearest 5th or 10th percentile; however, most commonly it is estimated according to some form of cover class (Brown 1954, Daubenmire 1959, Braun-Blanquet et al. 1965, Mueller-Dombois and Ellenberg 1974, Floyd and Anderson 1987).

A cover-class scale (Box 16.1) often has been used in grasslands (Daubenmire 1959). Division of class range (%) is facilitated by painting lengths on the frame in different colors. Zero has been used separately as a data integer by some users.

A variety of plot sizes has been used to estimate vegetation cover (Brummer et al. 1994). Daubenmire (1959) recommended using 20-cm × 50-cm quadrats for both shrubs and herbaceous vegetation, because cover is more easily estimated in small quadrats. However, data from a transect, generally having 20–30 quadrats, are summed into one mean for each variable. The transect is the basic unit of sampling. Meter-square frames also have been commonly used to estimate shrub cover. Cook and Bonham (1977) suggested dividing 1-m^2 frames into 5-cm × 5-cm cells, each corresponding to 0.25% cover. One may estimate cover with a gridded quadrat by counting the number of grid cells covered by shrubs and adding the number of obstructed cells to calculate the total percentage. Although ocular estimation is a rapid method of estimating data on basal or canopy cover, there are drawbacks. Ocular estimates are subject to personal bias; thus, estimation error among investigators may add unnecessary variability to the data. Hence, these methods require consistent training and calibration among investigators. Dimensions of plant cover, even on permanently marked plots, also are subject to the influences of precipitation, heat, and sunlight on plant growth. Consequently, care must be exercised in data interpretation, because a reduction in the cover of a species on the same plot in different years may be a result of drought as much as of interspecies competition for the same site.

Box 16.1. Scale of cover classes for a 2-dm × 5-dm quadrat

Data integer	Class range (%)	Midpoint (%)
1	0–5	2.5
2	5–25	15.0
3	25–50	37.5
4	50–75	62.5
5	75–95	85.0
6	95–100	97.5

Line-Intercept Method

The line-intercept method is particularly suited for measuring basal area of bunchgrasses or tussocks and canopy cover of shrubs, particularly in arid or semiarid lands (e.g., sagebrush [*Artemisia* spp.]; see Connelly et al. 2003*b*). The identification of intercept can be quite difficult and prone to error in less clumped forms of vegetation. In this technique, a line or tape measure is placed between 2 stakes, and basal width or canopy width of all plants touching the line or tape is measured, even if only a small part of the plant is in contact with the tape. Cover is expressed as a percentage of the total length of tape intercepted by vertical projections of the canopy. Keeping a tape line taut and straight may be difficult in tall, dense vegetation. Canfield (1941) reported that a minimum of 16 15–30-m transects was necessary to adequately describe shrub vegetation in Arizona rangelands. A 15.2-m transect was adequate in shrub fields with 5–15% shrub cover, whereas a 30.4-m transect was necessary on sites with 5% cover.

The principal advantages of the line-intercept method are the high levels of accuracy and precision that result from direct measurement rather than estimation of vegetation (Cook and Stubbendieck 1986, Connelly et al. 2003*b*). The main limitation of the method is the time required to measure intercepts compared to estimating cover in quadrats. Of the 2 methods, the line-intercept method was more precise, whereas the quadrat method was quicker. Hanley (1978) concluded the line-interception method is preferable to 0.1-m^2 quadrats in scientific research, when precision of the cover estimate may be more important than cost efficiency. Based on comparisons of several techniques, Floyd and Anderson (1987) and Etchberger and Krausman (1997) found the line-intercept method was equal to or better than alternative methods. Wambolt et al. (2006) recently standardized line-intercept methods for estimating shrub cover to ensure that vegetation measures yield reliable results for use in rangeland management.

Point-Intercept Method

Basal and canopy cover also may be measured as the percentage of points whose vertical or angled projections intercept vegetation. The point-intercept method is best suited for estimating cover of herbaceous and low shrub vegetation, but it also has been used to estimate leaf-area index in sagebrush steppe communities (Clark and Seyfried 2001). For relatively large-scale surveys of plant cover, points may

be defined by putting a V-shaped notch or line in the tip of a boot and using the notch or line as a single point (Evans and Love 1957, Etchberger and Krausman 1997) while walking over a tract of grassland. This method offers rapid assessment or survey of cover, but it may be prone to observer bias and is less repeatable than other point-sampling methods. When more precision is required, generally at a smaller scale of study, points may be defined with a multiple point frame (Levy and Madden 1933, Cook and Stubbendieck 1986) or a single point frame (Owensby 1973). With either method, a single pin is lowered toward the ground. The first strike of any part of the vegetation canopy becomes a canopy cover hit; if it strikes the basal area of a plant, it is a basal hit. Often a pin will miss all vegetation in its line of travel. Percent canopy or basal cover is calculated as the total number of hits divided by the total number of pin placements times 100. The diameter of the pin and the point affect the accuracy of cover estimates. Because a mathematical point does not have a diameter, but the pin point does, cover is generally somewhat overestimated (Winkworth 1955). The point-intercept method is frequently used along transect lines. The user should be aware the line is the sample unit and that it is better to have fewer points per line and more lines than vice versa (Bonham 1989).

Heady et al. (1959) reported that line-intercept and point-intercept procedures produced comparable estimates of shrub cover when ground cover was 3%; however, the point-intercept procedure was quicker and thus preferable. Species with ≤3% cover required extremely large samples with the point-intercept method. Thus, the line-intercept procedure should be used in sparse shrub communities.

Bitterlich Variable Radius Method

The **Bitterlich variable radius method** is a modified point-sampling method developed for use in forestry (Bitterlich 1948, Grosenbaugh 1952) to measure basal area of trees. The method was subsequently modified for use in range habitats to measure canopy cover of shrubs (Cooper 1957). Hyder and Sneva (1960) recommended the method for sampling basal cover of bunchgrasses. Shrubs or trees are viewed with one of several types of sighting devices (**angle gauges**) that delimit a certain sighting angle from randomly located sampling points (Cooper 1957, Mueller-Dombois and Ellenberg 1974:102). The sighting device must be held as nearly horizontal as possible. Shrubs with widths or trees with trunks larger in diameter than a specified angle when seen through the sighting device are reported. To be included in the count, small shrubs or trees must be relatively close to the observer, but larger ones can be farther away and yet exceed the viewing angle. The probabilities of species being sampled are proportional to their size, and the correction factor needed to calculate cover depend on size of the viewing angle. Percentage cover is defined as

$$P = [(n \times W^2)/L^2] \times 25,$$

where P is percentage cover, W is the width of the crosspiece of the sighting device, L is the distance of the crosspiece from the observer's eye, and n is the number of plants counted. Using a sighting device with a width:length ratio of 1:50 gives a viewing angle of 1°10′, and the count of trees within that angle is numerically equal to the tree basal area in square meters per hectare (Mueller-Dombois and Ellenberg 1974). Generally, a ratio of 1:7.07 is most acceptable for shrub communities (Fisser 1961, Cooper 1963), and the average count per plot is divided by the correction factor 2. Correction factors for different width crosspieces used for sampling shrubs were given by Cooper (1957).

Clear-glass **prisms** have largely replaced wooden sighting sticks as a means of measuring basal areas of trees (Dilworth 1989). The prism is a wedge-shaped piece of glass that refracts light rays to establish the critical angle used to estimate basal area of tree stems. In using the prism, the observer holds the prism immediately over the sample point while viewing tree stems both through the glass and over the top of the prism. Distance of the prism from the viewer's eyes is not a factor, as long as tree stems appear clearly when viewed through the glass. Viewed through the prism, tree trunks appear displaced to one side, due to refraction of light passing through the glass. Basal area is calculated by recording the number of trees whose trunks, when viewed through the prism, appear displaced within the trunkline of the actual tree. The tree is not recorded if the trunk viewed through the prism is completely displaced beyond the trunkline. Trees whose displaced trunklines are even with the actual trunk are counted as a half tree. Prisms are readily available through most forestry equipment suppliers and come in a variety of metric and English "**basal area factors**" that are used to convert stem counts to basal area per hectare or acre, respectively. The stem count per sample point multiplied by the basal area factor gives the total basal area of stems (m^2 or ft^2) per unit of area (ha or acre). Generally, a basal area factor should be chosen that gives a count of 4–8 trees per point (Dilworth 1989).

The utility of the variable radius method for sampling shrub stands is influenced by several factors. The method assumes the plant is round. Thus, the estimate of cover will be overestimated for species or stands with shrub crowns, particularly of irregular shape. Individual shrubs or trees that should be counted, but are shielded from view by another plant may be missed in dense stands. Cooper (1957) reported the method could be used in desert shrub stands when cover was 35% and Fisser (1961) observed that shorter investigators underestimated cover compared to taller investigators. The chief advantage of the variable radius method is that it is quick and requires counts rather than measurements in the field. Several studies have shown this method

produced estimates of cover comparable to those of the line-intercept method in shrub fields with 30% shrub cover (Cooper 1957, Kinsinger et al. 1960, Fisser 1961). Kinsinger et al. (1960) reported that readings from only 3–6 variable plots were required to produce the same precision as estimates obtained from 20 30-m long line transects that required considerably more time to measure. Cooper (1963) reasoned this precision, and the lower coefficients of variation, from the variable radius method was because of the larger area covered than that with point or line-transect methods. Kinsinger et al. (1960) concluded that within the stated constraints, the variable radius method was faster and more precise than the line-intercept method, but it could not be used as effectively to study subtle changes in shrub cover.

Tree Canopy Cover

At times, tree canopy cover is an adequate, perhaps even preferred, measure of overstory structure and composition. In this situation, line or point sampling or ocular estimates in plots can be used to estimate canopy cover. Many workers prefer to use a **spherical densiometer** (Lemmon 1957; Fig. 16.7) for making these estimates. The spherical densiometer uses a curved, gridded mirror that reflects the overstory at a point and provides estimates of relative amounts of the area covered. Although there are variations (Cook et al. 1995), usually the observer levels the densiometer at about chest height and counts the proportion of quarter cells (etched in the mirror) obscured by the reflected vegetation. Because the mirror is curved, the spherical densiometer measures canopy in a 30–60° angle of view projected upward through the canopy (Cook et al. 1995). Lemmon (1957) concluded that (1) there was no difference in overstory estimates between the spherical densiometer and other instruments used to estimate overstory, (2) variation among replicated measurements increased as overstory cover declined, and (3) reliability was greater when the actual grid count was used rather than broader overstory classes obtained from grouping the counts.

Fig. 16.7. A spherical densiometer used to estimate percentage overstory cover in woodlands.

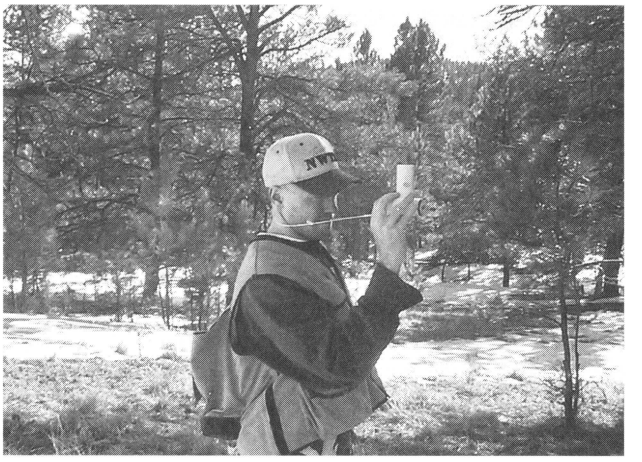

Fig. 16.8. A moosehorn densiometer used to estimate percentage overstory cover in woodlands.

Alternative ocular methods of estimating forest overstory cover include **sighting tubes** (Ganey and Block 1994), **moosehorns** (Cook et al. 1995), and **photographic fisheye lenses** (Chan et al. 1986). The moosehorn (Fig. 16.8) is a sighting tube with a 25-point grid etched in glass on one end. The observer sights through the tube and counts the proportion of dots obscured by overhead vegetation. Because the moosehorn samples a narrower (10°) angle of view than does the densiometer, it produced a truer estimate of the vertical projection of canopy on the ground (Bunnel and Vales 1990, Cook et al. 1995). Although the moosehorn provides the most accurate assessment of vertical projection of overstory canopy, spherical densiometers also may measure biologically relevant influences of tree canopies on an area (i.e., light interception or angular canopy cover; Nuttle 1997). The appropriate measurement tool depends on study objectives and consideration of how tree canopy influences the environmental properties of interest (Nuttle 1997).

Biomass or Standing Crop

One of the best indicators of species importance in a plant community is composition based on dry weight (Daubenmire 1968). Wildlife and land managers frequently require data on **biomass** or **standing crop** rather than on density or cover, because biomass is closely related to forage availability and habitat carrying capacity (Bonham 1989). Here, we use the term biomass to include both live and dead vegetation and synonymously with the term standing crop. Woody biomass and size structure are required to estimate fuel loading, a necessity for formulating fire prescriptions and predicting fire behavior in wildlands. Wildlife managers often are interested in measuring biomass of edible components of browse, such as current annual growth, foliage, or twigs. Total biomass and biomass of edible components may be estimated directly by clipping and weighing or indirectly by dimension analyses or through the use of capacitance meters (Gonzalez et al. 1990).

Clipping Techniques

Plant biomass can be measured directly by removing all vegetation in a sample plot to ground level and measuring its mass immediately (wet mass) or after air- or oven-drying the sample (dry mass). Clipping, drying, and weighing plant material directly is accomplished with minimal variation in results among investigators; however, proper implementation of methods necessary to obtain good data is both labor and time intensive. For consistency, herbage should be clipped at a specific height or location on the plant and may be separated into edible and inedible portions, depending on the objectives. Mean biomass per unit area then may be estimated as the product of mean biomass per plant (e.g., g/plant) and mean density of plants (e.g., plants/m^2). Sample variance may be computed as the variance of a product (Goodman 1960). Data from a site or transect is pooled into a mean. Variances are calculated from across sites or transects from which harvesting was conducted in each quadrat. Because clipping is a destructive sampling method, new plots must be selected in subsequent sampling periods to avoid the effects of previous sampling activities.

In wetlands, biomass samples of macrophytes may be obtained by harvesting all vegetation in a quadrat frame placed above the sediment level (Whigham et al. 1978). Harvesting consists of clipping plants in floating (Tanner and Drumond 1985) or submerged metal rod frames or in an open-ended cylinder or box enclosures (Sefton 1977, Anderson 1978). Water depth also should be measured near the center of each quadrat and recorded. Clipping can be done easily in conventional waders in shallow (1 m) wetlands. However, deeper wetlands (>1 m) may require sampling with specialty gear, such as swimmer's goggles, wetsuits, dredging equipment, modified rakes (Rodusky et al. 2005), or even scuba equipment. Vegetation samples should be dried to a constant weight. Drying temperature is dependent on the purpose of the plant materials; if one is interested only in dry weight, then 80° C for 48 hours may be used. If the plants are to be analyzed for nutritional analysis, lower temperatures (e.g., 60° C for 48 hr) are required to avoid volatilizing nutritional components. If drying and weighing cannot be done onsite, vegetation samples should be frozen or kept at 4° C to stop further respiration activity.

The "**clip-and-weigh**" method also may be used to estimate twig biomass in plots. Clipping all twigs in plots is a highly accurate yet laborious means of measuring browse biomass (Shafer 1963). Several investigations have reported that total browse collection may require 10–120 times as long as estimating browse biomass from dimension analysis or twig count methods (Shafer 1963, Uresk et al. 1977, Bobek and Bergstrom 1978). This time requirement is an important consideration, given high sampling variation inherent in browse estimation.

Ocular Estimations

Herbage biomass also may be ascertained by ocular estimation techniques (Pechanec and Pickford 1937, Ahmed and Bonham 1982, Ahmed et al. 1983, Stohlgren et al. 1998). Requirements of biomass estimation techniques include intensive training of investigators. This may be facilitated by incorporating double sampling procedures into the activity. **Double sampling** requires that ocular biomass estimates be made in each quadrat or for each plant and that a subset of quadrats or plants be clipped and weighed after the estimates are made. Weighing the plants helps the observer develop more accurate ocular estimates. Regression of the estimates and actual weights provides an estimator for the plots or plants for which only estimates were made. Procedures to calculate an adequate ratio of clipped to estimated samples were provided by Ahmed and Bonham (1982), Ahmed et al. (1983), and Reich et al. (1993).

Dimension Analyses

Dimension analysis has been used in forestry for timber attributes and in wildlife and range management for estimating shrub biomass. The technique assumes that plant attributes are related and that one attribute can be predicted from another that is more easily measured (Whittaker 1965). Because clipping, drying, and weighing require so much time, and yet biomass frequently is a critical attribute of a plant community, numerous investigators have developed regression equations of biomass and some more easily measured attribute. Biomass of individual grass plants has been estimated from volume as measured by height and basal diameter (Johnson et al. 1988). Biomass estimates of individual shrubs have been obtained with, as independent variables, measures of basal stem diameter (Telfer 1969*b*, Brown 1976); maximum plant height (Ohmann et al. 1976); and various crown dimensions, including diameter, area, volume, and height × circumference (Lyon 1968*b*, Rittenhouse and

Sneva 1977, Uresk et al. 1977, Murray and Jacobson 1982). Common forms of the predictive equations include linear ($y = a + bx$) and power ($y = ab^x$) curves. Traditionally, researchers have linearized the power curve with logarithmic transformations ($\log[y] = \log[a] + x \cdot \log[b]$), but such transformations may introduce bias (Baskerville 1972). There is little reason to transform the nonlinear relationships with nonlinear regression procedures commonly available in statistical software packages. Several independent variables may provide satisfactory estimates of shrub biomass (Oldemeyer 1982), but care must be taken to select those variables that provide the best predictive accuracy and are not correlated.

Generally, one measures stem and crown dimensions from a sample of individual shrubs in the field. The plant material then is clipped, taken to the laboratory, oven-dried, and weighed. A sample of 25 plants per species is usually adequate for calculating predictive equations for total shrub weight (Peek 1970). Care must be taken in the field to adequately sample the full range of plant sizes present, because one may not estimate biomass of plants that fall outside the size range of plants used to develop the regression. We believe more reliable regression equations may be developed if one stratifies the plants in the community into size classes, measures the variance of biomass in each size class, and calculates the number of plants to measure in each size class on the basis of the variance. For example, if the relative variance of the largest size class was 20% and if 25 plants were to be measured for the regression analysis, then 5 plants (0.2×25) would be measured from the largest size class.

Weight–dimension relationships of shrubs vary among sites and years (Oldemeyer 1982), making it necessary to test the influence of site factors on the regression parameters if predictive relationships are to be applied to a broad area. Developing separate predictive equations for each shrub species in each vegetation community of the study area is often necessary. Once satisfactory predictive equations have been developed, biomass can be estimated from data on shrub density and shrub biomass estimates without destroying shrubs. Dimension analysis represents a substantial savings in time and expenditure over traditional clip-and-weigh methods when only one, or at most a few, predictive relationships need to be developed for use for a variety of site conditions. Because the method is nondestructive, plants can be measured annually in the permanent plots.

Dimension analysis has been used to estimate twig and foliage production of individual shrubs in the same manner as described above for total aboveground standing-crop biomass. Production estimates for individual shrubs are obtained by measuring a sample of shrubs in the field; the shrubs then are harvested, and all current annual growth of twigs and foliage is clipped, sorted, and dried. Sampling and analytical considerations are the same as for estimating total shrub biomass.

Lyon (1968*b*) and Peek (1970) reported that total twig production was related linearly to crown volume and crown area, with the resulting equation explaining >80% of the variation in twig production. Oldemeyer (1982) used multiple regression procedures to estimate twig production as a function of shrub circumference, shrub height, crown length, and number of current annual growth twigs. Despite the high predictive accuracy of the equations, Lyon (1968*b*) and Peek (1970) warned that production–dimension relationships of shrubs were influenced strongly by site factors, and they varied among species, which necessitated developing unique predictive equations for each shrub species on each distinctive site type. Dimension analysis is a convenient, nondestructive alternative to the traditional clip-and-weigh methods, once predictive equations are developed for a particular site type.

The **twig-count** method (Shafer 1963) for measuring browse biomass is based on the simple conversion of twig counts to browse weight by using an average weight per individual twig. In its basic form, an average browsing diameter of a particular shrub species is calculated from a random sample of 100 browsed twigs. An average weight per twig then is calculated by weighing 50 unbrowsed twigs clipped at the average browsing diameter. Shafer (1963) suggested counting twigs in 9.3-m^2 circular plots. Twig densities then were converted to biomass estimates from a mean twig weight. Irwin and Peek (1979) observed that it was faster and easier to count twigs in 1-m × 1-m or 1-m × 4-m belt transects. Shafer (1963) reported the twig-count method was nearly as accurate as the clip-and-weigh method. The twig-count method also is nondestructive, making it suitable for repeated measurement of permanent plots. Additionally, individual twigs are easily counted and recorded in different height categories, permitting easy assessment of the influence of snow depth and browsing heights on available browse (Potvin and Huot 1983).

A commonly used modification of Shafer's (1963) twig-count method involves development of **weight–diameter** or **weight–length equations** to estimate mean twig weights (Basile and Hutchings 1966, Telfer 1969*a*, Halls and Harlow 1971). This method is based on the principle that average twig weights may be estimated by regressions of twig diameters or twig lengths. Predictive equations relating twig weight to twig diameter or length may be developed by clipping a number of unbrowsed twigs (50 are recommended), measuring twig length and basal diameter, oven-drying, and weighing to the nearest 0.01 g. Care must be taken to collect the full range of twig sizes from several shrubs and to stratify the sample among lower and upper portions of each shrub (Basile and Hutchings 1966). Because twigs are often elliptical in cross-section, it may be necessary to estimate twig basal diameter as the average of 2 perpendicular measurements. Linear regression produces acceptable predictive equations if the range of twig diameters or lengths is not

great (Basile and Hutchings 1966, Halls and Harlow 1971); however, curvilinear regression may be required if twig sizes vary widely (Telfer 1969*a*). Peek et al. (1971) reported there might be considerable site variation in length–weight and diameter–weight relationships of twigs that would require developing a separate regression equation for each shrub species and each site type under investigation.

Other Attributes

Visual Obstruction

Visual obstruction caused by vegetation may be functionally important to wildlife both as hiding cover (i.e., cover necessary to escape a sense of danger) and as thermal cover (i.e., cover that creates a beneficial thermal environment). The measurement of **horizontal cover** of vegetation has been used extensively by wildlife managers and researchers in assessing wildlife habitat suitability, habitat preference, and impacts of land use practices on wildlife habitats (Griffith and Youtie 1988, Reece et al. 2001, Vermeire and Gillen 2001, Uresk and Juntti 2008). Some measure of horizontal obstruction also has been used by researchers to examine the relative influence of visibility biases associated with wildlife surveys in different vegetation classes. Further, measures of horizontal obstruction have been used reliably in many instances as a relatively rapid surrogate measure to estimate standing crop biomass of grassland vegetation (Harmoney et al. 1997, Volesky et al. 1999, Benkobi et al. 2000, Vermeire and Gillen 2001).

A variety of devices has been used to measure horizontal visual obstruction caused by vegetation. Wight (1939) first proposed use of a **density board,** a 1.83-m tall board, each 30.48-cm mark labeled 1 to 5 (Fig 16.9). Horizontal cover is assessed by placing the board in cover, viewing the board from a distance of 20 m, and adding the numbers unobstructed by vegetation. The method produces an index of horizontal cover that ranges from 0 (no obstruction) to 15 (complete obstruction), but it provides no means of describing the vertical distribution of the obstructing vegetation.

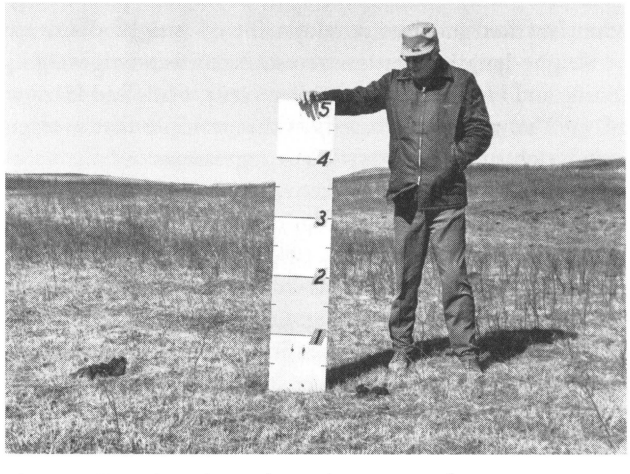

Fig. 16.9. Cover boards used to index or quantify cover or to provide visual records of changes in cover when photographed from the same reference point.

Nudds (1977) devised a **vegetation profile board** that enables the investigator to assess visual obstruction of shrub vegetation in 5 0.5-m vertical intervals above ground. The board is 2.5-m high and 30.48-cm wide and is marked in alternate black and white colors at 0.5-m intervals. Horizontal cover is assessed in each interval by viewing the board from 15 m in a randomly chosen direction. The percentage of each interval concealed by vegetation is recorded as a single-digit score, ranging from 1 to 5, corresponding to 0–20, 21–40, 41–60, 61–80, and 81–100% estimated concealment. Although the vegetation profile board has been widely used, its size, weight, and inconvenience associated with use in remote areas are drawbacks of the technique. The board may, however, be reproduced on thin vinyl or nylon material that is easily rolled and transported in the field; it can be held in place conveniently by a single pole or by a field assistant. Griffith and Youtie (1988) modified the Nudds-type checkerboard into standing and bedded deer silhouettes. Values of the height and percentage of the silhouette blocks covered by vegetation was estimated by eye from the 4 cardinal directions and at 4 0.5-m levels. Haukos et al. (1998) reported sample size, power, and other analytical considerations when using profile boards in wetland plant cover. Naugle et al. (2000) used a profile board to investigate black tern (*Chlidonias niger*) nest site selection in wetland vegetation.

Robel et al. (1970) used a pole-shaped cover board (3 cm × 150 cm) that could be read from a standard distance (4 m) and height (1 m) in any direction (Fig. 16.10). The pole was marked in decimeters, and the height of total visual obstruction was recorded. For example, if the pole was not visible until the fifth decimeter, the reading was 4. Additionally, all vegetation was clipped, dried, and weighed from a 2-dm × 5-dm quadrat next to the pole, and regressions were developed from the average obstruction reading and biomass of 30 transects. The $R^2 = 0.95$ indicated the obstruction reading could be used as a method of estimating biomass in tall grasses to assess prairie-chicken (*Tympanuchus* spp.) habitat. Benkobi et al. (2000) modified the Robel pole with alternating gray and white 2.5-cm rings and clipped vegetation around the pole. Their modified pole greatly improved the precision and accuracy for mid- and short-grass prairie. Sample size for number of pole stations and transects are presented, as are monitoring or sampling protocols for small areas (≤259 ha) to large landscape areas of 1,215–46,560 ha. Uresk and Juntti (2008) further modified the pole with 1.27-cm bands. This modification greatly improved the precision and accuracy of measures of short and sparse vegetation. More importantly, with this modification, critical cover structure can be detected for wildlife before a major change occurs caused by livestock grazing and other factors. Resource guidelines may be developed to meet wildlife ob-

Fig. 16.10. Estimating visual obstruction from a specific height and distance.

jectives to maintain habitat structure. The tool is fast, easy to use, highly accurate, and cost effective. This modified pole provides an assessment of standing crop on grasslands, can be used to monitor livestock grazing, and provides status of vegetation structure for wildlife habitat.

Alternatively, Griffith and Youtie (1988) reported that a 2.5-cm × 200-cm **cover pole,** easily transported in the field, produced measures of horizontal shrub cover indistinguishable from those produced by the vegetation profile board. The cover pole was painted with alternating 0.1-m black and white bands, and 3 red bands divided the board into 0.5-m zones. Visual obstruction in each zone is recorded as the number (1–5) of 0.1-m bands that are ≥25% concealed by vegetation in each 0.5-m level.

Collins and Becker (2001) developed a new point sampling method, the **staff-ball** method (Fig 16.11), to characterize horizontal cover and compared time and precision of use among observers and with 3 other methods (cover pole, profile tube, and checker board). Their results indicate the staff-ball method provided estimates of horizontal cover from 5.1 to 14.3 times faster than other methods and with greater precision, because observers only needed to make yes/no decisions rather than subjective estimates and/or counts. The staff-ball method also can be used in a variety of vegetation types. Staff-ball point cover readings are taken at the point where the ball meets the pole (one side only); the reading consists of determining whether this point is or is not obscured. The ball or balls are positioned at set heights on the pole, depending on vegetation type.

Marlow and Clary (1996) and Dudley et al. (1998) used photography in combination with cover boards to assess vegetation differences. Although the technique enables visual assessment of cover changes through time, it does not provide measurable differences. To ensure comparisons from year to year, photographs must be taken annually from the same point (height, distance, and direction) with similar film,

Fig. 16.11. Estimating horizontal cover using the staff-ball method of Collins and Becker (2001).

date, and time of day. At times, the date is adjusted to phenological characters of specific plant species.

Users of visual estimation techniques to characterize vegetation structure should be aware of the potential for interobserver judgments and associated biases (Schultz et al. 1961). In studies comparing visual estimation data sets to those obtained using instrument measurements, Gotfryd and Hansell (1985) and Block et al. (1987), using univariate and multivariate analyses, found significant differences between observer estimates and measurements for many vegetation variables. Thus, studies that rely solely on visual (ocular) estimation techniques may forfeit accuracy to save on labor and sampling costs.

Herbage Height

Height of herbage is probably the easiest attribute of vegetation to measure in grasslands, but it has received little attention in published literature. Plant height can be estimated with high precision in many grasslands. Plant height correlates well with other structural attributes of herbage important to the management of grasslands. For example, Higgins and Barker (1982) reported that herbage height explained 63% of the foliage density values that were taken concurrently with the use of a modified visual obstruction pole (Robel et al. 1970). Herbage height in grassland habitats has an important role in predator deterrence and prey security. Average plant (stubble) height also can be used to

evaluate the impact of livestock grazing on a pasture (reviewed by Clary and Leininger 2000, Turner and Clary 2001).

Herbage height can refer to the tallest portion of a plant or the effective cover height (generally the upper limit of vegetation leafiness), or to the area-height of herbage (where a 30-cm diameter plastic disk is lowered slowly, until it touches the vegetation). Maximum plant height can be measured readily with a calibrated ruler or tape placed next to a plant. Multiple measurements (≥10) usually are expressed as an average height.

Effective plant height usually is measured as the maximum height of leafy cover for grasses and forbs; however, effective plant height of a forb (e.g., alfalfa [*Medicago sativa*]) may be equivalent to its maximum height. Effective herbage height also may be measured by holding a pole or meter stick parallel to the ground and reading the effective height at the point where leafy plant parts touch the horizontal pole in a minimum of 3 places along its length. Bakker et al. (2002) found that effective plant height was associated with savannah sparrow (*Passerculus sandwichensis*) use of grassland habitats in eastern South Dakota.

The height of herbage per unit area can be measured with a disk or plate in combination with a ruler (Higgins and Barker 1982, Gonzalez et al. 1990). Clear or lightly colored plastic allows plant parts to be seen beneath the disk. Maximum area-height measurements are made at the point where the plastic disk is first touched by a plant part. If a weighted disk is used, measurements are made at the lowest point where the disk settles on the vegetation (Bransby et al. 1977, Gonzalez et al. 1990).

Rangeland canopy height also can be measured by counting the number of laser measurements by 1.3-cm height categories and dividing by the total number of laser measurements for a line transect (Ritchie et al. 1992). The laser transmits and receives reflected wavelength signals, and at 4,000 pulses/sec with an aircraft altitude of about 150 m and a speed of 60 m/sec, a vertical measurement is taken at 1.5-cm intervals along the flight line. These data can be obtained with a laser profiler mounted in a fixed-wing aircraft that measures the distance between the aircraft and the defined surface material to be sampled (e.g., vegetation) with this method.

Tree Dimensions and Structural Characteristics

The size and characteristics of individual trees affect the **physiognomic structure** of forested wildlife habitats. In many forested habitats, large trees provide critical structures necessary for nesting, reproduction, or survival. For example, studies of nesting sites of northern owls (*Strix occidentalis caurina*) and California spotted owls (*S. o. occidentalis*) indicate that presence of large old-growth trees or snags is a key characteristic of nesting habitat in western forests (Mills et al. 1993, North et al. 2000). In other situations, a variety of tree sizes, age classes, and structures contributes to habitat complexity and overall diversity of wildlife species inhabiting the forest. Choosing which characteristics of trees to measure depends on study objectives and biological characteristics of the species under study. Morrison et al. (1998:139–167) provides a complete discussion of measuring forest habitat structure. Here we describe a few of the most common measurements.

Three common, interrelated measures of tree size are height, crown volume, and trunk diameter. Height of tall trees may be measured using trigonometric functions based on the horizontal distance of the observer from the tree and angle measurements made to the base and top of the tree (Woodward et al. 2009). Although angle measurements may be made using a standard clinometer, a wide variety of laser rangefinders and hypsometers, available from many forestry outfitters, simplifies the task of measuring tree heights and eliminates the need for subsequent computations. Crown volume may be measured from similar measurements of minimum and maximum canopy heights and canopy diameters measured horizontally (Sturman 1968; reviewed in Morrison et al. [1998]).

Trunk diameter and cross-sectional area are the most common measurements of tree size because of ease of measurement and high correlation with height and volume. Diameter can be measured with a diameter tape (calibrated to give diameter from a measure of circumference) placed around the circumference of a tree trunk or with calipers (Fig. 16.12). By convention, the measurement (DBH) is made 1.4 m above ground level (Spurr 1964) and above the enlarged base of some trees; DBH also is a representative height where measurements can be made consistently and rapidly. Such data often are summarized as numbers of individuals of species per size class per unit of land area. If exact diameter measurements are not needed, a forester's Bilt-

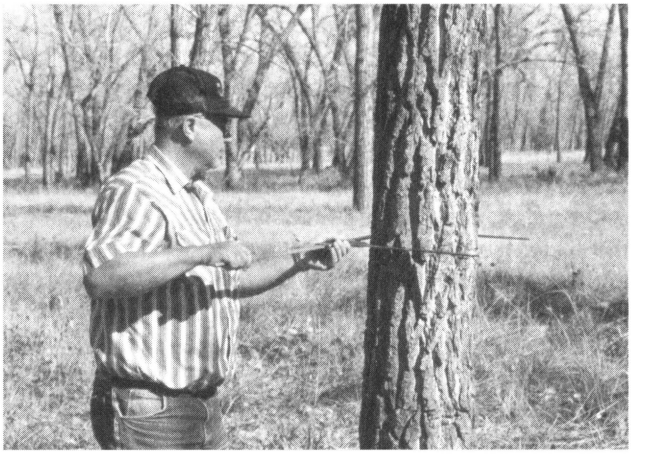

Fig. 16.12. Calipers used to measure tree diameter at breast height.

more stick (Avery 1959) can be used to estimate diameters in size classes.

Trunk cross-sectional area, calculated as $A = \pi r^2$ (r is the radius of the tree at breast height), also is measured at breast height, and the results (commonly identified by the misnomer "basal area") are given as area units of trunk per unit land area. Individual tree areas can be computed from diameter measurements or measured directly with a tape scaled with area equivalent units. Data can be presented as the value just described or as a relative value (percentage of the total contributed by a single species).

In addition to describing dimensions of trees, assessing the presence or frequency of trees with unique structural characteristics also may be important to wildlife managers or biologists in judging habitat suitability or studying wildlife habitat relationships. For example, the presence of trees with broken tops, nesting platforms, or snags of a particular decay class may be important for wildlife with specialized nesting requirements. Until recently, guidelines for assessing the many unique structures of trees were distributed broadly throughout the forestry and wildlife literature. The recent focus of the U.S. Forest Service on describing forest health at the national scale has led to the standardization of many protocols for describing such diverse characteristics of individual trees as live crown ratios, crown dieback, and decay classes of standing dead trees, as well as many other structural characteristics. The biologist concerned with measuring specialized tree characteristics may find it useful to study protocols available on the website of the U.S. Forest Service Inventory and Analysis National Program (http://fia.fs.fed.us/library/field-guides-methods-proc/; e.g., see Bate et al. 2008).

Tree Age

For many wildlife studies, it is sufficient to obtain one or more expressions of tree size, without age, although at times the latter also has value. Age data are beneficial in forest history and dynamics, including predictions of future status. For instance, knowledge of the approximate life span of a tree species aids in assessment of the current tree population age structure and of regeneration success. Past events influencing the forest and its wildlife inhabitants can be revealed by the presence of fire scars or periods of reduced growth.

Some wildlife species have tree-size and age-specific requirements. For example, in longleaf pine (*Pinus palustris*) forests of the southeastern United States, trees >95 years old have been judged important for red-cockaded woodpeckers (*Picoides borealis;* Hooper 1988). Ruffed grouse (*Bonasa umbellus*) in northern forests do best in a mosaic of aspen stands of various ages (Sharp 1963, Dessecker and McAuley 2001).

Age classification of trees is possible, because trunk lateral growth occurs in annular increments related to the seasonality of temperate zone climates (Raven et al. 1986). The increments are especially evident in so-called ring-porous species. Large-pored vascular tissue is formed early in the growing season, followed by small-pored tissue and then termination of growth that year, followed by the onset of obvious spring growth as another growing season begins. Examples of these species include oaks (*Quercus* spp.), ashes (*Fraxinus* spp.), and elms (*Ulmus* spp.). Diffuse-porous angiosperm species, e.g., maples (*Acer* spp.), aspens, and birches, have less apparent growth rings. Conifers, unlike angiosperms, have a somewhat different anatomical structure, yet they, too, typically have easily recognized growth rings. Extra treatments of the wood, such as applying light oil, certain stains, or water; sanding; or shaving with a razor blade can help make growth rings more evident.

Growth rings can be seen on trunk or stump cross-sections. Vegetation sampling in concert with timber harvest or removal of damaged and/or dead trees is an easy way to collect such data. Where destructive sampling is not in order, small cylindrical cores can be collected with a wood increment borer. Cores can be analyzed onsite or stored, for example in soda straws, until they are viewed in the laboratory. They also can be affixed to a grooved board and kept for future reference. Together with classifying age, tree ring analysis can be used to measure growth rate and to date discernable past events, such as fire (resulting in scarred tissue) or varied climatic or competitive regimes (revealed by varied growth ring widths).

Plant Use

Quantification of **plant use** and its effect on the ecosystem are important for estimating the number of herbivores that can use the land without deterioration of the soil base and plant community (Bonham 1989, Clary and Leininger 2000, Turner and Clary 2001). Maintenance of adequate plant and litter cover retards water runoff and reduces erosion. Early methods to evaluate use of range grasses were developed during 1930–1950 (Stoddart 1935, Pechanec 1936, Lommasson and Jensen 1938, Canfield 1944, Roach 1950), and with some modification, they are still used today. Many of the methods of estimating shrub use are modifications of those used for grasses, and we discuss methods for each in the following paragraphs. To avoid confusion, we use the term stems to refer to stems of grasses and twigs to refer to shrubs and saplings.

As with estimation of biomass, plant use may be estimated with ocular methods. These methods require training with ungrazed plants that are clipped to simulate different intensities of grazing. Such estimates vary by individual investigator and may be inconsistent from year to year. Commonly accepted methods of measuring use vary from simply counting used or unused stems, to obtaining "before and after" measures of stem lengths, to regression methods.

The **stem-count method** (Stoddart 1935, Cole 1956) is a minor modification of the range survey method described above, in which used and unused stems are counted rather than estimated. Stems may be counted in plots or along transect lines. Pechanec (1936) observed that stem counts did not compare favorably with other methods for estimating grass use. Stickney (1966) and Jensen and Scotter (1977) reported that proportion of shrub twigs used correlated well with proportions of lengths removed, but the method was insensitive under heavy use. Stickney (1966) observed that virtually all shrub twigs received at least minor browsing at use levels 55% of length for black chokecherry (*Prunus virginiana*) and 60% of length for Saskatoon serviceberry (*Amelanchier alnifolia*). Those wishing to compare among sites that receive >50% use will need to select a method that remains sensitive under a wider range of use.

Use may be estimated by measuring height of grass stems or length of shrub twigs before and after use by herbivores. Relationships are calculated for height/length removed and biomass used (Lommasson and Jensen 1938, Stickney 1966, Jensen and Scotter 1977). For both grasses and shrubs, the relationship is not linear, so curvilinear relationships must be developed. Jensen and Scotter (1977) reported the twig-length method provided a sensitive measure of shrub use across a range of use levels (0–100%). A primary disadvantage of the method is that it requires 2 trips to the field, one prior to and one following the browsing season, yet it provides no estimate of production. Curves must be developed individually for each species, site, and year to accurately estimate use (Bonham 1989).

Browse use also may be estimated with dimension analyses of twigs by predicting the prebrowsing lengths or weights of twigs from diameter–weight or diameter–length relationships (Basile and Hutchings 1966; Telfer 1969*a*, *b*; Lyon 1970). Once the diameter–weight or diameter–length equations have been developed, the technique requires 3 additional types of data:

1. an estimate of the percentage of twigs browsed,
2. mean diameters at the point of browsing of a stratified sample of browsed twigs, and
3. mean lengths or weights of the twig parts remaining after browsing.

Prebrowsing weights or lengths of browsed twigs can be estimated from regression equations. Postbrowsing weights of browsed twigs can be measured by clipping and weighing the residual twigs. Alternatively, postbrowsing lengths of browsed twigs can be measured directly. The percentage use can be computed from the formula

$$U = B \times [(P - A)/P] \times 100,$$

where B is the percentage of browsed twigs, P is predicted prebrowsing mean length or weight of browsed twigs, and A is postbrowsing mean length or weight of browsed twigs (Lyon 1970).

As an alternative to the above procedure, several workers have estimated weights of consumed twigs directly by using the diameter at point of browsing in weight–diameter equations (Oldemeyer 1982, Rumble 1987). In that instance, use may be computed as

$$U = [(B \times C)/P] \times 100,$$

where B is the proportion of browsed twigs, P is predicted prebrowsing mean weight of browsed twigs (based on diameter of current annual growth), and C is predicted mean weight of consumed portions of twigs (based on browsing diameter).

Several authors (Jensen and Urness 1981, Provenza and Urness 1981) demonstrated that use estimates obtained from twig diameter measurements are rapid and compare favorably with twig length measurements. Once diameter–weight or diameter–length equations have been developed for a site, the method represents a considerable savings in time over the twig-length method, because all measurements of use can be obtained during a single trip to the field after use has occurred.

Percentage of plants or stems used by herbivores often is used as an estimator of plant use. This method requires a combination of techniques. For grasses, one measures the percentage of biomass removed, using height–weight relationships, and regresses percentage of plants used on biomass removed from a sample of several sites (Roach 1950). Similar regressions can be developed for shrubs with percentage of plants used and results of dimension analysis (Oldemeyer 1982).

Another evaluation technique commonly used to assess levels of plant use at the landscape scale is classification of key browse species into **form and age classes** (Dasmann 1951, Cole 1959, Patton and Hall 1966). In this procedure, ≥25 plants of a key browse species are marked along permanently established survey courses in selected key winter range areas. For each plant in the survey, the observer records:

1. **hedging**—classified as light, moderate, or severe, based on the length and appearance of the previous year's growth below the current leaders;
2. **availability**—classified as available or unavailable, based on shrub height and maximum browsing reach of the principal browsing species; and
3. **age/decadence**—classified as seedling, young, mature, or decadent, based on stem diameter classes (any living plant with ≥25% of the crown dead is classified as decadent).

Hedging, availability, and age class are summarized as percentages of shrubs in each class. The method has the advantage of being quite rapid, allowing for completion of ex-

tensive surveys. However, as for all subjective ratings, there is considerable variation among individual examiners in the assignment of form classes.

Keigley (1997) recently proposed a new method of evaluating browse growth form based on explicit definitions of browsing intensity and **plant architecture.** In this procedure, browsing intensity of individual shrub stems is rated as light to moderate or intense, depending on whether the current annual production consistently develops from the previous year's growth (light-to-moderate browsing) or from stem segments >1 year old because the previous year's grow was killed by browsing (intense browsing). At the whole-plant level (including multiple stems that comprise the plant), plant architecture is classified as **uninterrupted growth type** (reflecting light-to-moderate browsing), **arrested type** (reflecting intense browsing), **retrogressed type** (reflecting light-to-moderate changing to intense browsing), or **released type** (reflecting intense changing to light-to-moderate browsing). Explicit definitions are given for each architecture type. Additional details and applications of the method are provided by Keigley et al. (2002*a*, *b*).

TECHNIQUES FOR SAMPLING FRUITS

Data on fruit abundance can be quite important when certain species of wildlife are dependent on annual fruit production (DeGange et al. 1989, McShea and Schwede 1993, Wolff 1996, McShea 2000, Suthers et al. 2000). However, few habitat analyses include an inventory of fruit production. An enumeration of the number and size of fruiting plants is often as far as managers go to describe fruit-bearing potential and its value to wildlife. The inconsistent and seasonal fruiting tendencies of plants, coupled with their often sporadic distribution, minimize the usefulness of simple enumeration of plants.

In studies of wildlife food habits, fruits generally are referred to as mast and are divided into 2 categories: hard and soft. Consequently, **mast** can be defined as the fruits and seeds of all plants, both woody and herbaceous, used as food by animals. The importance of fruit as wildlife food is well known; for example, oak mast alone is used by 185 wildlife species and is available for ≤8 months (Van Dersal 1940). Mast is high in food energy, especially carbohydrates and fats (Goodrum et al. 1971).

Soft mast includes fruits with fleshy exteriors, such as berries, drupes, and pomes. **Hard mast,** in contrast, includes fruits with dry or hard exteriors, such as achenes, nuts, samaras, cones, pods, seeds, and capsules. Numerous factors affect fruit production, including age of plant, size of plant, genetics of the individual plant, climate, soil, competition for resources, and previous use by animals (Schupp 1990). Annual variation in yields of wild food plants makes it difficult to estimate fruit production over large land units (Koenig and Knops 1995). Consequently, management practices that provide for the greatest variety of food-producing plants will ensure favorable conditions for the greatest variety of wild animals.

Large or Heavy Fruits of Trees

The sampling design necessary for species with large or heavy fruits depends on whether total mast production or an index of annual mast abundance is desired. Choosing a large number of random points for trap locations may be necessary if the objective is to characterize mast production at the landscape scale. Although this design is costly, it avoids intentional bias and allows statistical inference from the sample to the larger area. Depending on the objectives of the project, one may want to sample only under the canopies of mast-producing trees. This method would be appropriate if one is measuring the production per unit area of mast-producing canopy in the forest or obtaining an annual index of mast production.

Sampling may be random in forests with well-defined stands of trees (Thompson 1962) or stratified by vegetation type, stand age classes, or stand location (edge or interior). Sampling methods have been devised to estimate production by small versus large trees (Minckler and McDermott 1960), to compare production of ≥2 species of oaks (Tryon and Carvell 1962, Koenig and Knops 1995), and to estimate production in mixed oak stands 63–82 years of age (Beck and Olson 1968).

Mast production can be estimated by counts of mast in ground plots (Goodrum et al. 1971), counts of mast on trees (Gysel 1956, Koenig et al. 1994, Koenig and Knops 1995), or use of seed traps (Schupp 1990, Sork et al. 1993, Ostfeld et al. 1996). Counts of mast in plots on the forest floor are generally unreliable estimators of mast production, because mast frequently is taken by wildlife before counts are made; however, such counts, when used with seed traps, may be a good estimator of wildlife use of fallen mast. Total counts of mast on trees may be quite accurate for small trees, but they are difficult and time consuming for large trees. Consequently, many researchers and managers have opted to use relatively rapid indices of mast production rather than more labor-intensive methods. For example, indices based on visual counts have the advantage of being quick and permitting rapid assessment of acorn production. In the most general index, acorn production may be rated on a visual scale from 0 to 4: 0 (no acorns), 1 (a few acorns seen after close scrutiny), 2 (a fair number), 3 (a good crop), and 4 (a bumper crop; Koenig et al. 1994). The obvious disadvantage of such a rating system is its subjectivity. As an example of a more quantitative index, Koenig et al. (1994) and Koenig and Knops (1995) counted as many acorns as they were able on a single tree during a 30-second interval. Although such an index may be limited by the maximum rate at which an

observer may count under high acorn abundances, Koenig et al. (1994) found the index was highly correlated with values obtained from acorn traps. Alternatively, Wolff (1996) used visual counts of acorns on 10 randomly selected branches as an index of mast production in oak woodlands of California.

Many kinds of **mast traps** have been used to measure mast fall. Downs and McQuilkin (1944) developed square traps made of hardware cloth on a wood frame. These traps were about 1 m^2 in size, and 2 were placed under each tree. Since that time, several trap designs have been developed, ranging from makeshift types, such as large oil drums; to large fruit baskets; to those made from wood, cardboard, or polyethylene film and particularly designed for catching acorns. Because rodents and other wildlife will eat mast in the traps, early traps used predator guards; however, these deflected mast from the trap, and guards are not recommended. A study of 8 types of traps comparing catching efficiency, durability, and cost (Thompson and McGinnes 1963) revealed 3 types to be most suitable: polyethylene film traps, square wire-cage traps, and paperboard seed traps. The polyethylene conical-shaped seed trap sampled an area of 0.4 m^2 and had an acorn-retention efficiency of 99%. Fifty of these traps can be carried by one person a considerable distance without discomfort. The wire cage trap (Moody et al.1954) sampled 1.0 m^2. With a wire cover, it had an acorn-catching efficiency of 87% and a durability of 10 years. The design was similar to traps used by Downs and McQuilkin (1944). Of the 8 traps compared, the wire cage model was the most expensive to construct. The paperboard seed trap (Klawitter and Stubbs 1961) was a modified version of the pine seed trap (Easley and Chaiken 1951) that has a sampling area of 0.0003 ha (3.2 m^2). The paperboard trap had 96% acorn-retention efficiency and was durable for 2–3 years.

Christisen and Kearby (1984) constructed acorn traps of 8-gauge steel wire formed into a circle 0.73 m in diameter. They attached to the wire clear 4-mil plastic, cut into a semi-circle, forming a cone. Holes punched in the bottom of the cone allowed water to drain. The trap was attached to wooden stakes to hold it off the ground. They concluded the plastic cone was superior to baskets and wire mesh traps, because the soft plastic prevented acorns from bouncing out of the trap, acorn predation was eliminated, and traps were inexpensive and portable. The primary disadvantage was the plastic lasted only 1 year. Sork et al. (1993) and Schroeder and Vangilder (1997) used a similar seed collecting trap made of 6-mil plastic and a trap area of 0.5 m^2. Schupp (1990) studied seedfall from the understory trees in Panama using 1.0-m FD traps constructed of 1.5-mm mesh plastic window screening on 1-m × 1-m frames of 1.25-cm PVC tubing.

Mast production varies considerably among tree species (Sork et al. 1993), among trees of the same species, and among years (Christisen and Kearby 1984, Koenig et al. 1994). Thus, one must design a mast production study with great care. Traps have been placed under trees at a distance of two-thirds the crown radius from the trunk; however, we are not aware that a consistent distance from the trunk is required. Christisen and Kearby (1984) randomly placed 3 traps under each sample tree with the stipulations that no 2 traps were placed in the same direction and that no traps be placed under a side of a tree that lacked canopy. Further, they imagined the canopy as consisting of 2 concentric circles and either placed 2 traps in the inner circle and one in the outer, or vice versa. Traps should be examined at 1–2-week intervals from the time large fruits (e.g., acorns) begin to drop until all have fallen. Fruits removed from traps should be counted and may be placed into categories, such as (1) well developed and sound; (2) well developed, but damaged by birds or squirrels; (3) well developed, but showing insect emergence holes; and (4) imperfectly developed, deformed, or aborted (Downs and McQuilkin 1944, McQuilkin and Musbach 1977, McShea and Schwede 1993).

Gysel (1957) estimated acorn production by multiplying the number of acorns collected per trap and species by 1.1 to compensate for losses by deflection. He then multiplied that value (acorns per unit area of trap) by the average weight of sound acorns and total crown area of the stand to derive an estimate of the weight of acorn production per unit area.

Small or Light Fruits of Trees

Like large mast, smaller seeds and fruits are important wildlife foods used by many small rodents, tree and ground squirrels, and game and nongame birds (Trousdell 1954, Hooven 1958, Yeatman 1960, Abbott 1961, Abbott and Dodge 1961, Asher 1963, Powell 1965, Landers and Johnson 1976, McShea and Schwede 1993, Schroeder and Vangilder 1997, McCracken et al. 1999). Abundance of small or light mast (e.g., pine seeds) varies from year to year, as for all fruiting species. For example, loblolly pine (*Pinus taeda*) seed varied from nearly 0 to as high as 243,000 seeds/ha (Allen and Trousdell 1961). The 2 principal techniques of sampling small or light seed production of trees are placing seed traps in a stand (Lotti and LeGrande 1959, Allen and Trousdell 1961, Graber 1970, McCracken et al. 1999) or counting the number of ripening cones on a tree with binoculars (Wenger 1953). The latter method may be simplified by counting only a portion of the tree (Wenger 1953) or by categorizing the relative abundance of cones on the tree as none, few (1–25 cones), medium (29–90), and heavy (≥100).

Fruits of Shrubs

Soft and hard mast of shrubs often is within reach of a biologist and may be counted (Suthers et al. 2000) or harvested directly from the shrub (Perry et al. 1999). In Georgia, Johnson and Landers (1978) collected all fruits, by species,

in 4-m^2 plots on a monthly basis from April through October. Their small sample of 5 plots per line had such high sampling error they were not able to compare production among the months sampled. Harlow et al. (1980) counted mast on scrub oaks (*Quercus ilicifolia*) in Florida in a series of 0.004-ha circular plots to estimate mast abundance. Total counts of mast were made for each species in each of 20–40 plots in each stand. Stransky and Halls (1980) counted fruits of shrubs and woody vines in 20 1-m^2 quadrats in 0.6-ha plots in eastern Texas. They dried fresh fruits of each species to obtain an average weight of each fruit and projected the yield per quadrat based on the quadrat counts. Stransky and Halls (1980) further developed regressions between fruit yield and plant height and density to simplify the sampling effort, similar to regressions of browse production. Perry et al. (1999) conducted soft mast surveys for 31 taxa in Arkansas and Oklahoma by counting berries present in 3-m^2 plots during mid-June, mid-July, and mid-August to coincide with ripening phenology of the major fruit-producing species. To estimate **dry mass production,** they counted and weighed samples of each fruit type and developed wet- to dry-mass conversion factors. They developed species-specific regressions relating seed head volume with dry mass for species with large seed heads containing abundant fruits, so that dry mass was estimated from counts and measurements of seed heads rather than from individual berries. Like most total enumeration methods, estimating total production of berries may be quite time consuming. Consequently, soft mast production may be characterized for extensive surveys on a scale of relative abundance ranging from 0 to 4, in much the same manner as for hard mast (Clark et al. 1994). Further, double sampling methods have been used to calibrate relative abundance indices to actual production by measuring fruit production for a sample of plots on which relative abundance is measured (Noyce and Coy 1989). Biologists must remain aware of the potentially serious variation in relative abundance estimates made by different observers, or among different regions or years.

Fruits of Herbaceous Vegetation

Herbaceous vegetation provides an abundant supply of seeds for wildlife. Sampling seeds of herbaceous species has not been as well developed as for trees, because more plant species are involved, and wildlife that use those seeds generally are less obvious. Sampling for seeds of herbaceous species is a miniature version of sampling for large mast from trees; samples may be taken from the ground, from traps, or directly from the plant. Ripley and Perkins (1965) sampled ground seed supplies (primarily legumes) for northern bobwhite (*Colinus virginianus*) from soil samples. They removed soil cores (7.6-cm diameter × 2.5-cm deep), screened the cores of litter and soil, and counted number of seeds in each core. Eight soil cores were taken at each of 3 points along a transect line, and the 8 samples were combined to project an estimated seed density and weight. Variation among lines was not greater than variation among points; thus, Ripley and Perkins (1965) suggested that random sampling may be as efficient as using lines. They also reported decreased numbers of seeds in the soil cores from autumn to spring, suggesting removal by wildlife. Larger plots and different sampling depths have been used by others. Haugen and Fitch (1955) used 15 30.5-cm × 30.5-cm plots, but they took material only from the soil surface when sampling for lespedeza (*Lespedeza* spp.) and partridge pea senna (*Cassia marilandica*) seeds. Young et al. (1983) used 32-cm × 32-cm open-bottom metal boxes driven 15 cm into soil to estimate abundance of Indian ricegrass (*Oryzopsis hymenoides*) seed in Nevada. They further removed the soil in 2.5-cm depth increments to identify where seed reserves occurred.

Seed traps for herbaceous plant seeds are smaller than those used for tree mast. Traps with fine-screen wire for the bottom and 0.64-cm hardware screen for the top have been used for estimating seed yield for game birds (Davison et al. 1955). Traps of this type eliminate seed predation by wildlife. Others have used traps with adhesives to hold the seeds. A Petri dish containing filter paper sprayed with Tanglefoot® or other nondrying sticky substances was used by Werner (1975), Rabinowitz and Rapp (1980), and Potvin (1988) to sample seed deposition in prairie grasslands. Rabinowitz and Rapp (1980) believed that seed production was underestimated in tallgrass prairie, because leaves closed over the trap, and seeds were intercepted by overhanging leaves. When temperatures dropped below freezing or when traps became covered with snow, they were not effective for catching seed. Huenneke and Graham (1987) used house-construction insulation hangers coated with a smooth surface of adhesive to sample seed rain in grasslands. They observed that height of seedfall affected the proportion of seeds adhering to the trap surface; at 60 cm, only about 3% of the seeds adhered, whereas at 10 cm, 65% adhered to the trap surface. Exposure to light, high temperatures, and dust had little effect on capture rates, but shape and form of seed did affect capture rates.

Seed traps also can be used over water to sample seed production and availability in wetlands. Olinde et al. (1985) constructed 12-cm × 30-cm traps and floated the traps on Styrofoam™ blocks. These blocks were held in place with ropes and stakes driven into the soil, and the blocks could rise and fall with changing water levels.

Laubhan and Fredrickson (1992) and Gray et al. (1999) describe techniques to sample and estimate seed yields in wetland and moist-soil environments. Laubhan and Fredrickson (1992) collected inflorescence measurements and all seeds from inflorescences of 13 common moist-soil plant species in a 25-cm × 25-cm sample frame. Sample stations were randomly placed in distinct vegetation zones or patches in wetland area. They found that seed yield varied widely among plant species. Gray et al. (1999) developed models to

predict seed yield per wetland plant species that also required an estimate of plant stem density per species. They used regression calculations of the mean stem density multiplied by mean seed yield per 60 plants per species to provide extrapolated species-specific seed yield data. Metabolizable energy values per seed yields per species can be used to estimate waterfowl carrying capacities per unit area of moist-soil or wetland habitat.

MULTIPLE-SCALE VEGETATION SURVEYS

Vegetation measurement on the ground can be facilitated with several technologies. Ground-based digital imaging systems, such as digital cameras with and without infrared viewing, have been shown to measure vegetation cover, amount of green vegetation, and **leaf area index** in grass and shrub dominated ecosystems (White et al. 2000, Rundquist 2002). Dycam ADC (http://www.dycam.com/agri.html) and Decagon First Cover systems (http://www.decagon.com/) are specifically made for vegetation measurement. Measurement of green vegetation cover is accomplished through automated procedures by classifying pixels in the digital image as green vegetation, bare ground, litter, woody material, or other nongreen material. Software classifies the image as a percentage of each specified material. Species and plant-form coverages are developed by sampling digital images for each component using trained observers and viewer software after field image acquisition. Digital cameras provide rapid field collection with minimally trained personnel and provide an extensive record of field conditions that is easily moved to computers, where further and more detailed analyses can occur.

Wildlife personnel have long desired to have methods to estimate live herbaceous biomass or structure and use at a fine scale over large areas (Olenicki 2001). Ground-based passive sensors or **radiometers** that measure electromagnetic reflectance from vegetation have been used to measure biomass, amount of green cover, and biochemical constituents along with classifying vegetation in grass, shrub, and forest-dominated systems (Van der Meer and de Jong 2001). These sensors measure several areas of the **electromagnetic spectrum** (**multispectral**) and some can measure continuously from the visible to well into the thermal portion (**hyperspectral**). Calibration via ground truthing is often required to accurately relate reflectance to traditional vegetation measurements. Ratios of the amount of energy reflected in different regions or bands of the electromagnetic spectrum are used to develop the relationship between reflectance and traditional vegetation measures. Radiometer readings need to be taken during midday on sunny days, so that incoming electromagnetic radiation is similar for all readings. Differences among ecosystems, plant forms, soils, and changes in vegetation during the year prevent universal calibrations from being developed for ground-based radiometers (Asner 1998). Calibrations using local conditions are needed to ensure the best fit (Moulin et al. 1998). Calibration of radiometers with vegetation measurement techniques that have poor repeatability, such as ocular estimation of cover, will result in poor relationships to vegetation reflectance because of the inherent variability of ocular estimations (Bonham 1989).

Ground-based systems have become lighter, more mobile, and easier to use in the field, enabling operators to take more samples in less time than with traditional field methods. Resolution is in the centimeter to meter range, so large numbers of samples are needed to adequately characterize diverse vegetation types over large areas. These systems also can be automated, so that field personnel do not need to be extensively trained in instrument operation.

Olenicki (2001) proposed that real-time Global Positioning System (GPS) receivers or military precision lightweight GPS receivers can aid relocation of points within 1 m accuracy, making the combination of ground-based radiometers and real-time GPS units ideal for monitoring temporal and spatial changes in vegetation over large areas. As an example, Merrill and Boyce (1991) successfully linked field sampling of herbaceous phytomass in Yellowstone National Park with spectral values taken from **Landsat multispectral scanners** for the same field sites to describe trends in phytomass availability on the northern Yellowstone elk (*Cervus canadensis*) range.

Aerial or satellite based technologies have been used extensively to measure regional vegetation patterns at the largest scale of sampling (Avery and Berlin 1992, Van der Meer and de Jong 2001). Passive sensors ranging from panchromatic (**aerial photographs**) to multispectral to hyperspectral have potential applications to vegetation measurement for wildlife managers. Passive sensors have been used to develop digital land-use coverages that are available from government sources (O'Neil et al. 2005). Most current land use and vegetation type coverages are derived from either aerial photography or **Landsat thematic mapper** multispectral imagery (30-m resolution). Aerial photography provides detailed images with resolutions ranging from a 1 m to 100 m. Aerial photography is limited to expert visual interpretation that requires extensive training and many hours to interpret small numbers of images. In contrast, Landsat thematic mapper multispectral imagery can be processed with an automated classification that increases efficiency. However, the 30-m resolution might not be at the scale that is useful for wildlife managers. Smaller resolution multispectral sensors are available, such as Ikonos (http://www.satimagingcorp.com/gallery-ikonos.html), Quickbird (http://www.digitalglobe.com/index.php/85/QuickBird), Orbview (http://www.glcf.umd.edu/data/orbview/), and special aerial sensors, but efforts at vegetation measurement are project-specific, and full coverage is not available for large-scale areas. Wildlife managers who want vegetation measurements

at smaller resolutions will have to initiate and fund projects to acquire such information at increased effort and cost.

Satellite imagery is useful for deriving measures of **net primary productivity** and **vegetation phenology.** Often these measurements have been derived from observations at weather stations several kilometers from the study area. Furthermore, net primary productivity has been generally based on variation in annual (or seasonal) rainfall rather than on more direct measurements of vegetation. Although imagery from the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) and the National Aeronautics and Space Administration's Moderate Resolution Imaging Spectroradiometer (MODIS) satellites have coarse spatial resolution (250–1,000 m), they have high temporal coverage (daily) over large geographic areas. Imagery from these (and other) satellites may be used to calculate the **Normalized Difference Vegetation Index** (NDVI), which is related to the density of chlorophyll contained in terrestrial plants (Sellers 1985). NDVI is derived from the red to near-infrared reflectance ratio [NDVI = (NIR – RED)/(NIR + RED), where NIR and RED are the amounts of near-infrared and red light, respectively, reflected by vegetation and recorded by the satellite]. Chlorophyll absorbs red light, and mesophyll leaf structure scatters near infrared light. NDVI ranges between –1 and 1, with negative values corresponding to no vegetation (Asrar et al.1984, Sellers 1985, Myneni et al. 1995). A time-series of NDVI may be used to calculate biologically relevant metrics, such as start of the growing season, rate of green-up, and length of growing season (Reed et al. 1994; Table 16.3). The integral of the seasonal time-series is strongly related to net primary production (Fung et al. 1987, Goward et al. 1987, Running 1990). To remove contamination from clouds and other atmospheric effects, ≥7 NDVI images are generally combined, using their maximum value; still, smoothing of the time-series may be necessary (Reed et al. 1994). NDVI imagery from AVHRR satellites is available globally at 8-km resolution from 1981; for the conterminous United States, imagery is available from 1989 at 1-km resolution. MODIS imagery is available from 2000 at 250 m, 500 m, and 1,000 m resolutions (Pettorelli 2005). Pettorelli (2005) provided a useful review of NDVI imagery for ecological studies.

NDVI imagery and metrics derived from them have proved useful for ecological studies. Rasmussen et al. (2006) compared explanatory power of rainfall and NDVI to predict time-specific conception rate of African elephants (*Loxodonta africana*). They found that NDVI was a more accurate metric than rainfall for the link between ecological variability and demographic parameters, such as mortality, reproduction, and carrying capacity. Sanz et al. (2003) studied the reproductive output of pied flycatchers (*Ficedula hypoleuca*) using NDVI to monitor tree phenology. They found that oak leafing occurred earlier with a concurrent advancement of peak availability of caterpillars. However, the flycatchers did not change their arrival time from Africa, causing a mismatch between timing of peak food supplies and nesting demand. Nesting growth and survival were negatively affected. Pettorelli et al. (2006) studied the yearly variation in mass of roe deer (*Capreolus capreolus*) fawns in 2 regions of France. There was a strong influence of plant productivity, as measured by integrated NDVI, in the region of lower plant productivity, but none in the higher productivity region. This variation demonstrated the need to use these tools in places where there is a strong link between the canopy (that satellites observe) and ground level vegetation (see also Rasmussen et al. 2006).

Table 16.3. Metrics that may be derived from time-series of normalized difference vegetation index (NDVI) imagery and their phenological interpretation

Metric	Phenological interpretation
Temporal NDVI metrics	
Time of onset of greenness	Beginning of measurable photosynthesis
Time of end of greenness	Cessation of measurable photosynthesis
Duration of greenness	Duration of measurable photosynthesis
Time of maximum NDVI	Time of maximum measurable photosynthesis
NDVI-value metrics	
Value of onset of greenness	Level of photosynthetic activity at onset of growing season
Value of end of greenness	Level of photosynthetic activity at end of growing season
Value of maximum NDVI	Maximum measurable level of photosynthetic activity
Range of NDVI	Range of measurable photosynthetic activity
Derived metrics	
Time-integrated NDVI	Net primary photosynthesis
Rate of green-up	Acceleration of photosynthesis
Rate of senescence	Deceleration of photosynthesis
Modality	Periodicity of photosynthetic activity

After Reed et al. (1994).

Although much of the use of aerial or remote sensing methods relates to mapping, recent improvements in spatial accuracy of Geographic Information System (GIS) tools have helped bring science to vegetation measurement and sampling and to detect the lack of vegetation, such as in forest canopy gaps. The importance of forest canopy gaps for location of songbird nests (Fox et al. 2000) was evaluated with data obtained from color-infrared photographs scanned at high resolution and spatially rectified to ground control points. Using aerial stereo photographs and scopes, Fox et al. (2000) created 3-dimensional images of canopy gaps that could be used in Arc/INFO (ESRI, Redlands, California) computer GIS files to aid digital software analyses. Tanaka and Nakashizuka (1997) used similar methodology to ana-

lyze long-term (15 years) canopy dynamics of a 25.25-ha mixed deciduous forest in Japan.

Several other methods have been used to detect temporal changes in vegetation structure at 5 scales of resolution that could be transformed to digital data sets, including cameras on sticks (Bennett et al. 2000), tethered balloons or blimps (Mims 1990, Pitt and Glover 1993, Murden and Risenhoover 2000), tower crane with a horizontal jib (Parker et al. 1992), ultralight aircraft (Cohen et al. 1990), fixed-wing aircraft (Everitt and Nixon 1985, Everitt et al. 1991, Ritchie et al. 1992, Blackburn and Milton 1996), and high-altitude remote sensing (Satellite Probatoire d'Observation de la Terre's High Resolution Visible Imaging System panchromatic images and Landsat thematic mapper data; Cohen et al. 1990, Bradshaw and Spies 1992). Reviews of these methods are provided by Everitt et al. (1991), Ritchie et al. (1992), Pitt and Glover (1993), and Blackburn and Milton (1996).

Active sensors are finding more application in vegetation measurement and will have an increasing role in this area. Radar applications are being developed to measure forest canopy and stand characteristics (Waring et al. 1995, Ranson et al. 2001). **Lidar** or laser altimetry is currently being used in canopy measurement for forests and shrubs (Lefsky et al. 2002), and it has been applied to aquatic habitats (Wang and Philpot 2007). The basic measurement by a lidar device is the distance between the aircraft sensor and a target surface that is expressed as the elapsed time between the laser pulse and the time it took to reflect back to the sensor divided by 2. Lidar's capability to characterize 3-dimensional canopies at small resolutions holds much promise for wildlife managers. Lidar technology is being quickly implemented compared to radar, and there are many providers available. Lidar is still limited, in that clouds can interfere with its functions, whereas radar is an all-weather technology. Acoustic (echolocation) methods are active sensors that can be used to sample and map submerged aquatic vegetation and are not hindered by water clarity (Sabol et al. 2002, Warren and Peterson 2007).

Lefsky et al. (2002) discussed the state-of-the-art of applications of lidar remote sensing relative to natural resources. They noted that numerous applications are feasible, but have not yet been explored, making it difficult to predict which applications will be dominant in the future. According to their review, current applications of lidar remote sensing in vegetation and ecological measurements fall into 3 general categories: remote sensing of ground topography; measurement of the 3-dimensional structure of vegetation canopies; and prediction of forest stand attributes, such as aboveground biomass. They also identify efforts of bathymetric lidar systems to measure elevations in shallow bodies of water. According to Lefsky et al. (2002), mapping of topographic features is the largest and fastest growing area of application for lidar remote sensing, mainly for commercial land surveys (Flood and Gutelis 1997), and largely because airborne laser altimetry is more accurate and cost effective than other methods.

Measurements of vegetation canopy and function are of primary interest to wildlife researchers and managers who study forest animal–vegetation relationships. Allometric canopy heights (maximum and mean) and cover or lack of cover (gaps in the canopy) have been computed for temperate (Maclean and Krabill 1986), tropical (Nelson et al. 1997), boreal (Magnussen et al. 1999), and temperate deciduous (Ritchie et al. 1995) forests. Caution must be made if considerable understory vegetation is present under the tree canopy, because it can disrupt exact elevation measures to the ground surface.

Relative to forest-stand structure attributes when species composition was noted, Maclean and Krabill (1986) were able to account for 92% of the variation in timber volume in stands of oak and loblolly pine. Nelson et al. (1997) successfully estimated basal area, volume, and biomass in tropical wet forests. The availability of information and results from lidar devices will increase as technology and analytical skills improve, including satellite lidar devices. Lidar measurements will have application to estimating levels of taxon biodiversity ranging from guilds and communities to specific species (e.g., natural cavities that are natural nesting sites for wood ducks in old-growth forests).

APPLICATIONS OF VEGETATION MEASUREMENT

We have presented methods for measuring plants or plant attributes of different forms of vegetation. We now discuss how some of these methods have been applied to studies of wildlife habitat.

Loft et al. (1987:656) evaluated mule deer (*Odocoileus hemionus*) habitat during 3 growing seasons in California. Their objectives were to "determine the effects of cattle stocking rate on hiding cover structure during the summer grazing season" and to measure levels of herbivory on willows and herbaceous meadow vegetation. Estimates of herbaceous forage production, deer hiding cover, and browse use were made in 0.1-ha cattle exclosures and adjacent sites subjected to moderate and heavy levels of cattle grazing. Herbaceous forage was clipped from 0.1-m^2 plots, oven-dried, and weighed 2–5 times each growing season. Hiding cover in aspen and meadow habitats was estimated at 8 locations around circular plots of 5.65-m radius with a 1-m^2 grid subdivided into 100 cells. A narrower 1.0-m × 0.4-m grid, similar to that described by Nudds (1977), was placed at 2-m intervals along 2 20-m transects, and the grids were read from a distance of 5.65 m in patchy willow habitat, where structure of the shrubs precluded use of the larger grid. The grids were read at 3 0.5-m increments to 1.5 m; the percentage obscured by vegetation from ground level to 1 m was considered hiding cover for fawns, and the percentage

obscured from 0.5 m to 1.5 m was considered cover for adult deer. To evaluate the browsing level of willows, Loft et al. (1987) tagged willow branches with ≤24 new shoots and measured the percentage of shoots browsed after cattle were removed from the site.

Litvaitis et al. (1985*b*:866) studied understory characteristics of snowshoe hare (*Lepus americanus*) habitat in Maine. Their objectives were to "examine hare habitat use and density in 2 areas of Maine with differing forest composition, and determine how those variables were influenced by forest understory characteristics." Snowshoe hare pellets were counted in 105 circular plots of 1-m radius on 7 700-m transects at each of 2 sites at each study area. Vegetation features were measured at each pellet plot. Percentage ground (canopy) cover of softwood, hardwood, herbaceous plants, and moss was estimated in each circular plot by projecting the plant crown to the ground surface. Understory stem density was estimated by counting the number of hardwood and softwood stems ≤7.5 cm DBH and ≥0.5 m tall in 2 15-m × 0.5-m quadrats, beginning at each pellet plot and running perpendicular to the transect. Visual obscurity at each pellet plot was estimated from a distance of 15 m for 3 0.5-m strata 0.50–2.0 m above the plot with profile boards (Nudds 1977). Overstory canopy closure was estimated with a spherical densiometer (Lemmon 1957) at each pellet plot. Correlation coefficients were calculated between each of the vegetation variables and the associated snowshoe hare pellet counts to identify which variables influenced pellet density.

Sedgwick and Knopf (1990:112) studied habitat relationships of cavity-nesting birds in plains cottonwood (*Populus sargentii*) along the South Platte River, Colorado. One of their objectives was to "compare nest sites of cavity-nesting birds with available (random) nesting habitat." Each nest tree was characterized by its species, DBH, height (measured with a clinometer), and the estimated length of dead limbs ≥10 cm diameter. Habitat was characterized in a 0.04-ha circle centered at each nest tree and at 31 random points in the cottonwood-dominated riparian vegetation type. Numbers of snags, trees 23 cm DBH, trees 23–69 cm DBH, and trees >69 cm DBH were counted in each circle to estimate density of the 4 classes. Overstory canopy cover was estimated at 4 points on the perimeter of each circle with a spherical densiometer. Tree basal area was measured in a circle around each tree and random point with a 10-basal-area-factors prism. These data were compared among the species of cavity-nesters, using the cavity to characterize habitat use.

Kirsch et al. (1978) studied habitat characteristics of upland nesting birds, particularly ducks, in North Dakota. One of their objectives was to evaluate the height-density (obstruction) of residual grassland vegetation structure in relationship to success and density of duck nests. Height-density of grassland was measured with a modified version of a visual obstruction pole (Robel et al. 1970); readings of 100% obstruction were taken from a distance of 4 m and an eye-level height of 1 m. Results of their study indicated that higher nest density and success for ducks occurred in residual grassland cover, with the highest average height-density readings at 100% obstruction.

Gilbert and Allwine (1991) studied relationships between small mammals and habitat characteristics of unmanaged Douglas-fir (*Pseudotsuga menziesii*) forests in Oregon. One of their objectives was to identify which environmental factors might be responsible for differences in small mammal communities among young, mature, and old growth Douglas-fir stands. They sampled small mammal abundance and vegetation in 56 young, mature, or old growth stands in 3 locations. At each stand, mammals were sampled in a 6 × 6 pitfall grid or 12 × 12 snap trap grid. In the pitfall grids, 9 points were sampled for vegetation; 16 points were sampled in the snap trap grid. Measurements were made in nested circular plots of 5.6-m and 15-m radius. In the 5.6-m radius plot, cover of logs by decay class, and cover on the ground of bare rock, exposed bare mineral soil, organic litter, moss, and lichen were estimated visually. Cover of foliage to 2-m height and by life form was estimated visually. Number and species of small and medium-sized live trees, snags, and stumps were counted to obtain density. In the larger circular plot, cover of shrubs and trees 2-m height was estimated in 3 canopy layers (midstory, main canopy, and super canopy). Number and species of large live trees and snags were counted. In the larger circle, the presence and type of water and occurrence of rock outcrop and exposed talus were recorded. The number of recent tree-fall mounds with exposed roots and mineral soil was counted. Vegetation components and small mammal numbers were summarized by stand, and data from the 56 stands were analyzed by detrended correspondence analysis (Hill and Gauch 1980) to explore relationships between species abundance and environmental variables.

Hobbs et al. (1982:12) studied carrying capacity of elk in Colorado. Their objectives were to "demonstrate that estimates of nutritional carrying capacity are viable habitat-evaluation procedures and to identify sensitive parameters in the range supply-animal demand algorithm." Estimates of biomass of plants comprising 2% of the elk's diet were necessary to develop the carrying capacity model. They obtained biomass estimates from 32 1-ha stands stratified by vegetation type. In each stand, forbs and grasses were clipped at ground level in 30 0.25-m^2 plots. Ten 2-m^2 plots were sampled for shrubs, and current stem growth was collected between ground level and 2.5-m high. Species were individually separated, dried, and weighed. These data were used to develop biomass estimates for vegetation types in the winter range of elk and were combined with nitrogen concentrations and in vitro dry-matter digestibility to estimate range supply of energy and nitrogen.

Schupp (1990:504) studied seed fall and seedling recruitment of a fruit-producing tree in Panama. Fruits of this tree

are eaten by monkeys and birds, and the seeds are eaten by a variety of rodents. Seedlings are eaten by deer and other large browsers. One of the objectives of the study was to examine whether there were "extensive year-to-year differences in viable seed fall, post-dispersal seed predation, seedling emergence, early seedling mortality, and seedling recruitment." Seed fall was monitored with 84 1.0-m^2 traps constructed of 1.5-mm mesh plastic window screening in 1-m × 1-m frames. Two traps were placed randomly in each of 42 adjacent 20-m × 20-m plots. Traps were not intentionally placed either under or outside the canopy of individual trees, although no traps occurred in large openings. Seeds were counted and removed from traps on a weekly basis. Seedling emergence was studied by scattering a known number of seeds and fruits directly under traps and counting the number of seedlings that emerged. Seedling recruitment was estimated in 3-m × 3-m plots that centered at the seed trap. Newly emerged seedlings were counted twice a year and marked with numbered colored plastic bird bands. The number of seedlings marked in a year was an estimate of that year's seedling emergence. From 58% to 74% of the seedlings marked in the first count of the year were present in the second, indicating moderate mortality of newly emerged seedlings. The total number present at the second count represented the year's seedling recruitment. Predation of individual seeds was measured by gluing a 30-cm piece of nylon fishing line to 576 seeds each year, attaching that line to wire-stake flags, and measuring unnatural changes in position or loss of the seed. Schupp's (1990) experiments showed that removal generally indicated loss to vertebrate seed predators. Among-year variation in viable seed fall, seedling emergence, seedling recruitment, and seedling survival was analyzed with parametric and nonparametric analysis of variance methods. An actuarial life-table method was used to analyze seed predation.

Wildlife ecologists have spent considerable time linking fine-grain vegetation measurements (e.g., quadrats and point-centered-quarters) to wildlife habitat use. In contrast, comparatively little research has been conducted to assess the importance of vegetation characteristics to habitat use at larger scales. As a result, resource managers confronted with conserving ecosystems extrapolate local recommendations to regional levels, because landscape studies are lacking.

Advances in the capabilities of electronic equipment (e.g., computers, video cameras, and GPS units) and increased availability of **landscape scale** data or mapping units for soils, aquatics, vegetation, weather, climate, and land use effects have allowed natural resource researchers and managers to scale up measurements of vegetation made in individual quadrat plots to the landscape level and to combine multiple coverages of other environmental attributes with vegetation data. These advances include digital imaging systems, radiometers, laser altimetry or lidar, and satellite or aerial systems that use active sensors (radar) or passive sensors (panchromatic to hyperspectral imagers). These technologies can be used to measure vegetation at different scales, from high resolution studies in small site-specific areas (measured in cm^2 or m^2) to regional or global assessments. Selection of the correct technology is a function of such factors as cost, time, highest resolution of vegetation to be measured, scale, and availability of technology. In addition, field data can be electronically entered onsite on palm or laptop computers or data loggers (Fig 16.13) and can be identified to specific transects, quadrats, or points using GPS locator Universal Transverse Mercator (UTM) coordinates.

Researchers have used remotely sensed land-cover data to incorporate regional variation in climate and land use into vegetation sampling schemes (Meentemeyer 1989, Bakker et al. 2002). Sampling designs that account for regional variability provide more reliable information to land managers who must deliver habitat programs across large geographic regions. Results from this type of work are being used to direct conservation planning efforts and design na-

Fig. 16.13. Electronic data logger with bar codes referenced to specific attributes of plants or animals.

ture reserves (Askins et al. 1987, Hansson and Angelstam 1991, Pearson 1993).

Scale issues are now widely recognized in wildlife science as a critical concept that influences the way that organisms relate to landscape vegetation patterns. Turner et al. (2001) formally defined **scale** as the spatial or temporal dimension of an object or process. Scale is important, because individual species often perceive the same spatial arrangement of habitats quite differently (Wiens 1989*a*, Levin 1992). For example, a highly mobile species, such as northern harrier (*Circus cyaneus*), that forages widely may be less sensitive to fine-scale changes in grassland vegetation than a sedentary meadow vole (*Microtus pennsylvanicus*) that uses dense grasslands to escape predation. Although it is easy to acknowledge that scale is an important study component, identifying the "right" scale at which to work remains a challenging issue. A key to selecting appropriate scales is to replace our own human perceptions of scale with a view of how individual wildlife species experience the landscape in space and time (Wiens 1976, Pearson et al. 1996). The concept of **ecological neighborhoods** (Addicott et al. 1987) provides a useful framework for thinking about how space and time components of an organism's behavior may be used to define an appropriate scale for study. However, studies of wildlife habitat at different spatial scales have confirmed there is no single correct scale at which to work: ecologists should identify a suite of appropriate scales at which to analyze their data (Pearson 1993, Sisk et al. 1997, Woodward et al. 2001). Relatively new information-theoretical approaches (Burnham and Anderson 1998) provide statistical methodology for conducting multiscale habitat analyses.

Specific software is needed for display and data analysis to use the new technologies. At the most basic level, workers need to view the imagery. Providers of free viewer products include ESRI (http://www.esri.com/), Erdas (http://www.erdas.com/Homepage.aspx), PCI (http://www.pcigeomatics.com/), ER Mapper (http://www.erdas.com/Homepage.aspx), Leica Geosystems (http://www.leica-geosystems.us/en/index.htm), the University of California at Berkeley, ENVI (http://www.ittvis.com/language/en-US/Company.aspx), and Global Mapper (http://www.globalmapper.com/). Full-featured programs that can view and analyze data range from modestly priced packages, such as Idrisi (http://www.clarklabs.org/), to expensive packages, such as Erdas, ENVI, ER Mapper, PCI, and those from ESRI. Other software packages, such as Adobe Photoshop®, have some use for applications using digital cameras.

Although some techniques are fairly recent in application, by combining a knowledge of the spatial characteristics of tree canopy and canopy gaps with principles of plant ecology, wildlife ecology, and landscape ecology, several inferences can be made regarding the distribution and diversity of wildlife and plant species in habitats across and at edges of geographic ecosystems and gradients of extensive scale.

SUMMARY

Vegetation structure, arrangement, and location are considered the primary components of wildlife conservation and management. Natural resource managers and research biologists use a variety of equipment and techniques to sample and measure vegetation in a multitude of different aquatic and terrestrial plant communities and vegetation types.

Aquatic vegetation assessment is more difficult to accomplish than that for terrestrial vegetation, because it involves floating, submergent, and emergent plant species. In most years, aquatic vegetation assessment is conducted while wading, from a boat, or from aerial photography. In these circumstances, such equipment as quadrat frames must be constructed of materials that will float to facilitate aquatic vegetation sampling and measurement in wetlands.

Terrestrial vegetation assessment is fairly straightforward, but sampling and measurement techniques vary considerably among grassland, shrubland, and woodland vegetation types. For example, rulers and tape measures can be used to measure plant height or canopy coverage (e.g., line intercept) for grass and forb species, whereas prisms, angle gauges, and spherical densiometers are needed to obtain the same measurements on trees. Relative to vegetative food items, the amount of fruit or mast production may be estimated by ocular counts on sample limbs or by collecting falling mast in various traps.

Vegetation sampling and measurement are generally conducted in vegetation patches or field-sized units of a local nature. In contrast, landscape-level assessments of vegetation are usually conducted using satellite, aerial, or video photography coupled with GIS techniques. Recent advances in computer capabilities have enabled managers and researchers to work with larger and more complex data sets to assess vegetation characteristics. These capabilities also enable the integration of other data sets, such as those for animal population demographics, weather, topography, and soils, with the vegetation data for greater in-depth analytical and modeling exercises.

To comprehensively address all possible ways to sample and measure vegetation would require volumes of text and figures. Here we have introduced the reader to as wide an array of vegetation sampling and measuring techniques as possible within the limits of this chapter. We encourage others to explore the literature we have presented and any new literature that will enhance their ability to assess vegetation in a manner that best fits their research or management objectives.

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