
Chapter 4. Monitoring Vegetation Composition and Structure as Habitat Attributes

Thomas E. DeMeo

Mary M. Manning

Mary M. Rowland

Christina D. Vojta

Kevin S. McKelvey

C. Kenneth Brewer

Rebecca S.H. Kennedy

Paul A. Maus

Bethany Schulz

James A. Westfall

Timothy J. Mersmann

4.1 Objectives

Vegetation composition and structure are key components of wildlife habitat (McComb et al. 2010, Morrison et al. 2006) and are, therefore, essential components of all wildlife habitat monitoring. The objectives of this chapter are to describe common habitat attributes derived from vegetation composition and structure and to provide guidance for obtaining and using existing and new vegetation data to monitor wildlife habitat.

We begin this chapter by addressing key concepts relevant to monitoring vegetation. Next, we describe each of the common habitat attributes associated with vegetation composition and structure and how they are measured or derived using field-sampled and remotely sensed data. We also describe sources of existing data, as well as methods for obtaining new data using established protocols. We conclude the chapter with a call for standardization and consistency in habitat monitoring efforts.

In developing a habitat monitoring program, the choice of attributes requires careful consideration of species ecology, available data and resources, and other factors (chapter 2, section 2.3). Although many vegetation attributes are associated with wildlife habitats, we chose to address these attributes (table 4.1) based on national technical guides (Warbington 2011, Winthers et al. 2005), a survey of the literature (e.g., Elzinga et al. 1998, Herrick et al. 2005, Morrison et al. 2006), and the practical experience of wildlife and vegetation ecologists.

Monitoring teams should check for existing data before planning for new data collection. To assist with this prework, we provide a list of numerous data sources that could be used for monitoring at broad, mid, and local scales (table 4.2). For example, data collected through the Forest Service Forest Inventory and Analysis (FIA) program

Table 4.1.—*Key habitat attributes of vegetation structure and composition for wildlife habitat monitoring.*

Attribute	Definition
Vegetation composition	
Vegetation type	A named category of plant community or vegetation defined on the basis of shared floristic and/or physiognomic characteristics (e.g., structure, growth form, floristic composition, and cover) that distinguish it from other kinds of plant communities or vegetation (FGDC 2008, Tart et al. 2011).
Cover type	A designation based upon the plant species forming a plurality of composition and abundance; typically based on the dominant species in the uppermost stratum of vegetation (e.g., Oak-Hickory) (adapted from Brewer et al. 2011b, FGDC 2008).
Association	The finest level of vegetation classification, defined on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions, and physiognomy (Jennings et al. 2006, as cited in FGDC 2008). Associations reflect topographic climate, substrates, hydrology, and disturbance regimes. Defined using diagnostic species, usually from multiple growth forms or layers, and more narrowly similar composition. As many as five species may be necessary to define an association in an unusually diverse region with even dominance (FGDC 2008).
Species abundance	The total number of individuals in a taxon or taxa in an area or community, often measured as cover (Lincoln et al. 1998).
Vegetation structure	
Trees	
Canopy cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the tree layer. Small openings in the crown are included (Warbington 2011).
Canopy closure	The proportion of the hemispherical sky obscured by vegetation when viewed from a single point on the ground (Jennings et al. 1999).
Diameter-derived attributes:	
Tree diameter	The length of a line passing through the center of a tree bole at breast height (4.5 ft), measured outside of the bark and perpendicular to the tree bole (Helms 1998).
Basal area	The cross-sectional area of the stem or stems of a plant or of all plants in a stand, generally expressed as square units per unit area.
Quadratic mean diameter	The diameter of the tree having the arithmetic mean basal area of a stand (Graves 1908, cited in Curtis and Marshall 2000).
Height	Distance from base of tree at ground level to growing tip of tree (Oliver and Larson 1996).
Canopy complexity	Diversity in number of layers and species within layers of forest vegetation (Lowman and Rinker 2004).
Stand density	A quantitative measure of stocking expressed either absolutely in terms of the number of trees, basal area, or volume per unit area, or relative to some standard condition (Helms 1998).
Snags^a and defective trees^b	
Decay class	A categorical measure of the amount of wood deterioration that is typically used to stratify diameter, height, and density into classes (table 4.8).
Diameter	Same metrics and definitions as for live trees, applied to dead or defective trees.
Height	Same definition as for live tree height, applied to dead or defective trees.
Density	Same definition as for stand density, applied to dead or defective trees.
Cavity size	Holes in trees; size is usually expressed as the width of the hole (Carey and Sanderson 1981).
Down wood	
Decay class	A categorical measure of the amount of wood deterioration that is typically used to stratify diameter, height, and density into classes (table 4.9).
Diameter:	
Line-intercept diameter	The diameter of a down log at the point where it is intersected by a line transect (Bate et al. 2008a).
Large-end diameter	For a log with root structure attached, it is the length of a line passing through the center of the log at the point equivalent to breast height if the log were standing. If the log has no attached root structure, it is the length of a line passing through the center of the log at its largest end (Bate et al. 2008a).
Length	Length of each log piece that meets the minimum diameter for inclusion in the sample (Bate et al. 2008a).
Cover	Percentage of ground covered by logs, derived from length and diameter of all pieces encountered on a line transect or within strip plots (Bate et al. 2008a).

Table 4.1.—*Key habitat attributes of vegetation structure and composition for wildlife habitat monitoring (continued).*

Attribute	Definition
Volume	Cubic feet of log per acre or cubic meter per hectare, derived from length and diameter of all pieces encountered on a line transect or within strip plots (Bate et al. 2008a).
Density	Number of logs per unit area, usually stratified by decay class and/or diameter class (Bate et al. 2008a).
Shrubs	
Shrub cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the shrub layer (Warbington 2011). Use the term canopy cover when small openings in the shrub canopy are included in the measurement; use the term foliar cover when small openings in the shrub canopy are excluded (SRM 1989).
Height	Height from ground to top of shrub (Johnson and O'Neill 2001).
Herbaceous vegetation	
Herbaceous cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the herbaceous layer (Warbington 2011). Use the term canopy cover when small openings in the herbaceous canopy are included in the measurement; use the term foliar cover when small openings in the herbaceous canopy are excluded (SRM 1989).
Height	Height from ground to top of herbaceous plant, or base of flower if plant is flowering.
Structural stages/seral stages	
Structural stages	Stand classification based on the horizontal and vertical distribution of components of a forest stand, including the height, diameter, crown layers, and stems of trees, shrubs, herbaceous understory, snags, and down woody debris (Helms 1998).
Seral stages	Stand classification based on temporal and intermediate stages in the process of succession (Helms 1998).

ft = foot.

^a A snag is "...a standing, generally unmerchantable dead tree from which the leaves and most of the branches have fallen—note for wildlife habitat purposes, a snag is sometimes regarded as being at least 10 inches (25.4 centimeters) in diameter at breast height and at least 6-ft (1.8-m) tall (Helms 1998: 168–169); see section 4.3.2 for further description.

^b Defective trees are living trees with wounds, scars, decay, and/or cavities; see section 4.3.2 for further description.

contains field-sampled and derived variables that are equivalent to wildlife habitat attributes (USDA Forest Service 2011) (table 4.3 provides a crosswalk between the habitat attributes listed in table 4.1 and FIA variables). In addition, Natural Resource Manager (NRM) database modules, particularly Field Sampled Vegetation (FSVeg; tabular data) and FSVeg Spatial (a polygon spatial layer), provide vegetation data at the forest level if they have been populated by local datasets (chapter 9). Moreover, many national forests and grasslands have databases of habitat attributes associated with both vegetation composition and structure that were measured in the process of vegetation **classification** and mapping. The national *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011) provides guidance for measuring vegetation-based habitat attributes. Within FIA, the Vegetation Indicator provides standard protocols for data collection of vegetation composition and structure attributes (Schulz et al. 2009). Data for FIA indicators are collected on a subset of plots, but the grid can be intensified as needed (sections 4.4.1, 4.4.3). Using standard protocols for measuring habitat attributes across a region greatly facilitates data integration and comparison among local management units, and it enhances the utility of compiled datasets. More information on acquiring and using **legacy data** is available in section 4.4.

The habitat attributes addressed in this chapter are important indicators of vegetation diversity as well as wildlife habitat and are, therefore, also relevant to vegetation monitoring. For example, a local management unit may choose to monitor vegetation composition and structure to determine whether progress is being made toward desired vegetation

Table 4.2.—Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details).

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	Existing data source	Methods	Existing data source	Methods	Existing data source
Vegetation composition						
Vegetation type	NN, data summaries	FIA/CVSc/local data, satellite imagery, and aerial photos	NN, data summaries	FIA/CVS/local data, satellite imagery, aerial photos	Ocular macroplot and other fixed area plots, quadrats, line intercept, point intercept, frequency	FIA/CVS/local data
Species abundance	NN, FIA/CVS data summaries	FIA/CVS/local data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats, line intercept, point intercept, frequency	FIA/CVS/local data
Vegetation structure						
Trees						
Canopy cover and closure	NN, dot grid/Digital Mylar	Satellite imagery, aerial photos	Dot grid/Digital Mylar, LIDAR	Aerial photos	Ocular macroplot or fixed-area plot; line intercept; point intercept; fisheye lens, moosehorn, ground-based LIDAR	CSE/CVS/FIA/local data
Diameter-derived attributes						
Diameter	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data
Basal area	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, LIDAR	Satellite imagery with FIA/CVS/other plot data	Variable radius plots, fixed area circular plots; prism	CSE/CVS/FIA/local data
Quadratic mean diameter	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data
Height			LIDAR		Ocular macroplot or fixed area plot; point intercept; laser scope, clinometer, Relaskops	CSE/CVS/FIA/local data
Canopy complexity	NN, FIA/CVS data summaries					FIA/local data
Stand density	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data. Difficult at this scale.	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data

Table 4.2.—Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details) (continued).

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	Existing data source	Methods	Existing data source	Methods	Existing data source
Snags and defective trees						
Decay class	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Diameter	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Height			LIDAR		Ocular macroplot or fixed area plot; point intercept; laser scope, clinometer, Relaskops	CSE/CVS/FIA/local data
Density	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	CSE/CVS/FIA/local data
Cavity size	Not applicable	Not available	Not applicable	Not applicable	Fixed area plots	Local data
Down wood						
Decay class	NN, FIA/CVS data summaries	Not applicable	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	Local data
Diameter	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Length					Line transects, fixed area plots	CSE/CVS/FIA/local data
Cover					Fixed area plots	CSE/CVS/FIA/local data
Volume					Line transects, fixed area plots	CSE/CVS/FIA/local data
Density	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	Local data
Shrubs						
Canopy cover	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	Local data
Height	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	Local data

Table 4.2.—Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details) (continued).

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	Existing data source	Methods	Existing data source	Methods	Existing data source
Herbaceous vegetation						
Canopy cover	NN, FIA/CVS data summaries	FIA/CVS/local data	NN, data summaries, autocorrelation analysis	Landscape transects, FIA/CVS/local data	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Height	Not applicable	Not applicable	Data summaries, autocorrelation analysis	Landscape transects, FIA/CVS/local data	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Structural stages/seral stages						
Structural stages	Derive from CVS/FIA data summaries	CVS/FIA/local data summaries	NN, data summaries	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Seral stages	Map analysis	Aerial photos and satellite imagery	NN, data summaries	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data

CSE = Common Stand Exam. CVS = Current Vegetation Survey (used only in the Pacific Northwest Region). FIA = Forest Inventory and Analysis (section 4.4.1). LIDAR = Light Detection and Ranging. NN = Nearest-neighbor methods (section 4.5.2).

Note: Table 4.10 provides descriptions of various types of satellite imagery used in habitat monitoring.

Table 4.3.—Cross-walk of vegetation structure and composition habitat attributes with FIA program variables.

Attribute	FIA variable(s) ^{a, b}	FIA table(s)	FIA sampling phase	Explanation
Vegetation composition				
Vegetation type				
Cover type	FORTYPECD = forest cover type	COND	P2	Forest cover type code ^c
Association	NA	NA	NA	Not directly available in FIA, but can use species-level data in plots to key sites to local plant association
Species abundance	VEG_SPCD = species code; SPECIES_CANOPY_COVER_TOTAL = total canopy cover of species	VEG_SUBPLOT_SPECIES	P3 VEG	For each vascular species recorded on P3 plots, abundance is recorded as ocular estimate of percent cover of the subplot area
Vegetation structure				
Trees				
Canopy cover	VEG_SPCD = species code, SP_CANOPY_COVER_TOTAL, and either SP_CANOPY_COVER_LAYER_3 and SP_CANOPY_COVER_LAYER_4 or MAX_COVER_LAYER_NBR_PRE2004	VEG_SUBPLOT_SPECIES	P3 VEG ^d	Ocular estimates of tree species canopy cover;
	TOTAL_CANOPY_COVER_LAYER_3 and TOTAL_CANOPY_COVER_LAYER_4	VEG_SUBPLOT	P3 VEG	Layer 1 = 0 to 2 ft Layer 2 = 2 to 6 ft Layer 3 = 6 to 16 ft Layer 4 = > 16 ft Ocular estimates of total cover (all species; can include trees, shrubs, and vines) in four layers over a standard subplot area
Canopy closure	Unavailable from FIA		NA	NA
Diameter-derived attributes:				
Tree diameter	DIA = tree DBH (in)	TREE	P2	Current diameter measured at breast height in the field, in inches
Basal area	BALIVE = live basal area (ft ² /ac), in FIA table name = COND; DIA = tree DBH (in)	TREE	P2	Computed from diameters of all live trees > 1-in DBH sampled in the condition; expressed as ft ² /ac
Quadratic mean diameter	DIA = tree DBH (in)	TREE	P2	Compute basal area of each tree on the plot: basal area = (0.005454)(DBH ²) (when DBH is in inches and basal area in ft ²); next determine mean basal area of all the trees on the plot or stand, then convert this back to quadratic mean diameter using: Dq = (mean basal area/0.005454) ^{1/2}

Table 4.3.—Cross-walk of vegetation structure and composition habitat attributes with FIA variables (continued).

Attribute	FIA variable(s) ^{a, b}	FIA table(s)	FIA sampling phase	Explanation
Height	HT = total tree height (ft)	TREE	P2	Develop height distributions and associated parameters (e.g., mean, standard deviation, maximum); summarize data by user-defined height classes
Canopy complexity	TOTAL_CANOPY_COVER_LAYER_1, TOTAL_CANOPY_COVER_LAYER_2, TOTAL_CANOPY_COVER_LAYER_3, and TOTAL_CANOPY_COVER_LAYER_4	VEG_SUBPLOT	P3 VEG	Ocular estimates of total cover (all species) in four layers over a standard subplot area.
Stand density	STATUSCD = tree status, DIA = tree DBH (in)	TREE	P2	STATUSCD indicates whether trees are alive, dead, removed, etc., compute density measures (e.g., trees/ac) based on user-defined tree size classes
Snags and defective trees				
Decay class ^c	STANDING_DEAD_CD = standing dead trees, DECAYCD = decay class	TREE	P2	FIA uses five decay classes (recorded only for dead trees)
Diameter	STANDING_DEAD_CD = standing dead trees, DIA = tree DBH (in)	TREE	P2	Can develop diameter distributions and associated parameters (e.g., mean, standard deviation, maximum); summarize data by user-defined diameter classes or FIA-defined classes using FIA data tools
Height	STANDING_DEAD_CD = standing dead trees, HT = total tree height (ft)	TREE	P2	Can develop height distributions and associated parameters (mean, standard deviation, maximum); summarize data by user-defined height classes
Density	STANDING_DEAD_CD = standing dead trees, DIA = tree DBH (in)	TREE	P2	Compute density measures (e.g., snags/ac), by size class if desired (using DIA)
Cavity size	Unavailable from FIA		NA	NA
Down wood				
Decay class ^d	DECAYCD = CWD decay class	DWM_COARSE_WOODY_DEBRIS	P3 DWM	FIA uses 5 decay classes for coarse woody debris ^e (CWD); see also Woodall and Monleon (2008)
Diameter				
Line-intercept diameter	TRANS DIA = CWD transect diameter (in)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Diameter of a piece of coarse woody debris where it intercepts the line used to tally large wood pieces
Large-end diameter	LARGEDIA = CWD large-end diameter (in)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Summarize data by user-defined diameter classes

Table 4.3.—Cross-walk of vegetation structure and composition habitat attributes with FIA variables (continued).

Attribute	FIA variable(s) ^{a, b}	FIA table(s)	FIA sampling phase	Explanation
Length	LENGTH = CWD length (ft)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Summarize data by user-defined length classes
Cover	NA	NA	NA	NA ⁱ
Volume	NA	NA	NA	NA
Density	NA	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Compute density measures (e.g., number of pieces/ac), by decay class if desired
Shrubs				
Canopy cover	VEG_SPCD = species code; SP_CANOPY_COVER_TOTAL	VEG_SUBPLOT_SPECIES	P3 VEG	Ocular estimates of percent cover for species of interest, collected only in forested condition classes; compute shrub cover by summarizing total cover of shrub species
Height	VEG_SPCD = species code; SP_CANOPY_COVER_LAYER_1_2, SP_CANOPY_COVER_LAYER_3	VEG_SUBPLOT_SPECIES	P3 VEG	Shrub height measurements are not collected specifically, but species canopy cover is collected by height layers in addition to total canopy cover
Herbaceous vegetation				
Canopy cover	VEG_SPCD = species code; SP_CANOPY_COVER_TOTAL	VEG_SUBPLOT_SPECIES	P3 VEG	Ocular estimates of percent cover for herbaceous species of interest; collected only in forested condition classes; compute herbaceous cover by summarizing total cover of herb species
Height	VEG_SPCD = species code; SP_CANOPY_COVER_LAYER_1, SP_CANOPY_COVER_LAYER_2	VEG_SUBPLOT_SPECIES	P3 VEG	Herbaceous height measurements are not collected specifically, but species canopy cover is collected by height layers in addition to total canopy cover
Structural stages/seral stages				
Structural stages	NA	NA	NA	NA
Seral stages	NA	NA	NA	NA

CWD = coarse woody debris. DBH = diameter at breast height. ft²/ac = square feet per acre. FIA = Forest Inventory and Analysis. ft = foot. in = inch. NA = Not applicable. P2 = Phase 2. P3 = Phase 3.

^a Table 4.1 provides definitions of vegetation-based habitat attributes.

^b Visit the Web site for more information (e.g., current field guides, FIA P2 and P3 sampling protocols, and FIADB documentation): (<http://www.fia.fs.fed.us/library>).

^c Requires crosswalk of codes; available in FIA table REF_FOREST_TYPE.

^d Tree canopy cover can also be derived from data collected in the more abundant P2 plots using modeled relationships (see Toney et al. 2009 for one example).

^e Table 4.8 provides descriptions of decay classes used by FIA for snags and defective trees.

^f Table 4.9 provides descriptions of decay classes used by FIA for down wood.

^g Coarse woody debris is sampled on transects, thus requiring different summarization processes than area-based samples.

^h Estimation procedures for cover and volume of CWD in FIA are available (Woodall and Monleon 2008), and DWM raw data can be downloaded.

conditions described in the unit's plan. When vegetation monitoring relates to habitat monitoring for a selected set of emphasis species or species groups, it can also be considered a **coarse filter** strategy for conservation. In this approach, representation of natural communities in protected reserves is hypothesized to protect a large percentage of associated species (Noss 1987, Noss and Cooperrider 1994). Using this approach, key **vegetation types** that serve as habitat for several emphasis species can be identified and protected, leading to more effective conservation.

4.2 Key Concepts

4.2.1 Vegetation as Habitat

Components of vegetation composition and structure frequently are the primary descriptors of habitat for a wide variety of wildlife species. Plant species are often indicators of site conditions. Compared with ecosystem processes, such as nutrient cycling, water flows, or disturbance, vegetation attributes are relatively easy to measure. Wildlife species can be grouped and associated with specific vegetation types and **structural stages** to increase efficiency of both management and monitoring (e.g., Johnson and O'Neil 2001, Wisdom et al. 2000; chapter 2, section 2.2.5). Vegetation types describe the dominant species present, whereas structural stages describe the size, height, and vertical arrangement of those dominant species.

Often, habitat attributes are only proxies for the true environmental relationship of interest. For example, prey for insectivorous birds is difficult to accurately quantify, so biologists typically measure other attributes, such as foliage volume, that serve as proxies for prey abundance (Morrison et al. 2006). When deciding which attribute to measure in a particular habitat, the conceptual basis for selecting that attribute must be clearly stated (Morrison et al. 2006). Chapter 2 (section 2.2) further addresses attribute selection.

Although this chapter focuses on attributes of **existing vegetation** for monitoring wildlife habitat, the concept of **potential natural vegetation (PNV)** may aid in delineating habitat or in stratifying the area of interest. PNV is the plant community that would become established if all successional sequences were completed without human interference under the present environmental and floristic conditions, including those created by humans (Tüxen 1956, as cited in Winthers et al. 2005). Potential vegetation is a useful organizing concept to delineate habitat by elevation bands, microclimates, productivity, or soils, which may be related to wildlife occurrence. The *Terrestrial Ecological Unit Inventory (TEUI) Technical Guide* (Winthers et al. 2005) is the Forest Service standard for potential vegetation classification and mapping. The agency is also developing a national potential vegetation classification and mapping guide; definitions and concepts in that document concur with the *TEUI Technical Guide*.

4.2.2 Vegetation Composition and Wildlife Habitat

Vegetation composition includes the kinds, absolute amounts, or relative proportions of plant species present in a given area (Warbington 2011). At the most basic level, **physiognomic** types (e.g., forests, shrublands, and meadows) describe the vegetation present. Vegetation types are defined on the basis of floristic and physiognomic characteristics that distinguish them from other kinds of vegetation (Tart et al. 2011, table 4.1). Using vegetation types, researchers can rapidly evaluate the relative value of various vegetation communities to the emphasis wildlife species of a habitat monitoring program.

Information about vegetation composition is vital to understanding and managing wildlife habitat because plant species are closely tied to wildlife use, past or future disturbance, and site productivity. For example, susceptibility to fire, associated wildlife species, and forage production could differ vastly between a loblolly pine (*Pinus taeda*) and a longleaf pine (*Pinus palustris*) forest. Differences in vegetation composition lead to opportunities for niche differentiation for birds, mammals, reptiles, and amphibians as well as for insects and other invertebrates that are prey (Morrison et al. 2006, Odum 1969). Vegetation composition data can be used in wildlife habitat monitoring in many ways, such as (1) identifying how plant species are capturing site resources (e.g., evaluating nonnative cheatgrass [*Bromus tectorum*] **dominance** in a native shrub community), (2) determining how key plant species are distributed across an environmental gradient in relation to the wildlife emphasis species, and (3) assessing changes in vegetation composition following management actions that may affect habitat of an emphasis species.

4.2.3 Vegetation Structure and Wildlife Habitat

Structure is the spatial arrangement of the components of vegetation, such as live and dead stems, branches, and foliage (Lincoln et al. 1998). It is a function of plant size and height, vertical stratification into layers, and horizontal spacing of plants (Mueller-Dombois and Ellenberg 1974, Warbington 2011). Plant condition also creates structure; for example, whether plants are alive, diseased, dead, heavily browsed or grazed; and, for trees, whether they are standing or fallen. In general, more structural diversity means more wildlife species diversity (Huston et al. 1999, MacArthur and MacArthur 1961) because vegetation structure enables organisms to occupy different niches within the same ecosystem (Morrison et al. 2006, Willson 1974). Greater diversity of organisms results in food webs that are more complex. Structural diversity contributes to greater diversity of food resources for most species within the system while also providing refuges for potential prey. Structure also creates sites for resting, denning, conducting breeding displays, avoiding inclement weather, and overwintering. Marcot et al. (1997) identified compositional and structural habitat elements for wildlife, and Johnson and O'Neil (2001) further associated these elements with a number of species.

4.2.4 Monitoring Vegetation at Different Spatial and Temporal Scales

We use scale in this guide to mean areal extent (as ecologists do), rather than as a map ratio (as geographers do). Spatial scale is a critical consideration in habitat monitoring for many reasons. For one, the relative importance of vegetation composition compared with structure can depend on the extent of the area of interest (Morrison et al. 2006, Rotenberry 1985). The habitat needs of wildlife species can vary greatly in areal extent; consider the foraging area of grizzly bears (*Ursus arctos*) or wolves (*Canis lupus*) compared with that of field mice. In addition, data resolution influences the derived values and, hence, the understanding of habitat conditions. For example, when measured in a Geographic Information System (GIS), edge density (total length of edge per unit area) declines as pixel size increases because at the coarser resolution patch edges are smoother. As a result, the amount of habitat for edge-associated species appears to be less at coarser resolutions (Trani 2002). Likewise, habitat of interior forest specialists, such as the hooded warbler (*Wilsonia citrina*) and worm-eating warbler (*Helminthos vermivorus*), tends to be underestimated at coarse resolution because the percentage of forest interior declines with loss of resolution (Trani 2002). In a more general sense, effects of spatial aggregation and spatial resolution could lead to underestimation when a certain vegetation type (e.g., hardwood forest) is uncommon, and to overestimation of the same type when it is abundant. This inaccuracy in estimation is true for thematic attributes but not for continuous attributes (Nelson et al. 2009b). The concept of spatial and temporal scale in relation to habitat monitoring is addressed in detail in chapter 2 (sections 2.2.6, 2.3.2; Tavernia and Reed 2010).

Monitoring methods vary by spatial scale because not all methods are appropriate at the same or at multiple scales; moreover, a trade-off generally exists between level of detail and cost. As spatial extent increases, it is usually necessary to place plots at increasing distances and to use remotely sensed data at coarser resolutions. Monitoring implies repeated measures through time to detect change; therefore, before selecting a monitoring approach, consider the costs of acquiring new data with each time step. Thus, the area of analysis for a monitoring program will greatly influence decisions regarding using existing data and collecting new data. Also, some questions, such as habitat quality or abundance for a large predator, can be addressed only at specific scales. For example, fine-scale vegetation data collected within a small portion of a watershed will be of little use in evaluating grizzly bear habitat but may be critical for evaluating the habitat of a small invertebrate.

Throughout this chapter, we refer to three general spatial scales: local, mid, and broad. This framework follows the national *TEUI Technical Guide* (Winthers et al. 2005) and *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011). We modified these approaches somewhat by omitting the national scale and by using the term local scale to refer to the base scale described in Warbington (2011) and the **land unit** scale of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005). The following

three scales (referred to as levels in table 1.1 of the *Existing Vegetation Classification and Mapping Technical Guide* [Warbington 2011]) provide an organizing concept for sampling strategies.

Local scale. Ranges from a few acres to a few thousand acres. At this scale, the integration of soil, vegetation, and local topography define ecological units.

Midscale. Equivalent in area to a watershed in the range of a sixth to a fourth field hydrologic unit of capability (HUC) (i.e., in the thousands to low hundreds of thousands of acres). At this scale, geomorphology and broad vegetation zones become the primary drivers of diversity. Midscale is equivalent to the landscape scale of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005).

Broad scale. Large regional and subregional areas defined by consistent climate and geology. Examples include the Central Appalachians and the Piedmont in the Eastern United States and the Coast Range and the Klamath Mountains in the Pacific Northwest. Areas range from thousands to millions of acres. At this scale, the primary drivers of ecosystem function are climate and geology (Cleland et al. 1997, Winthers et al. 2005). As used in this technical guide, broad scale is equivalent in area and ecological function to the ecoregion and subregion scales of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005) and is also consistent with its usage in the *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011).

Temporal Scale

Monitoring objectives will determine monitoring frequency. Often long-term monitoring is needed for demonstrating trends, but it can be difficult to implement effectively because of erratic funding, personnel changes, and shifting importance of issues. If the objective requires long-term monitoring, ensure a structure is in place that includes written support from leadership, commitment from partners, and a contingency plan in the case of unforeseen reduced funding and personnel changes. Long-term monitoring efforts are also more likely to succeed if the selected attributes are relatively simple and straightforward to measure.

Shorter term monitoring (1 or 2 years) may sometimes be appropriate, such as in testing the efficacy of a monitoring method or determining if a short-term answer will meet monitoring objectives. For example, if you implement a silvicultural treatment with an objective of providing only transitory deer forage, and monitoring reveals that the treatment area has lost its deer forage value after 2 years, you can end data collection and complete a monitoring report.

4.3 Habitat Attributes—Vegetation Composition and Structure

In this section, we address specific vegetation composition and structural attributes, including definitions, wildlife use of the attribute, and standard methods of measurement. Because of the length and complexity of this section, we have also included table 4.1, which presents the attributes in the same order and with the same hierarchical structure as we present them here, along with a standard, published definition for each attribute. The first subsection (subsection 4.3.1) focuses on two primary attributes of vegetation composition that are important to wildlife: vegetation type and species abundance. The second subsection (subsection 4.3.2) describes 25 structural attributes, organized under the general **life form** and functional categories of trees, snags, down wood, shrubs, and herbaceous vegetation. Within both subsections, we describe standard methods of obtaining attribute values, either through field measurement or through estimation from remote sensing. We present standard ways to summarize attribute data in table 4.4.

4.3.1 Vegetation Composition Attributes

Vegetation composition can be an important component of wildlife habitat (section 4.2.2). A common link between vegetation composition and wildlife habitat is food. The relative forage value of plant species to herbivores varies greatly. For example, differences in food value of an oak (*Quercus* spp.) compared with a Douglas-fir (*Pseudotsuga menziesii*) stand can be substantial, even if the two stands are identical in other attributes, such as structure or density. When evaluating the value of vegetation composition data for habitat monitoring, it is especially important to collect data that are biologically relevant to the emphasis wildlife species. If a plant species has forage value, for example, the absolute amount of the species will be most relevant, followed by its relative proportion. Simple presence/absence data will be much less informative.

Many plot types and methods are available to assess vegetation composition; the protocol you select will depend on monitoring objectives. Use fixed-area plots (section 4.4.2) of various sizes to quantify species abundance at local scales. You can also use large, circular **macroplots** with a technique developed by Braun-Blanquet known as the **relevé method** (Barbour et al. 1987, Warbington 2011; see table 2.2 in Warbington [2011] for a listing of commonly used macroplot sizes for vegetation classification). Elzinga et al. (1998) provide comprehensive guidelines for particular measurements of vegetation composition. Vegetation composition plot data are often compiled into a plot-species matrix for analysis (see Warbington [2011] for details). Collect plant abundance, height, and other measurements concurrently, providing more detail on how various species contribute to vegetation structure (section 4.3.2).

Begin collecting vegetation composition data with recording plant species of interest in the plot. The level of information needed for a particular monitoring program can vary

Table 4.4.—Common data summaries for vegetation habitat attributes.

Habitat attribute	Data summary methods
Vegetation composition	
Vegetation type	Report the percentage of area and number of acres of each vegetation type present in a given spatial extent. For example, a given landscape might be composed of 74 percent Douglas-fir/western hemlock (<i>Tsuga heterophylla</i> ; 740 ac), 15 percent western redcedar (<i>Thuja plicata</i> ; 150 ac), and 11 percent red alder (<i>Alnus rubra</i>) vegetation types (110 ac) in a subwatershed of 1,000 ac.
Species abundance	Report number of individuals of a species, the species' frequency of occurrence (density), biomass, or percent cover. Summarize and report abundance on either absolute or relative scales. Relative abundance most commonly is reported, e.g., calculating mean cover of each species across the sample units and comparing estimates among all species of interest. The range of values observed may also be reported. See Schulz et al. (2009) for equations for variance for plant abundance.
Vegetation structure	
Trees	
Canopy cover	Report percent cover within the area sampled, or the mean percent cover for the species or vegetation type/ structural stage combination in the area of interest. Classify canopy cover if monitoring objectives have been defined for cover classes.
Canopy closure	Report percent closure within the area sampled, or the mean percent closure for the species or vegetation type/ structural stage combination in the area of interest. Classify canopy closure if monitoring objectives are defined for closure classes.
Diameter-derived attributes:	
Tree diameter	Report diameters in classes, i.e., the number of individual trees tallied per diameter class. Classes will vary with the species of interest, so store raw, unclassified data and classify as dictated by monitoring objectives. Deciding on the classes should be an interdisciplinary effort that reflects multiple objectives within data constraints. For example, 2-in diameter classes can probably not be accurately determined using satellite imagery.
Basal area	Derive from diameter class data where basal area (in ft) = $(\sum \pi r^2)/144$, where π is the constant 3.1416, and where r is the radius (one-half the diameter [in]).
Quadratic mean diameter (QMD)	Calculate QMD from diameter class data using formula from Buckingham (1969): QMD = the square root of $[n_s/\text{the sum of } (1/d^2)]$, where d represents the diameters and n_s is the number of trees viewed in the sample using an angle gauge or prism.
Height	Report mean height of predefined overstory class or for all tree diameter classes of interest.
Canopy complexity	Generally, report as the number of canopy layers when measured vertically. Various equations can be used (Herrick et al. 2005), but data often are summarized as the proportion of vegetation occurring in each canopy layer relative to total vegetation intercepted.
Stand density	Report number of trees per unit area (stems per acre). Data for multiple samples or stands can be used to report the mean and range; density can also be used to identify structural and seral stages. For example, knowing that an area has 10,000 trees/ac indicates a young, regenerating site with high productivity. Stand density becomes more useful when coupled with diameter information; i.e., reporting the number of trees per acre in each diameter class, rather than a simple total of trees per unit area.
Snags and defective trees	
Decay class	Report snags by decay class, using the five decay-class system recommended by Forest Inventory and Analysis. Summarize as the frequency distribution of snags and defective trees by decay class; can also report by diameter class within decay classes.
Diameter	Report snags by diameter classes as dictated by objectives (Bate et al. 2008b). For wildlife use, snag diameter often is reported in terms of a threshold (e.g., all snags at least 10-in DBH). Defective trees can be reported using the same diameter classes as other live trees, unless some compelling reason to use a different class system exists that is based on the emphasis species or monitoring objective. Data can also be summarized by diameter class within decay classes; can also be reported by frequency distribution of snags and defective trees by diameter classes.
Height	Report mean height of predefined overstory class or for each decay class of snags; can also report frequency distribution of snags and defective trees by height classes.
Density	Report number of snags per acre by species and/or decay classes; can also report for stand level.
Cavity size	Report cavities based on the method in McComb et al. (1986) using four diameter classes: 12.5 to 19.9 cm (5 to 8 in), 20.1 to 39.9 cm (8 to 16 in), 40 to 59.9 cm (16 to 24 in), and 60 cm (24 in) or greater (Pattanavibool and Edge 1996, McComb et al. 1986).

Table 4.4.—Common data summaries for vegetation habitat attributes (continued).

Habitat attribute	Data summary methods
Down wood	
Decay class	Report logs by decay and diameter classes using the three decay classes defined by Bate et al. (2008a).
Diameter:	
Line-intercept diameter	Report mean diameter of logs at the point that logs are intercepted along transect lines, using the intercept method described by Bate et al. (2008a). Report diameters by decay and length classes relevant to the habitats or species of interest.
Large-end diameter	Report mean diameter of logs as measured at their large end, when the large end is equivalent to the measurement of DBH of trees (see Bate et al. 2008a for details). Report diameters by decay and length classes relevant to the habitats or species of interest.
Length	Report mean length of all logs measured within strip plots or similar sample units, averaged among all sample units by vegetation types or areas of interest, following methods of Bate et al. (2008a).
Cover	Report percent cover of down wood using the methods of Bate et al. (2008a) or using the conversion methods of Mellen-McLean et al. (2012).
Volume	Summarize log volume using the method in Bate et al. (2008a). Calculating volume by diameter class of logs is probably the most useful approach, rather than simply reporting overall volume. Report density by number of pieces per unit area, by decay and diameter class.
Density	Report mean number of logs per unit area, summarized among all sample units by vegetation types or areas of interest. Mean log density is typically summarized by log decay and length classes (Bate et al. 2008a).
Shrubs	
Shrub cover	Report shrub canopy cover as average percent cover of the plots sampled or for the area assessed (such as on an image or photograph). Also report range of values. Depending on objectives, total shrub cover may be adequate; for some monitoring programs, cover by individual species or genera may be needed.
Height	Report mean and range of shrub heights for each species of shrub of interest, or for life forms of shrubs, such as shrubs below or above a specified height (short versus tall shrubs).
Herbaceous vegetation	
Herbaceous cover	Report mean canopy or foliar cover occupied by each species of interest, or the mean frequency and mean length that cover is intercepted along a sampling line (e.g., line-intercept sampling) within sample units for vegetation types or areas of interest.
Height	Report mean and range of herbaceous vegetation heights of each species of interest or for life forms of interest. Example life forms of herbaceous species for which summaries are reported include prostrate versus vertical growth forms of species.
Structural stages/seral stages	
Structural stages	Report percentage area and number of acres of each structural stage present in a given spatial extent. For example, a given landscape may be composed of 25 percent old forest (250 ac), 40 percent sapling-pole (400 ac), and 35 percent grass-forb (350 ac) structural stages.
Seral stages	Use the same summary procedures as for structural stages.

ac = acre. cm = centimeter. DBH = diameter at breast height. in = inch. m = meter.

from basic physiognomic types (forests, woodlands, shrublands, meadows) to specific plant **associations**. Existing remotely sensed data, local vegetation type maps, and plant association guides may provide the required information. If not, you may focus collection of additional data for inventory or monitoring on all or a portion of the plant species present. For example, data may include (1) only vascular plants, (2) only life form, (3) a subset of species associated with a particular habitat attribute (e.g., huckleberry [*Vaccinium* spp.]), or (4) all plant species present at more than a certain abundance threshold (e.g., 5 percent canopy cover).

Vegetation composition can be assessed at multiple scales but generally requires field measurements at a local scale that are then either grouped and summarized at a

broader scale or related to the landscape by associating plot data to remotely sensed data (see Nearest Neighbor Imputation, section 4.5.2). Conducting literature searches and conferring with experienced colleagues can help identify the best assessment strategy. Follow these actions with preliminary surveys using various combinations of numbers and sizes of sample units to determine the optimal sample size for quantifying vegetation composition (Elzinga et al. 1998). After researchers obtain an adequate sample, the resulting list of species and their abundance (measured as counts of individuals, cover, or size) will provide a coarse characterization of vegetation composition and enable the monitoring team to make spatial (across multiple areas) and temporal (across multiple years or sampling events) comparisons (Daubenmire 1968). When comparing estimates of vegetation composition through time in a habitat monitoring program, sample vegetation with the same effort each time (i.e., number and size of sample units should be equal) and preferably at the same time of year to capture or exclude ephemeral species (species that appear only seasonally). Chapter 3 further addresses sampling design practices.

Vegetation Type

Vegetation type, a plant community based on its unique characteristics (table 4.1) is often the first and sometimes the only vegetation attribute used to describe wildlife habitat. For example, Nelson et al. (2009a) estimated breeding **habitat abundance** for flammulated owls (*Otus flammeolus*) across western North America, primarily using the distribution of ponderosa pine (*P. ponderosa*) and Jeffrey pine (*P. jeffreyi*) vegetation types within specific size or diameter classes, as determined from FIA data. Biologists often use vegetation type or **cover type**, combined with structural stages (section 4.3.2), to describe wildlife habitat relationships. Examples include the California Wildlife Habitat Relationships System (Meyer and Laudenslayer 1988), which uses CalVeg (<http://www.fs.fed.us/r5/rsl/projects/classification/system.shtml#hier>), and the wildlife-habitat type relationships described for Oregon and Washington (Johnson and O'Neil 2001). Wisdom et al. (2000) used cover type and structural stage combinations to describe habitats for more than 90 wildlife species of concern in the interior Columbia River Basin. For example, habitat for white-headed woodpecker (*Picoides albolarvatus*) included old multistory and old single-story Pacific ponderosa pine (*Pinus ponderosa* var. *ponderosa*). The terms vegetation type and cover type are sometimes used interchangeably but, in accordance with the Federal Geographic Data Committee (FGDC) (2008), we distinguish between them, defining cover type as a floristic classification within vegetation type (table 4.1).

Vegetation types are defined in vegetation classification systems that are typically hierarchical, with the highest levels using broad combinations of dominant general growth forms to define classes, such as mesomorphic shrub (FGDC 2008). Classification systems use floristics (species composition) to classify vegetation at lower levels. For example, in the National Vegetation Classification (FGDC 2008), the two lowest levels of classification are **alliance** and association. An alliance contains one or more associations and is named for the dominant growth forms (e.g., northern pin oak [*Quercus ellipsoidalis*] or

mountain big sagebrush [*Artemisia tridentata vaseyana*]). An association is described by the dominant species in each of several vegetation layers (e.g., sugar maple-American basswood [*Acer saccharum-Tilia americana*]/stinging nettle [*Urtica dioica*]) (table 4.1).

To determine what level of vegetation type is appropriate for the monitoring program, first consider the level of habitat selection by the emphasis species (Johnson 1980; chapters 2 and 10 of this technical guide). This information will help guide the corresponding selection of vegetation types and the resolution of data that is appropriate. After selecting the level of vegetation type, such as broad cover types, determine whether field-sampled or remotely sensed data, or a combination of both, are needed to measure this habitat attribute.

For example, the Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) and closely related Virginia northern flying squirrel (*G.s. fuscus*) are associated with specific boreal conifer and mixed-conifer cover types, especially red spruce (*Picea rubens*), in the southern Appalachian Mountains (Loeb et al. 2000, Odum et al. 2001, Payne et al. 1989, Weigl 2007). The squirrels are seldom found in pure conifer stands (Weigl 2007), however, but are often associated with open understories supporting isolated, large-diameter conifers (Odum et al. 2001). Understory vegetation is an important habitat component for these subspecies, but understory vegetation composition and cover vary widely among sites used by the squirrels (Payne et al. 1989, Weigl 2007). Thus, habitat monitoring for these subspecies is best accomplished using field-sampled data, supplemented by remotely sensed data when available and of sufficient accuracy.

In contrast, remotely sensed data provide a method for measuring vegetation type when the amount or configuration of vegetation types is important. For example, in chapter 10, the hypothetical monitoring plan for the American marten (*Martes americana*) focuses on amounts of particular vegetation types and structural stages, which can be obtained from classified vegetation maps derived from remotely sensed data. For some species, the spatial distribution of key vegetation types may be important. The area in these types may need to be distributed in large polygons or patches, monitored through landscape metrics, such as patch size, shape, or isolation (chapter 6).

Even if vegetation type is not used as an attribute in a habitat monitoring program, it can be a filter to help define the monitoring area. For example, if an emphasis species is associated with only paper birch (*Betula papyrifera*), identifying the areas where this type occurs can quickly focus the monitoring effort. Vegetation type may also serve as the framework for sampling other vegetation composition attributes (e.g., species abundance). Potential vegetation can also fill this filtering role; it is often an efficient first step for identifying areas of wildlife habitat interest across a landscape. After this step, measure specific vegetation composition or structure attributes within the vegetation type of interest. Another key metric is the number of patch types or vegetation types within a particular area, expressed as habitat diversity or patch richness (for examples see Saab 1999 and Sawyer et al. 2007).

All available sources should be checked before initiating a new vegetation classification and mapping project for habitat monitoring because classification and mapping can be costly and time-consuming depending on the level of information required and the area involved. This guide provides examples of existing vegetation classification systems (table 4.5) and map products (table 4.6). Also, most national forests and grasslands have maps of existing vegetation, typically accessible through agency servers or file transfer protocol sites; many forests also have developed guides to local plant associations or communities. Contact the GIS staff for the land management unit of interest to access these products and to determine if existing vegetation maps are static (i.e., one-time products) or will be updated. If no existing vegetation maps exist for the monitoring area, or the maps do not meet the specifications of the monitoring objectives, follow the guidelines in the *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011) to classify and map existing vegetation in the monitoring area.

Vegetation classification and mapping are not the same as habitat classification and mapping, although the two approaches are closely related. Vegetation classification and mapping focus on comprehensively describing the composition of existing vegetation to meet a specific information need, which may or may not include describing habitat for an emphasis species or species group. Because existing vegetation is often a key component of wildlife habitat, however, classifying and mapping vegetation can provide important inputs to habitat classification and mapping. In some cases (e.g., if vegetation type is the only habitat attribute monitored), vegetation classification and mapping units may directly match habitat classification and mapping units for a species or species group needed. Vegetation mapping, however, usually forms a core spatial layer from which wildlife habitat maps are derived, based on the species or group of species of interest.

Species Abundance

Measurements of plant species abundance typically reflect the total number of individuals per taxon and their size in an area or community. If the association between a species and certain site conditions is strong, then the abundance of that plant can be used as an indicator of site conditions and, by extension, it can function as a surrogate index of habitat. For example, if a mollusk species is closely associated with particular nutrient-rich soils and shield fern (*Dryopteris* spp.) grows only on those soils, the fern may serve as an indicator of the mollusk's habitat.

Plant abundance can be assessed in several ways, such as cover, counts, biomass, or volume, but it is commonly expressed as canopy cover of a genus, species, or species group. Canopy cover is the percentage of a given area covered by some part of the plant, typically the foliage (section 4.3.2); as such, canopy cover is also a measure of vegetation structure. Cover can be reported for individual species, groups of species, by life form, or as total vegetation cover for a plot or specific area regardless of whether referring to trees,

Table 4.5.—*Examples of existing vegetation classification systems and standards.*

Name	Extent	Author/steward	Current version	Reference	Web site
Ecological systems of the United States	United States	NatureServe	2003	Comer et al. 2003	http://www.natureserve.org/library/usEcologicalsystems.pdf
Rangeland cover types	United States	Society for Range Management	1994	Shiflet 1994	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044255.pdf
Forest cover types	United States and Canada	Society of American Foresters	1980	Eyre 1980	
Silvicultural systems	United States	USDA Forest Service	1983	Burns 1983	http://www.fs.fed.us/rm/pubs_other/wo_1973_agric_handbook445.pdf
Existing vegetation types	Pacific Northwest	Oregon State GNN team/IMAP	2009	Ohmann and Gregory 2002	http://www.fsl.orst.edu/lemma/main.php?project=imap&id=home
National Vegetation Classification Standard	United States	Federal Geographic Data Committee	2008	FGDC 2008	http://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/NVCS_V2_FINAL_2008-02.pdf

GNN = gradient nearest neighbor. IMAP = Interagency Mapping and Assessment Project. USDA = U.S. Department of Agriculture.

shrubs, herbaceous plants, or grasses. Techniques to estimate cover vary (section 4.3.2) depending on growth habit and life form, but the most common method is ocular or visual cover estimation. Potential weaknesses in ocular estimation, including observer bias and lack of precision, can be reduced somewhat by rigorous training, multiple quality control checks throughout the sampling period (e.g., randomizing observer sampling schedules), and use of multiple small quadrats rather than one large, fixed-area plot.

Dominance is the extent to which a given species influences a community because of its size, abundance, or coverage (Warbington 2011); it is estimated by calculating relative cover. Dominance can be assessed for all species in a sampling unit (e.g., plot), across all species within a life form, or only for a group of species of interest (e.g., nonnative or invasive species). Vegetation ecologists use dominance to characterize plant communities and to group them into dominance types, thereby defining vegetation communities at a broader scale (Barbour et al. 1987, Hall 1998).

Counts of individual plants as a measure of abundance or density (usually assessed in a plot or quadrat) may be appropriate in some cases but can be very time consuming and are usually limited to a few species, such as the number of berry producing shrubs in a fixed-area plot. Plot size should be sufficiently large to capture vegetation pattern but small enough to count the individual units, such as stems or seedlings, efficiently (Elzinga et al. 1998). Belt or strip transects, which are long, rectangular plots, are typically used for tree and shrub density estimates. Develop boundary rules (i.e., which individuals are counted as in or out) before sampling.

Abundance can also be estimated using biomass, usually as annual production. Biomass is often measured in herbaceous (primarily grassland) systems and is based on the current year's growth. Biomass also can be estimated in woody vegetation. Multiple small plots are clipped and weighed and vegetation is typically air or oven dried; green vegetation also can be corrected to air-dry weight. Double sampling (clipping small units

Table 4.6.—Example existing vegetation map products currently available at State, regional, and national extents.

Existing vegetation maps	Spatial extent	Classification system	Remote sensing source	Resolution	Date	Additional comments/references
LANDFIRE EVT	Nationwide	Ecological systems ^a	Landsat TM	30 m	2006	"Refresh" products are updates available for 2001 and 2008; http://www.landfire.gov/NationalProductDescriptions21.php
NLCD	Nationwide	NLCD	Landsat ETM+	30 m	2006	NLCD; broad land cover classes (e.g., evergreen forest); http://www.mrlc.gov/
NW ReGAP	OR, WA	Ecological systems	Landsat ETM+	30 m	2008	http://www.pdx.edu/pnwlamp/existing-vegetation
SW ReGAP	AZ, CO, NM, NV, UT	Ecological systems	Landsat ETM+	30 m	2004	http://fws-nmcfwrn.mnsu.edu/swregap/default.htm
Other State-level GAP maps	Statewide	Various	Various	Various	Various	Jennings 2000.
Forest Service regions:						
R1 (Northern)	All NFs except Beaverhead-Deerlodge	R1 vegetation classification system (Barber et al. 2009)	Landsat 7 (west-side); Landsat 5 and NAIP color infrared (east-side)	15 m (west-side), 5 m (east-side)	2001 (west-side); 2005 (east-side)	Known as VMap; created different products for west-side versus east-side forests; downloads available at http://www.fs.usda.gov/detail/r1/landmanagement/gis/
R3 (Southwestern)	All NFs in R3	Dominance types (Triepke et al. 2005), size and cover classes (Warbington 2011)	Landsat 7	1:100,000	2004–2009	http://fsweb.r3.fs.fed.us/eng/MID-SCALE_VEG/index.html
	All lands in R3	ILAP	Landsat 7	1:100,000	2006	Pacific Northwest Research Station, Oregon State University Institute of Natural Resources (ftp://131.252.97.79/ILAP/)
R4 (Intermountain)	Humboldt-Toiyabe (H-T) NF	Midlevel existing vegetation maps	NAIP, DOQQ, Landsat 5, resource air photos	10 m	2004	H-T and B-T are being updated. Caribou-Targhee and Sawtooth National Forests will be completed in 2013. Remaining R4 forests are scheduled through 2016.
	Bridger-Teton (B-T) NF			5 m	2007	
	Boise NF			5 m	2012	
	Payette NF			10 m	2012	
R5 (Pacific Southwest)	All national forests in R5	Calveg	Primarily Landsat TM and SPOT	5 m	2012	http://www.fs.fed.us/r5/rsl/projects/mapping/mapping_minimum_mapping_unit_2.5_ac_maps_updated_on_10-year_schedule
R6 (Pacific Northwest)	OR, WA		Landsat	30 m	2006 (OR); various (WA)	Known as ILAP; uses a gradient nearest neighbor approach with ground data; http://www.rsl.orst.edu/lemma/
R8 (Southern)	All NFs in region	NA	NA	NA	In progress (1996 for SAA)	Under development for Southern Appalachian Assessment (SAA); see http://sunsite.utk.edu/samab/data/SAA_data.html
R9 (Eastern)	NA					

ac = acre. DOQQ = Digital Orthophoto Quarter Quads. ETM = Landsat 7 Enhanced Thematic Mapper Plus. ETV = existing vegetation type. GAP = Gap Analysis Program.

ILAP = Integrated Landscape Assessment Project. m = meter. NA = data not available. NAIP = National Agriculture Imagery Program. NF = national forest, NLCD = National Land Cover Database. NW = Northwest. SPOT = Satellite Pour l'Observation de la Terre. SW = Southwest. TM = Thematic Mapper.

^a Corner et al. (2003) provide descriptions of ecological systems.

of vegetation, weighing these units, calibrating the estimate using the weighed unit, and estimating biomass/annual production) increases efficiency in estimating biomass. The interagency technical reference titled *Utilization Studies and Residual Measurements* (Interagency Technical Team 1996) describes several methods to estimate or measure biomass. The Robel pole field guide (<http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml>) also provides protocols to estimate biomass in herbaceous vegetation communities. (This site and other Intranet sites beginning with “fsweb” are internal to the Forest Service and, thus, not available to external users.)

Volume is typically a measure associated with shrubs. Biologists estimate shrub volume from the combined measurements of shrub height and shrub canopy length and width (horizontal measurements of canopy taken at varying heights of each plant). The volume of each species or life form of interest may be reported by height class. Crimmins et al. (2009) estimated woody browse abundance in recent clearcuts in West Virginia using image texture analysis with 1-meter (m) (3-feet [ft]) National Agriculture Imagery Program (NAIP) photography.

Plant species abundance can sometimes be estimated effectively using remotely sensed data and applied in a wildlife context. For example, Larson et al. (2003) and Rittenhouse et al. (2007) used the relative proportion of white oak (*Quercus alba*) and red oak (*Q. rubra*, *Q. coccinea*, *Q. velutina*, and *Q. marilandica*) species as an indicator of hard mast production. They incorporated this index as a variable in landscape-level habitat suitability models for several eastern species that rely on mast crops. In the central hardwoods region of the United States, Rittenhouse et al. (2007) used the dominant over-story tree species as an input variable in habitat suitability models for 10 wildlife species.

4.3.2 Vegetation Structure Attributes

The importance of vegetation structure in wildlife habitat is addressed in section 4.2.3. In this section, we describe a suite of key structural attributes of wildlife habitat (table 4.1). First, we define each attribute and describe it in the context of wildlife habitat. Next, we present typical methods for measuring the attribute with field-sampled data and remotely sensed data, when appropriate. We also describe how some attributes can be obtained through FIA data (see table 4.3 for the attribute-to-FIA crosswalk). Finally, we also address structural and seral stages; wildlife may be associated with particular structural stages, such as early successional or young forest vegetation (for examples, see Wisdom et al. 2000).

Trees

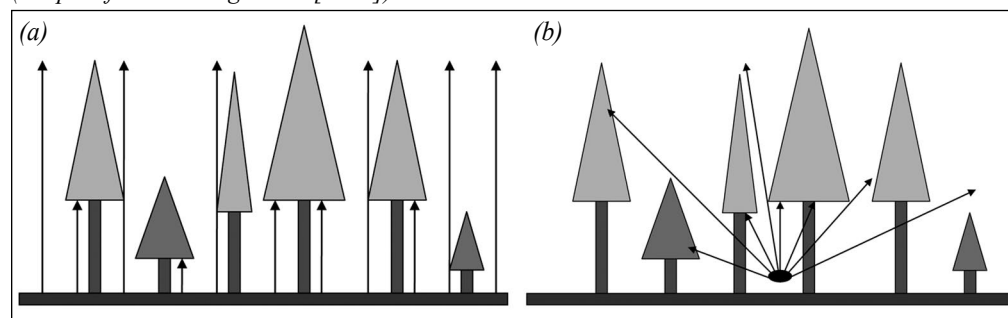
Canopy Cover and Canopy Closure. The terms canopy cover and canopy closure are often used interchangeably, but we recommend following Jennings et al. (1999) in distinguishing between them. In forested systems, canopy cover is the proportion of the forest floor covered by the vertical projection of tree crowns, whereas canopy closure is

the proportion of the sky hemisphere obscured by vegetation when viewed from a single point on the ground (Jennings et al. 1999; figure 4.1). Hemispherical instruments integrate across a larger area and include more canopy cover from tree trunks than do vertical methods. For this reason, hemispherical measures of canopy closure tend to produce higher canopy values than vertical estimates of canopy cover (Ganey et al. 1994). If habitat monitoring is based on an existing habitat relationship model that includes a measure of canopy, determine whether vertical or hemispherical projections were used and then select the equivalent measure for monitoring.

In a wildlife habitat context, the two measures reflect different aspects of the environment. Canopy cover, when combined with species composition, is often used to indicate plant abundance and dominance (section 4.3.1). Canopy closure is indicative of light conditions that affect tree growth, temperature, and humidity regimes. The habitat monitoring objective must clearly state whether the intent is to measure tree canopy cover or canopy closure by distinguishing between the need to obtain a true vertical projection of tree canopy as an indication of tree status (Nuttle 1997) or the need to measure light interception (and its influence on ecological processes). For example, if the habitat attribute of interest is the ability of the forest canopy to intercept snowfall, then canopy cover should be measured. By contrast, if the attribute of interest is the influence of the total tree canopy on a point, such as an animal's perception of cover or total understory production, then canopy closure is best (Nuttle 1997). We address each of these metrics separately in the text that follows.

Canopy cover. Field estimates of canopy cover are challenging to obtain, especially in forested systems where canopy cover is highly variable across space, thus requiring many measurements to make a useful estimate. Jennings et al. (1999) reported very low precision of field-sampled canopy cover when using fewer than 100 measurements/stand. Consider the level of confidence needed in the canopy cover estimates; often habitat requirements are described in broad ranges of canopy cover and precise estimates are not needed. If suitable resources exist and the level of precision in canopy cover is acceptable to meet monitoring objectives, estimate canopy cover from remotely sensed data.

Figure 4.1.—Illustration of (a) vertical projection used to estimate canopy cover (adapted from Jennings et al. [1999] and Nuttle [1997]) and (b) angle of view to estimate canopy closure (adapted from Jennings et al. [1999]).



See the field-sampling methods for the cases when remotely sensed data are not adequate or available. Record canopy cover for all trees combined, by species, or species group (e.g., hardwoods or conifers).

Estimates of canopy cover are available from FIA data and LANDFIRE (section 4.5). For FIA, canopy cover can be obtained from either Phase 2 (P2) or Phase 3 (P3) plots (table 4.3; see section 4.4.1 for more information about FIA plot types). In P3 plots, tree canopy cover is estimated for individual species and can be summarized by species or for all trees combined. Use data from the larger sample of P2 plots to derive tree canopy cover through models that incorporate species-specific crown-width equations and sapling contributions to total cover (Toney et al. 2009). In LANDFIRE, the Existing Vegetation Cover (EVC) layer is available for the conterminous United States at 30-m (98-ft) pixel resolution (<http://www.landfire.gov/NationalProductDescriptions23.php>). This layer represents vertically projected cover of the live canopy layer and merges data from herbaceous, shrub, and tree life forms into a composite EVC layer. The derived data layer is based on field-sampled data coupled with Landsat imagery, elevation, and other data. The Forest Service is developing a new national-scale tree canopy cover map as part of the 2011 National Land Cover Data release (NLCD; <http://www.mrlc.gov/>) (Coulston et al. in press); publication is expected in December 2013.

GIS analysts can estimate canopy cover using dot grid sampling from either aerial photographs or satellite imagery (section 4.5.2). Using this technique, the analyst superimposes a dot grid on a digital image and assigns each dot to the type class in which it falls. Determining where tree crowns end and shadows begin, however, is difficult and midcanopy trees may be hidden in shadows. The time of year the image or photo was taken, tree species, and canopy complexity can confound the method. With photos, oblique images can also be a problem. Estimate cover as a percent coverage of the area of interest using software (e.g., Digital Mylar; section 4.5.2) to analyze digital images, whether from aerial photographs or satellite imagery. You can also estimate cover on aerial photography visually or using a dot grid, but these methods are rapidly becoming obsolete with the development of digital dot grid methods.

Another method of estimating canopy cover remotely uses a vegetation or greenness index from the amount of light absorbed by chlorophyll, which relates to the amount of leaf area on a site. A common approach to creating a greenness index is to apply the tasseled cap transformation on satellite imagery, which transforms spectral data into estimates of brightness, greenness, and wetness (Huang et al. 2002, Lillesand and Kiefer 2000). As with dot grid sampling, greenness measures do not accurately separate overstory from understory.

Aerial Light Detection and Ranging (**LIDAR**) is a data-rich method of estimating tree canopy cover, even for individual canopy layers (Lefsky et al. 2002; section 4.5.1). LIDAR is accurate and repeatable and separates overstory from other layers well, but it may overemphasize the contributions of very small gaps. Aerial LIDAR is similar to

a very precise dot grid, with each laser reading representing a dot. Because the LIDAR beams are very thin, however, they can pass through minute canopy gaps. These small gaps are invisible to photo interpreters and generally ignored by ground measurements; thus, systematic differences in canopy cover measures can be expected when comparing LIDAR-derived estimates with those derived using other methods.

When measuring canopy cover in the field, the surveyor can use a sighting tube (James and Shugart 1970) to obtain the vertical projection; the observer takes numerous readings at random or systematic points, which are then averaged to obtain a percentage of canopy cover. Jennings et al. (1999) recommend a minimum of 100 points/canopy cover estimate. Surveyors must establish and document criteria for the size of small openings in tree crowns to include in the measure of canopy cover (Warbington 2011: 52). No established standard exists for the minimum size of openings to use in measuring canopy cover, and this lack of a standard is a major source of variability in canopy cover estimates between observers and between methods.

Ocular estimation of tree canopy cover on a large circular plot is generally used to generate data for ecosystem classification efforts (Bonham 1989, Braun-Blanquet 1965, Daubenmire 1959), because the large plot design is designed to capture the full array of species characteristic of an ecosystem. This approach is adequate for many wildlife habitat applications as well. In this method, users define a standard plot area on the ground and estimate the percentage of canopy covering the area by eye, using the outermost perimeter of the natural foliage of the plants. Small openings in the canopy are included as cover (SRM 1989, USDA NRCS 1997). The key weakness of this method is the unknown amount of observer bias (Elzinga et al. 1998), but careful training and comparison of results from different observers will improve the consistency of the results.

Canopy cover increases as the eye moves from treetops to the forest floor, and changes in canopy cover can be large and relatively sudden if tall brush is present. In some forests, a clear break exists between overstory and understory vegetation, but in many systems tree heights are relatively continuously distributed. Thus, biologists may need to define canopy cover for a particular height or stratum above the forest floor to avoid differences in cover estimates because of measurement methods.

Canopy closure. A visual estimate of canopy closure may provide sufficient accuracy when the monitoring objective is to meet or avoid a predetermined threshold (chapter 3, section 3.2.5). Before seeking greater precision, first consider whether the time, training, and expense are justified.

If greater precision is needed, such as for statistical analyses of 2 or more years of data, a number of tools are available for estimating canopy closure from ground plots. Hemispherical photography uses a fisheye lens at the measurement point, and a threshold in pixel darkness is used to distinguish canopy from sky (Chan et al. 2003, 2006; Fiala et al. 2006). The advent of digital photography has facilitated rapid, portable analysis of photographic data. Some software (e.g. Pocket PC; see http://www.idruna.com/products_pocketpc.html)

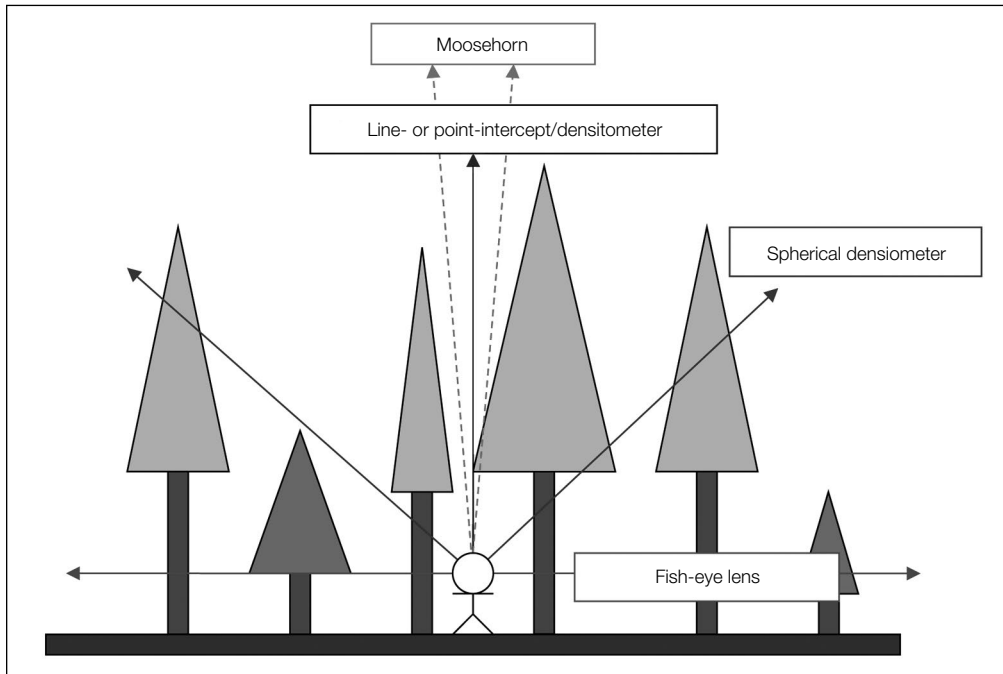
provides accurate, on-the-fly estimates of tree canopy cover from digital camera images. Bright or reflective vegetation, however, as well as slight changes in the threshold value, can result in substantial differences in canopy closure values (Jennings et al. 1999).

In recent years, ground-based hemispherical LIDAR has become an additional option for estimating canopy closure (Van der Zande et al. 2006). As with aerial LIDAR, the distance measures provide the advantage of differentiating canopy layers, so this method also can be used to estimate canopy complexity, which is addressed later in this section.

Other options include hemispherical photographs or ground-based LIDAR for monitoring canopy closure. Both options provide accurate, repeatable measurements and introduce less observer bias. Most published wildlife habitat models that include canopy measures were developed using previous sampling tools, often the **spherical densiometer** (Lemmon 1956) or the **moosehorn** (Robinson 1947; figure 4.2). Both instruments were designed as tools for improving visual estimates of canopy cover, although both use a hemispherical approach and thus measure canopy closure. Each instrument provides a wide-angle field of view of the canopy above the surveyor, and the surveyor tallies the proportion of points covered by vegetation. A densiometer can be insensitive to variations in cover (Cook et al. 1995) and can be prone to low accuracy and precision (Cook et al. 1995, Griffing 1985, Strickler 1959). Observer variation, which can be significant and difficult to quantify (Block et al. 1987), makes the densiometer method ill-suited for monitoring, although it may be useful for rapid assessment. Little information exists about the accuracy of the moosehorn. Fiala et al. (2006) compared canopy estimates from hemispherical photography, the moosehorn, and the spherical densiometer and found that estimates from the moosehorn were consistently lower than those from the densiometer or hemispherical photography. The authors provide simple linear regression models to convert estimates of canopy closure from one technique to another, which can be of value in adapting prior estimates of canopy closure (e.g., from a habitat model) to other techniques.

For all methods of estimating canopy closure, measurements will change depending upon the **zenith angle** selected (figures 4.1 and 4.2). The zenith angle should reflect the intent of the canopy measurement; usually a strictly vertical (90-degree) zenith angle is appropriate. With digital images, however, photos can be analyzed repeatedly using different zenith angles (Rich et al. 1999), as can ground-based LIDAR data. Equally critical is the height above the forest floor at which canopy closure is assessed. Unlike canopy cover, which is tree-oriented, canopy closure measures the light environment at a point of biological interest. For a salamander, logically this would be at the forest floor. For a spotted owl (*Strix occidentalis* sp.), it could be above the brush layer if the interest were in the thermal environment of potential roost sites or at the forest floor if the interest were in the ability of the owls to perch-drop on prey. Canopy closure is a meaningful variable for habitat monitoring to the extent that it captures potential changes in the

Figure 4.2.—Comparison of angles of view and associated effects on cover estimates for devices commonly used to measure canopy cover or closure (adapted from Fiala [2003]).



operational environment of the organism of interest. Because of the many techniques available to measure canopy cover or closure, use caution if these attributes are used in long-term monitoring.

Diameter. Tree diameter is the cross-sectional width of each tree at breast height (DBH), which is 4.5 ft above ground level. For woodland tree species less than breast height, the measurement is diameter at root collar. FIA and Common Stand Exam (CSE) protocols call for using a diameter tape to measure the diameter of all trees in the sampling plot with a DBH of 5 inches (in) or more.

Tree diameter is an important habitat attribute, especially for species that require cavities in large-diameter trees or snags for nesting. The distribution of diameter size classes describes the diversity of tree sizes in an area and is the primary variable used to delineate structural stages (section 4.3.2; table 4.7). Habitat management for old-growth-associated species often is based on diameter thresholds, especially for species that require large-diameter trees or snags for nesting. Individual tree diameters are not always the habitat attribute of interest, however, but instead may be the building blocks for deriving several stand-level attributes, such as basal area, quadratic mean diameter, and basal area weighted average diameter (table 4.4), which we describe in the following section. Also use tree diameter in reporting other attributes, such as stand density by diameter class. Individual tree diameters are part of the tree list data used for nearest neighbor modeling of forest stands (section 4.5.2).

Each of the metrics derived from individual tree diameter data provides a different interpretation of stand structure. Therefore, biologists must be aware of these differences to ensure they effectively use the metric as a habitat attribute. Basal area, quadratic mean diameter, and basal area weighted average diameter are derived from all individual tree diameters in a plot, whereas overstory diameter uses only a subset of individual tree diameter data. All these metrics are summary statistics with a measure of variability (standard deviation) at the plot and stand levels. In contrast, diameter class distribution is not a summary statistic; report it as a frequency distribution or histogram.

All these diameter metrics are available in FS Veg from either FIA or CSE data (table 4.3), but see caveats in section 4.4.1 regarding sample size for local scale and midscale analyses. If one or more of the diameter metrics are key habitat attributes for the emphasis species, we recommend using field-sampled data rather than remotely sensed data for monitoring, because neither aerial photos nor satellite imagery can reliably estimate any of the diameter metrics using current technologies. Current advances in regression modeling approaches do allow for estimation of tree diameters by combining field-sampled data with satellite imagery (e.g., quadratic mean diameter; Ohmann and Gregory 2002; O'Neil et al. 2000). Modeled estimates of tree diameter are more appropriate for inventory than for monitoring, however, given the potential for inconsistent interpretation of imagery among years and changes in modeling algorithms.

The monitoring team must decide which diameter metric is most meaningful from the standpoint of the emphasis species. For example, the team should ask such questions as: Is habitat adequately characterized by the average diameter of trees in the stand, or is it more important to ensure the existence of a certain number of trees of a particular species that exceed some specified diameter? To what extent do small-diameter trees influence habitat quality and contribute to a metric of average tree diameter? These questions and ones like them should be carefully considered when monitoring the habitat of the species of interest. We recommend a thorough literature review of species-habitat interactions before proceeding. The following description of diameter metrics should assist in making decisions about which to use as habitat attributes.

Basal area. Basal area is the cross-sectional area of a tree at DBH. A minimum basal area value is frequently used in wildlife habitat relationship models to represent a rough threshold below which a forest stand no longer serves as habitat for the emphasis species (or conversely becomes desirable for an early successional species). Use basal area in concert with other stand structure variables, however, because similar basal area values can be obtained for high density, small-diameter stands and for low density, large-diameter stands.

FIA and CSE protocols calculate basal area from individual tree diameter data and summarize basal area as ft²/ac (square feet per acre) at the plot and stand levels (table 4.3) (USDA Forest Service 2010b, 2011). There is a long tradition of deriving basal area from a basal area factor prism or Relaskop; however, we do not recommend using this method

Table 4.7.—*Examples of vegetation structural stage or class systems.*

Structural class system	Forest conditions		Shrubland/grassland conditions	
	Stage/class	Measure/unit	Stage/class	Measure/unit
Oliver and Larson (1996)	Stand initiation	Single and multiple cohorts	Not applicable	
	Stem exclusion	Single and multiple species		
	Understory reinitiation			
	Old growth			
Johnson and O'Neil (2001)	Tree size	DBH	Shrub height	Feet
	Shrub/seedling	<1 in	Low	< 1.6 ft
	Sapling/pole	1 to 9 in	Medium	1.6 to 6.5 ft
	Small tree	10 to 14 in	Tall	> 6.5 to 16.5 ft
	Medium tree	15 to 19 in		
	Large tree	20 to 29 in		
	Giant tree	At least 30 in		
	Canopy cover	Percent	Shrub cover	Percent
	Open	10 to 39 percent cover	Open	10 to 69 percent cover
	Moderate	40 to 69 percent cover	Closed	70 to 100 percent cover
	Closed	70 to 100 percent cover		
	Canopy layers	Number	Shrub age class	Amount crown decadence
	Single story	1 stratum	Seedling/young	Negligible
	Multistory	2 or more strata	Mature	< 25 percent
			Old	26 to 100 percent
Pacific Northwest Region Structural standards	Structural stage	DBH		
	NA			
	Grass/forb	NA		
	Shrub/seedlings	< 1 in	NA	
	Sapling/pole	1 < 5 in		
	Small tree	5 to < 15 in		
	Medium tree	15 to < 20 in		
	Large Tree	20 in plus		
	Canopy cover	Percent		
	(No class name)	< 10 percent cover		
	(No class name)	10 to 59 percent cover		
	(No class name)	60 to 100 percent cover		
	Tree canopy structure	Number of layers		
	Single	One		
	Multi	Two or more		

Table 4.7.—*Examples of vegetation structural stage or class systems (continued).*

Structural class system	Forest conditions		Shrubland/grassland conditions	
	Stage/class	Measure/unit	Stage/class	Measure/unit
Interior Columbia Basin Assessment (Hann et al. 1997)	Structural stage	DBH		
	Stand initiation	< 5 in	Open low-medium shrub	A canopy of low (< 20 in) or medium-sized (20 to 39 in) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Stem exclusion	5 to < 20 in		
	Understory reinitiation	5 to < 20 in	Closed low-medium shrub	A canopy of low (< 20 in) or medium-sized (20 to 39 in) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Old	20 in plus		
	Canopy cover	Percent		
	Open	10 to 59 percent cover	Open tall shrub	A canopy of tall (6.6 to 16.4 ft) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Closed	60 to 100 percent cover		
	Tree canopy structure	Number of layers		
	Single story	One	Closed tall shrub	A canopy of tall (6.6 to 16.4 ft) shrubs with at least 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Multistory	Two or more		
LANDFIRE Succession Classes	Seral stage	Age class	Seral stage	Age class
	Early seral	Varies with the ecosystem	Early seral	
	Midseral closed		Midseral closed	Varies with the ecosystem; also often mixed with descriptive structural attributes
	Midseral open		Midseral open	
	Late seral open		Late seral open	
	Late seral closed		Late seral closed	

DBH = diameter at breast height. in = inch. ft = feet. NA = not applicable.

if the data will eventually be combined with FIA plots for a single analysis because of problems stemming from combining data collected by using different field methods. In addition, basal area can be modeled by combining field-sampled data and remotely sensed data using gradient nearest neighbor methods (Ohmann and Gregory 2002; see section 4.5.2).

Quadratic mean diameter. Quadratic mean diameter (QMD) is a stand metric that corresponds to the diameter of a tree representing the stand's mean basal area (Graves 1908, cited in Curtis and Marshall 2000). It is calculated from the square root of the arithmetic mean of squared diameter values (table 4.4). QMD is widely used in forestry; it has a higher correlation to stand volume than does the arithmetic mean because it places greater weight on larger diameter trees. Depending on the variance, it will be equal to or greater than the arithmetic mean diameter. Moeur et al. (2005) used large QMD as an indicator of late-successional forest structure in the Pacific Northwest, but a single-storied large-diameter stand can also produce a relatively large QMD.

Another diameter metric that reflects the contribution of large trees is the basal area-weighted average diameter, which is calculated as the sum of each tree diameter multiplied by its basal area and then divided by total basal area. QMD and basal area-weighted average diameter are weighted toward large-diameter trees, but the latter metric reduces the influence of small trees, even for large numbers of small trees. If the emphasis species is a cavity nester, basal area-weighted average diameter could be a useful diameter metric because it approximates the average diameter of dominant and subdominant trees and indicates whether diameters are suitable for nesting cavities.

Height. Height is a basic attribute collected in most vegetation data sets. Tree height has implications for **seral stage** and canopy complexity (see following section), and, in mature forests, it is a rough measure of site productivity. Tree height is an important habitat attribute for many wildlife species. For example, northern goshawks (*Accipiter gentilis*) often select tall, sturdy trees for nesting, placing the nest at the base of the tree canopy (Speiser and Bosakowski 1987).

In the field, record tree height using a laser **clinometer** while standing a defined distance from the tree bole. Heights of individual trees can be tallied, but often the heights of only one or two representative trees are measured. FIA protocols prescribe measuring the height of each tree in the plot (table 4.3), however. Remote sensing methods to estimate tree height traditionally have involved using stereoscopes with paired aerial photographs, but recent advances in LIDAR and interpretation of high-resolution satellite imagery allow for accurate estimates of tree height with these methods as well (section 4.5.1; McCombs et al. 2003).

Canopy Complexity. Canopy complexity is a measure of diversity in the number of layers and associated species in forest canopies (Lowman and Rinker 2004). A closely related concept, **foliage height diversity** (FHD), indexes how evenly vegetation is distributed in vertical space, typically through measurements of foliage density at various heights within a vegetation community (Cooperrider et al. 1986, MacArthur 1964, MacArthur and MacArthur 1961). Both attributes have important implications for wildlife

niche diversity, particularly in avian communities, where they have been demonstrated to be reliable predictors of species diversity (MacArthur 1964, MacArthur and MacArthur 1961, Magurran 1988). Management activities, such as thinning, that result in potentially large changes in the vegetation component of a habitat often affect diversity of vegetation layers, and thus canopy complexity (Morrison et al. 2006).

At the broad scale, use remote sensing approaches to estimate canopy complexity, but not FHD, in forested ecosystems. A newer form of LIDAR, multiple-return LIDAR, can provide detailed and accurate measures of canopy complexity (section 4.5.1; Lefsky et al. 2002). In this method, major peaks (typically up to five) in the return signal are identified, which correspond to distinct vegetation layers.

Nearest neighbor methods offer a second approach in estimating canopy complexity and are appropriate at broad and mid scales (section 4.5.2). In this approach, field-sampled data (e.g., FIA or Current Vegetation Survey [CVS]) are related to environmental gradients of the monitoring area (e.g., biophysical attributes), some of which are estimated using satellite imagery. For example, data collected for the vegetation diversity and structure indicator (VEG) in P3 FIA plots include total canopy cover in each of four layers of vegetation (table 4.3); this information can be used to calculate canopy complexity. Use other data sets independently or to supplement FIA data to calculate canopy complexity using nearest neighbor methods.

Another approach is to use image texture and satellite imagery or digital photographs to indicate complex canopy structure through measures of roughness (Lillesand and Kiefer 2000). Regardless of which method is used, these broad-scale approaches, with the exception of LIDAR, are coarse, generally resulting in canopies described simply as single-storied (one stratum) or multistoried (two or more canopy strata) (O'Neil et al. 2001). (Section 4.5 addresses other methods for analyzing satellite images.) Moreover, because of potentially large differences in estimates of canopy complexity arising from different imagery sources and technicians, remote sensing methods for deriving this attribute may be most useful for one-time inventory or for threshold monitoring versus monitoring to detect change (chapter 3, section 3.2.5).

In contrast to canopy complexity, FHD is derived from a variety of field measurements (James and Shugart 1970, MacArthur and Horn 1969, MacArthur and MacArthur 1961). The methods use systematic sampling of the canopy at several heights above the ground (e.g., 2 ft, 10 ft, 30 ft, and 75 ft) recording the number of times that a vertical line from the ground through the canopy intercepts foliage. The resulting data provide a useful index of canopy complexity; individual layers can be compared, as well as the overall score.

In nonforested environments, such as shrublands, vertical diversity is much less complex. In these sites, measuring clump size of shrubs and their height distribution may provide a more meaningful measure of canopy complexity (Morrison et al. 2006, Roth 1976). In grassland or shrubland environments, calculate FHD using a marked pole to calculate the number of bands obstructed by vegetation (see Herrick et al. [2005] for equations to calculate FHD in nonforested vegetation types).

Stand Density. Stand density is the number of trees in a given unit area (Bonham 1989) and is an important attribute in describing structure because of its relation to canopy closure and understory development. In a wildlife context, stand density has implications for nesting success, hiding cover, and other aspects of species' life cycles. Tree stem density is an important habitat attribute for many species of forest-associated wildlife, including bird communities (Hagar et al. 1996), snowshoe hare (*Lepus americanus*) (Sullivan and Sullivan 1988), and other small mammals (Homyack et al. 2005).

Stand density can also be used to identify structural and seral stages. For example, an area with 10,000 trees/ac indicates a young, regenerating site capable of supporting high productivity. Stand density becomes more useful when coupled with diameter information (i.e., the number of trees in each diameter class provides a more meaningful indicator of structure than a simple count of trees per unit area). If density is recorded for individual tree species, this measure reflects an attribute of vegetation composition, namely species abundance (section 4.3.1). In addition to calculating density from field-sampled data, stand density can be estimated using LIDAR (section 4.5.1).

Snags and Defective Trees

Snags are standing dead trees or stumps that provide habitat for a broad range of wildlife (Johnson and O'Neil 2001). Defective trees are living trees with wounds, scars, disease (e.g., dwarf mistletoe or brooms), decay, and/or cavities; they also provide wildlife values by creating microhabitats (Johnson and O'Neil 2001). Snags not only provide nest or den cavities for specific vertebrate species, but they also are a vital part of functioning ecosystems. For example, they affect nutrient cycling, water retention, and regeneration seedbeds. They also support complex food webs and habitats for a variety of nonvertebrate life forms, such as fungi and insects (Johnson and O'Neil 2001, Maser and Trappe 1984, Maser et al. 1988).

The primary habitat attributes for snags are diameter, height, and density, which are usually stratified by tree species and decay class (table 4.8). The species of snag is important because tree species vary in hardness, which affects the ability of bird species to excavate nesting cavities. In addition, tree species decompose at different rates, which affect snag longevity. Decay class matters because some wildlife species use snags only at a specific stage of decay. Diameter is important because some species forage on snags of smaller diameters (less than 20 in DBH) but require larger snags for nesting or roosting (at least 20 in DBH) (Bate et al. 2008b).

Monitoring teams will generally find existing data for snags in FSVeg and on the FIA Web site because CSE and FIA collect similar data on snags and defective trees as they do for live trees (table 4.3). Use FIA or CSE protocols to augment these existing data. Decay classification systems vary across geographic locales, but all of the snag sampling protocols can accommodate whatever system is used locally. FIA recommends a 5-class system (table 4.8).

An alternative to CSE and FIA protocols for small monitoring projects is SnagPRO (Bate et al. 2008b), which includes software for sampling and analyzing snags and defective trees at the scale of stands and small landscapes. SnagPRO identifies optimal transect lengths that minimize sampling variance. If surveyors use a line intercept sampling method for sampling logs (section 4.4.2), a belt transect (strip plot) can be added along the line transect to streamline data collection for snags and logs simultaneously.

Cavity Size. A cavity is a hole in a tree, with estimated horizontal depth of at least 7.5 centimeters (cm) (3.0 in) (Gumtow-Farrior 1991) and an entrance width of at least 3.0 cm (1.2 in) (Pattanavibool and Edge 1996). McComb et al. (1986) specified a 2.5-cm (1.0 in) minimum width requirement for cavities in den trees (live, cavity-bearing trees). Cavities provide habitat critical in the life cycle of a number of wildlife species, including flying squirrels, a variety of woodpeckers, other birds, and bats (Hunter 1990). It is possible to estimate the availability of cavities of different sizes using a variety of protocols (Bechtold and Knight 1982, Knight and McClure 1979, Lehmkuhl et al. 2003, McComb et al. 1986, Pattanavibool and Edge 1996). We recommend the criteria in McComb et al. (1986), used on thousands of FIA plots in the Southern United States, in which all cavities at least 2.5 cm (1.0 in) wide on live trees at least 12.5 cm (4.9 in) in diameter were counted. This protocol records only cavities found in the two largest trees on the plot. Correction factors may be necessary to account for cavities that are too high up on tree boles to detect, or to estimate the depth of their excavation.

For upper bole cavities that are difficult to reach, surveyors climb and record data on a subsample of trees; these data can then be used to develop a correlation allowing for extrapolation to other trees (Pattanavibool and Edge 1996). We recommend categorizing cavities into diameter classes. Pattanavibool and Edge (1996) used three diameter classes: 20.0 to 39.9 cm (7.9 to 15.7 in) DBH (small), 40.0 to 59.9 cm (15.7 to 23.6 in) DBH (medium), and greater than 60.0 cm (at least 23.6 in) DBH (large). We also recommend an additional class from 12.5 to 19.9 cm (4.9 to 7.8 in), based on McComb et al. (1986).

Table 4.8.—*Snag/defect tree decay classes.*

Decay class stage ^a	Limbs and branches	Top	Percent bark remaining	Sapwood presence	Sapwood condition	Heartwood condition
1	All present	Present	100	Intact	Minimal decay	Sound and hard
2	Few limbs, no fine branches	May be broken	Variable	Sloughing	Advanced decay	Sound at base but beginning to decay in the outer part of the upper bole
3	Limb stubs only	Broken	Variable	Sloughing		Advanced decay in upper bole and is beginning at the base
4	Few or no stubs	Broken	Variable	Sloughing	Cubical, soft, reddish to dark brown	Advanced decay at the base and is sloughing in the upper bole
5	None	Broken	< 20	Gone	Gone	Sloughing throughout

^a From Forest Inventory and Analysis Phase 2 Field Guide: <http://www.fia.fs.fed.us/library/field-guides-methods-proc/>.

Characteristics are for Douglas-fir (*Pseudotsuga menziesii*). Snags for other species may vary somewhat; use this table as a guide.

Down Wood

Down wood, also known as logs or coarse woody debris (CWD), is a category of dead and down pieces of wood generated from trees and large shrubs. The FIA program uses the term CWD, and defines it as pieces of wood with at least a 3-in diameter that are at least 3-ft long and detached from the bole of a standing live or dead tree; if still partially rooted, the lean angle of the piece must be greater than 45 degrees from vertical (Woodall and Monleon 2008). Down wood is an important habitat attribute for many forest-dwelling wildlife species because it provides denning, resting, and thermal cover sites and serves as a foraging substrate (Bate et al. 2008a, Maser and Trappe 1984). Down wood fulfills numerous other ecological roles in the process of decay, such as providing microclimatic conditions for fungi, plants, insects, and a variety of microorganisms, and serving as nutrient reservoirs (Harmon et al. 1986).

The primary habitat attributes for down wood are percent cover, volume, and density. Because all these attributes are derived rather than measured, we first describe the data measured in the field and then describe the habitat attributes. The measured data, collected under the FIA and SnagPRO protocols (addressed in the following section), are tree species of the log, decay class, diameter at point of intersection with the line, and log length. Tree species and decay class are descriptors used to stratify down wood attributes into categories meaningful to a wildlife emphasis species; whereas diameter and length are the building blocks for deriving percent cover, volume, and density.

It is not always possible to determine the tree species from which a log originated, especially if it is substantially decayed. Tree species can be important if the wildlife emphasis species uses log cavities for dens, however, because some species form cavities more readily than others. The cavities form when the tree is still standing rather than after the tree becomes down wood (Bate et al. 2008a). Decay class is a key descriptor because certain species (e.g., American marten) require logs in early stages of decay, whereas other species, such as ruffed grouse (*Bonasa umbellus*) require more advanced decay. SnagPRO (Bate et al. 2008a) uses two decay classes (sound and rotten) as the default, but the software can accept more detailed decay classes. Improved precision of these estimates is obtained by post-stratifying the sample using geospatial datasets (Hatfield 2010). FIA uses five decay classes of down wood (table 4.9).

Existing data for down wood, in general, are less available than are data for live trees and snags, but monitoring teams should check NRM FS Veg to see what information exists locally. The FIA program collects information on all classes of down woody material on P3 plots (a subset of P2 plots; see section 4.4.1 and table 4.3) at a spacing of approximately 1 plot/96,000 ac (and these data are stored in NRM FS Veg). Most wildlife monitoring programs will need to augment P3 plot data to obtain a sufficient sample of log information for monitoring purposes. FIA provides core data summaries of CWD biomass (tons per acre, volume (cubic feet per acre), the number of pieces per acre, and

percent cover (Woodall and Monleon 2008), which can be reported for subgroups of the data as defined by diameter class, species, or decay class. Improved precision of these estimates is obtained by post-stratifying the sample using geospatial datasets (Hatfield 2010).

Current remote-sensing technologies provide low accuracy for estimating any of the down wood metrics. Researchers are exploring options for using nearest neighbor methods to derive useful estimates of down wood for midscale and broad-scale analyses.

We recommend two protocols for measuring down wood, the *FIA Field Guide for Phase 3 Measurements*, available at <http://fia.fs.fed.us/library/field-guides-methods-proc>, and the log sampling methods in SnagPRO (Bate et al. 2008a). Both protocols use the line intercept method (Brown 1974), but SnagPRO also uses the strip-plot method (Bate et al. 2004), a recommended design for sites with low density of logs (Bate et al. 2008a). The FIA field guide focuses primarily on how to use the line intercept method for measuring down wood and how to resolve a variety of data-collection issues that arise in the field. SnagPRO has similar field protocols, but also provides software for conducting a pilot test so that users can identify the optimal length of the transect to minimize the variance of the metrics of interest for future sampling. Down wood information from FIA is most useful for midscale and broad-scale monitoring, whereas SnagPRO provides software for sampling and analyzing down wood at the scale of stands and small landscapes.

Percent Cover of Down Wood. Mellen-McLean et al. (2012) found that percent cover of CWD was the most common metric used in studies of wildlife habitat use (20 of 50 studies). In the past, biologists made visual estimates of percent cover, but this attribute is more accurately derived from algorithms using the number of pieces, length, and diameter. Mellen-McLean et al. (2012) provide tables that convert volume and number of pieces to percent cover, with these conversions specific to many of the common

Table 4.9.—Down wood decay classes (known as coarse woody debris [CWD] in *Forest Inventory and Analysis*).

Decay class ^a	Structural integrity	Texture of rotten portions	Color of wood	Invading roots	Branches and twigs
1	Sound, freshly fallen, intact logs	Intact, no rot; conks of stem decay absent	Original color	Absent	If branches are present, fine twigs are still attached and have tight bark
2	Sound	Mostly intact; sapwood partly soft (starting to decay) but can not be pulled apart by hand	Original color	Absent	If branches are present, many fine twigs are gone and remaining fine twigs have peeling bark
3	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Reddish-brown or original color	Sapwood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Throughout	Branch stubs pull out
5	None, piece no longer maintains its shape, it spreads out on ground	Soft; powdery when dry	Red-brown to dark brown	Throughout	Branch stubs and pitch pockets have usually rotted down

^a From the Down Woody Material Coarse Woody Debris Table, *Forest Inventory and Analysis Database Version 4.0* (Woodall et al. 2010).

vegetation types of the Western United States. These tables are available on the DecAID Web site (<http://www.fs.fed.us/r6/nr/wildlife/decaid>). FIA also provides percent cover estimates for P3 plot data.

Down Wood Volume. Volume is the second most common attribute of down wood used in studies of wildlife habitat use (14 of 50 studies, Mellen-McLean et al. [2012]). If down wood volume is reported not in size classes but as raw data, changes in down wood volume through time may be small and not easily detected. Although this attribute has value as a habitat descriptor and therefore could be an important attribute for inventory or assessment, total down wood volume across all diameter classes may show little change through time and may not be the best down wood attribute for monitoring purposes. The ability to detect change might improve if down wood volume is reported using diameter classes.

Formulas for estimating volume use log diameter, log length, and a taper coefficient specific to the tree species. Bate et al. (2009) found that diameter at the large end of the log is a more accurate measure for deriving volume than diameter at the line intercept. Line intercept diameter underestimates the proportion of total volume from large-diameter logs and overestimates the contribution of smaller diameter pieces (Bate et al. 2009). Because of the added costs of leaving the intersect line to measure large-end diameter (LED), Bate et al. (2009) recommend making a visual estimate of the LED size class while standing at the intersect line. Down wood density is the number of pieces per unit area, usually reported by diameter class and/or decay class.

Shrubs

Cover. Shrub cover is defined as the proportion of ground, usually expressed as a percentage, occupied by the aerial parts of the vegetation of one or more shrub species (table 4.1; Warbington 2011). Canopy cover estimates include small openings or gaps in the canopy, whereas foliar cover estimates exclude small openings (SRM 1989). Foliar cover is an important concept in quadrat and line intercept methods because it is more useful for detecting subtle changes in cover than the canopy cover method. Bonham (1989) recommended measuring canopy cover, however, with an appropriate gap rule, rather than foliar cover because foliar cover measurements may have less user repeatability. Shrub cover can be recorded by individual species or all shrubs combined, depending on the monitoring objectives.

Shrub canopy cover can sometimes be estimated at broad and mid scales using aerial photography. Forest canopies often obscure detection of the shrub layer, which is a disadvantage of this method in forested landscapes. When the method is appropriate, cover is estimated as the percentage of the area of interest, using software to analyze digital imagery, whether from satellites or aerial photographs. Cover of shrubs on aerial photography can also be estimated visually or manually using a dot grid, but these methods are rapidly becoming obsolete because photographs can be converted to digital format and electronic dot grids can be superimposed on images (e.g., with Digital Mylar; section 4.5.2).

Collect shrub canopy cover data at local scales using one of the following methods: (1) ocular estimation within plots or quadrats; (2) line intercept along a line or multiple lines; or (3) point intercept along multiple lines, corners of quadrats, **point frames**, or by step point transects (section 4.4.2; see also Bonham 1989 and Herrick et al. [2005]). Selecting an appropriate method and its variants depends on the size, canopy pattern, and spacing of the shrubs. Large fixed-area plots (either circular, rectangular, or square) can be used for visual estimates of shrub canopy cover, but these estimates are less repeatable owing to the angle of observation (oblique) and size of plot. Line intercept is best for large, widely spaced shrubs. Quadrats are appropriate for sampling cover of closely spaced small shrubs or **subshrubs**. The point intercept method can be used to measure cover on any type of shrub, but the number and spacing of points should be adjusted based on these characteristics. In shrublands, such as sagebrush, line intercept is used most often to measure shrub foliar or canopy cover. The *Existing Vegetation Classification and Mapping Technical Guide* (section 2.4.5 in Warbington [2011]) provides detailed guidance on canopy cover estimation. The NRM field guides for these methods are located at: <http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml>. (See section 4.4.2 for more details on field methods described previously.)

For some wildlife species, such as snowshoe hare, the degree to which shrubs, saplings, and woody debris provide hiding cover is important and may be critical to survival (Sullivan and Sullivan 1988). Sometimes referred to as horizontal cover, this attribute is generally measured using a vertically held quadrat. A board (or cloth) divided into small squares is held vertically at a specified distance from a plot center and height off the ground, and the number of obscured squares is used to index horizontal cover.

Horizontal cover has the same relationship to shrub cover as canopy closure has to canopy cover. Whereas shrub cover is measured as a vertical projection of cover on the ground and includes only shrubs, horizontal cover incorporates all objects that create visual obstruction. As with canopy cover and closure, the biological roles of horizontal cover and shrub cover are different. Measurements of horizontal cover are not standardized and are mostly absent from existing data sources. If a habitat-relationship model indicates that horizontal cover is an important habitat component for the emphasis species, the best approach is to determine how horizontal cover was measured in the model, and then collect data using the same method.

Height. Shrub height, defined as the distance from the growing tip of the shrub to the ground, is an important habitat attribute for many terrestrial vertebrates. For example, optimal sagebrush height for brood-rearing habitat of greater sage-grouse (*Centrocercus urophasianus*) is 40 to 80 cm (16 to 31 in), whereas sagebrush heights of 25 to 35 cm (10 to 14 in) are best for winter habitat (Connelly et al. 2000). Shrub height is an indicator of plant vigor (Elzinga et al. 1998) as well as plant physiological response to browsing, and thus can be used to measure changes in habitat in response to herbivory. A method for assessing plant architecture as a function of browsing pressure, based on height and other

factors, is available and can be used to determine whether shrubs and deciduous trees (especially aspen [*Populus tremuloides*]) can either escape browsing pressure or recover after the pressure is removed (Keigley and Frisina 1998).

For field sampling, use a tape measure to record height of low (less than 0.5 yard [yd]) or medium (0.5 to 2 yd) shrubs, or a clinometer for tall (greater than 2 yd) shrubs. If only coarse estimates of height are required, shrub height can be measured rapidly using a lightweight pole, such as 0.5-in PVC pipe, with marked gradations. Samplers can collect shrub height data concurrently with canopy cover when using line intercept methods (Herrick et al. 2005; section 4.4.2) or in fixed-area plots and quadrats. Remote sensing methods can also be used to measure shrub height; sagebrush height and canopy cover were characterized using classified Landsat imagery to describe greater sage-grouse winter habitat in Utah (Homer et al. 1993). More recently, researchers used LIDAR to estimate shrub heights in sagebrush steppe, although LIDAR-derived estimates are uniformly lower than field-measured data (Streutker and Glenn 2006).

Herbaceous Vegetation

Cover. Herbaceous cover functions in a variety of roles as wildlife habitat. In addition to its obvious value as forage for herbivores, herbaceous vegetation provides hiding cover and nesting habitat for many species, such as grassland birds, and supports insect populations important as prey. For example, eastern meadowlarks (*Sturnella magna*) prefer moderately tall grasslands with a high proportion of grass and moderate to high forb density (Hull 2003). Herbaceous cover is also an important indicator of level of herbivory by domestic and wild ungulates, which may affect ecosystem processes such as nutrient cycling and primary productivity (Hobbs 1996).

Use quadrats of varying sizes and shapes to visually estimate cover of herbaceous vegetation, small shrubs, and subshrubs (plots and quadrats are further addressed in section 4.4.2 for more details). Cover can be recorded for all herbaceous plants by life form (e.g., grasses versus forbs) or by species. If small openings are included, record canopy cover of herbaceous vegetation; however, if small openings are excluded from measurements, record cover as foliar cover (SRM 1989). Foliar cover is an important concept in quadrat and line intercept methods because it is more useful for detecting subtle changes in cover than the canopy cover method. Line intercept (section 4.4.2) can also be used on tufted herbaceous vegetation with discrete canopies to measure intercept, but it is more difficult to use on rhizomatous vegetation. The point intercept method can be used, either along lines (line-point intercept), on corners of multiple quadrats, or less commonly by using the step point method or point frames (Elzinga et al. 1998). Point intercept is superior to line intercept or plot/quadrat methods when assessing cover of fine-leaved (grasses) and/or open, lacy vegetation, such as ferns. See section 4.4.2 for more details on these methods.

Height. As described previously, herbaceous vegetation can be an important habitat attribute, and height is simply another metric to describe their quantity. A tape measure

or ruler is used to measure height of graminoids, forbs, and other herbaceous vegetation, often along a transect (Herrick et al. 2005). A modification of height estimation is the Robel pole method, or visual obstruction reading, developed to estimate herbaceous vegetation biomass and vegetation height density in grasslands (Robel et al. 1970, Toledo et al. 2010). Height density is highly correlated with vegetation height, but these are not equivalent (Higgins et al. 2005). The pole can also be used to record maximum vegetation height, however. Depending on the vegetation height at the sampling site, the pole is marked with bands that are typically in alternating light and dark colors varying in width (Robel et al. 1970, Uresk and Juntti 2008). The number of the lowest visible band is recorded, typically from a distance of 13 ft from the pole and from a height of 3 ft (e.g., Benkobi et al. 2000, Robel et al. 1970). In general, five transects with 20 stations each, typically 30 ft apart, are adequate to characterize one section (640 ac). For larger areas, however, a stratified random design is advised.

Vegetation height and visual obstruction readings are often highly correlated, but height measurements obtained from a pole, such as at specified intervals along a line transect, are more repeatable and interpretable than are estimates of visual obstruction (Toledo et al. 2010). A field guide for using the Robel pole method to measure vegetation structure is available through the Rangeland Inventory and Monitoring Web site (<http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml>).

Herbaceous height also can be measured in quadrats by using a calibrated ruler or tape (Higgins et al. 2005), and reported as described previously for shrubs. Effective plant height is measured as the maximum height of the leafy portion of herbaceous vegetation (Higgins et al. 2005). For example, measure graminoid height at the maximum height of the vegetative part of the plant, not the flowering culms. Stubble height is a measure of herbaceous vegetation remaining after grazing (Clary and Leininger 2000), often in relation to grazing by livestock. Compared with other grazing intensity monitoring indicators, recording stubble height has the advantage of simplicity, rapidity, high repeatability, and accurately reflecting grazing severity (Holechek and Galt 2004). Rodgers (2002) found stubble height correlated with pheasant (*Phasianus* spp.) abundance on the Great Plains. Stubble height also is used as a habitat measure for great gray owls (*Strix nebulosa*) in California (Lile et al. 2003). The value of stubble height as a wildlife habitat attribute needs further research on a species-by-species basis.

Structural Stages

Vegetation structural stage and seral stage are closely related, but are not synonymous concepts. Structural stages are based on vegetation community processes of initiation, growth, competition, and mortality (Johnson and O'Neil 2001, Oliver and Larson 1996). By contrast, seral stages are intermediate communities in an ecological succession (Johnson and O'Neil 2001). It is possible to have multiple structural stages within a seral stage. For example, open and closed structural stages are commonly used divisions of

seral stages in the Pacific Northwest (Johnson and O'Neil 2001, Moeur et al. 2005; table 4.7). In many wildlife habitat applications, structural, rather than seral, stages are used.

After vegetation type (section 4.3.1), structural stage is probably the most important wildlife habitat concept in a management context. Johnson and O'Neil (2001) define wildlife habitat as cover type plus structural conditions, in conjunction with specific habitat elements. Wildlife managers often think of structural stages in defining older forests, but an increasingly important focus for wildlife and land managers is early successional habitats, in which seral and structural stage concepts are used (Fritcher et al. 2004, Jenkins and Starkey 1993, Thompson and DeGraaf 2001).

Johnson and O'Neil (2001; chapter 3) provide an excellent organization and practical illustration of using structural stages in describing wildlife habitat. Although written for the Pacific Northwest, the structural stages presented apply to a wide variety of ecosystems. For forested ecosystems, structural stages are combinations of tree size groups (based on diameter classes), percent canopy cover (in classes), and the number of canopy layers. For example, one structural stage is referred to as "sapling/pole-closed," indicating small-diameter trees (1 to 9 in) with relatively high canopy cover (more than 70 percent) and a single canopy layer (Johnson and O'Neil 2001). Table 4.7 presents the criteria used for all forest and shrub/grassland structural stages.

We recommend this table as a starting point for use of structural stages in habitat monitoring. The table can be refined based on specific needs, but regions should carefully coordinate and define the structural stage definitions they will use. Because wildlife habitat needs are often defined based on specific thresholds (e.g., trees with diameter greater than 21 in and trees older than 80 years), structural stage definitions should incorporate these thresholds when possible.

For habitat monitoring, structural stage is a derived attribute associated with attribute measures, such as tree size distribution and canopy cover. Structural stages assigned through visual estimation are difficult to replicate and change statistics will be of unknown value.

Vegetation Phenology

Vegetation phenology relates to the timing, interannual and within 1 year, of recurring life history events, such as bud burst, leaf emergence, first flowering, and senescence (Morissette et al. 2009, Willis et al. 2008). Weather and climate are strongly tied to changes in plant phenology, especially in temperate climates, which in turn can affect plant growth, herbivory effects, forage availability, or even community composition and structure (Cleland et al. 2007, Morissette et al. 2009, Parmesan 2006). Changes in plant and animal phenology have been key indicators of climate change (Parmesan 2006). Thus, monitoring vegetation phenology may be useful in predicting future modifications of wildlife habitat, including geographic shifts or changes in quality, as a result of climate change (chapter 2, section 2.2.7; chapter 7, section 7.2.1).

Altering vegetation phenology can affect wildlife habitats in multiple ways. For example, timing of flowering is variable among taxa; those taxa that do not respond to changes in temperature may experience sharp declines in abundance, thus altering vegetation composition and potentially affecting habitat quality (Willis et al. 2008). Links between wildlife species and vegetation components of their habitats can become uncoupled with climate-induced shifts in phenology. These broken links can lead to mismatches in life cycle events between predators and prey or insect pollinators and plants, often with negative consequences for fitness (Miller-Rushing et al. 2010, Parmesan 2006). For example, in Colorado, yellow-bellied marmots (*Marmota flaviventris*) emerged from hibernation 23 days earlier during a span of 25 years, but the timing of plant flowering and snowmelt did not change leading to asynchrony between the marmots and their food sources (Inouye et al. 2000). For these reasons, assessing plant phenology as part of a habitat monitoring program may be essential for understanding changes in habitat quality or amount through time, and how those changes may ultimately affect wildlife populations (Miller-Rushing et al. 2010).

Metrics to assess vegetation phenology can be derived from field-sampled and remotely sensed data. In the field, characteristics, such as dates of first flowering or timing of leaf emergence of key plant species are often measured. Although such records can be valuable, they are typically limited in geographic scope and context, and local measurements of phenology are highly variable and strongly influenced by microclimate (Fisher et al. 2006, Morisette et al. 2009). Newer technologies have emerged using digital cameras and wireless imagers to monitor plant phenology. For example, researchers can accurately estimate the number of flowers on images from a pan-tilt-zoom camera (Morisette et al. 2009). Although local in extent, historical records of vegetation phenology have been invaluable in documenting changes in plant phenology for hundreds of years (Bradley et al. 1999, Cleland et al. 2007).

Remote sensing methods are increasingly used to measure aspects of vegetation phenology (Cleland et al. 2007, Morisette et al. 2009). Two especially useful metrics that can be captured from moderate resolution satellite imagery (e.g., 250 meters) are the Normalized Difference Vegetation Index (NDVI) and the Wide Dynamic Range Vegetation Index (WDRVI) (Morisette et al. 2009). These indices reflect land surface greenness and are thus good indicators of seasonality, such as season start and end dates and length of season (Morisette et al. 2009, Viña et al. 2008). Recent studies have demonstrated the value of field-sampled data in interpreting remote sensing derived measures of plant phenology (Fisher et al. 2006).

Resources for addressing phenology, including protocols and data sets, are available from a variety of sites. The National Phenology Network (<http://www.usanpn.org>) has developed a suite of protocols for monitoring phenology for plants and animals, and is an excellent source for emerging technologies and uses of phenology in resource management, as well as phenology data sets. We encourage use of these standardized protocols

for measuring phenological events for habitat monitoring when appropriate, and sharing data collected for habitat monitoring with the network to augment the data available for others interested in phenology. A National Phenology Data Set, based on NDVI values, is available; maps of these data can be viewed in Google Earth through a KML file (Hargrove et al. 2009; <http://data.forestthreats.org/phenology/>). Products available include a variety of parameters including spring arrival (date when 20 or 80 percent of maximum NDVI for the year attained) and cumulative phenology (summed NDVI values) and derived products, such as duration of fall or spring, and the variability of these seasonal lengths.

Two additional potential sources of information for habitat monitoring related to phenology and climate change are the Climate Change Tree Atlas (Prasad et al. 2007–ongoing) and the Climate Change Bird Atlas (Matthews et al. 2007–ongoing). These Forest Service products present current distributions of 134 tree species and 150 bird species of the Eastern United States, along with their predicted distributions under a suite of emission scenarios and climate models (<http://www.nrs.fs.fed.us/atlas/index.html>). The atlases are easy to use in a Web-based environment, and individual species can be selected and results summarized. The site also produces information about which factors limit the current distribution of species, which factors are the best predictors of current distributions, and which range of precipitation conditions a species will experience in the future.

4.4 Existing Protocols and Sources of Field-Sampled Data

To improve efficiency and transferability, we recommend using existing data collected using standard protocols rather than collecting new data, if this approach will meet the objectives of the monitoring plan. Carefully evaluating available datasets before initiating a habitat monitoring program is a good investment of time, especially when budgets and personnel are limited. Establishing a new monitoring program in the context of other monitoring at subregional and regional scales will offer gains in efficiency. Often a carefully designed monitoring plan can yield useful data at multiple scales, with only minor changes in sampling design required. If specialized data collection is required, consult Elzinga et al. (1998) for a comprehensive review of all aspects of vegetation monitoring. (See also chapter 8 for guidance on data analysis and chapter 9 for information about data management and reporting.)

The following sections describe sources of existing field-sampled data, protocols for data collection, and guidelines for use of field-sampled data. Some of these data are currently being collected under well-established protocols (e.g., FIA data), and vary in quality and age. To be useful for monitoring purposes, data must be associated with a specific sampling protocol, and the data need to have a sampling design that can be intensified or extended to the area of interest for the monitoring program. FIA provides several tools, such as EVALIDator, to help determine the number of plots required to achieve population estimates with desired confidence. Occasionally older data sets (i.e., legacy data) can

provide baseline information. Use legacy data carefully, however, because they may have been collected in the absence of a sampling design or protocol, or collected using a protocol that is not consistent with more recent data collection. As detailed in the following section, methods of data collection can result in differences in the derived attribute values. Monitoring is the business of change detection, and managers need to ensure that the observed changes from baseline conditions are biological rather than sampling artifacts.

4.4.1 Existing Protocols and Data in NRM

The NRM is the standard system of the Forest Service for data-collection protocols, standards, and formats. (See <http://fsweb.nris.fs.fed.us/products/index.shtml>.) The most relevant NRM modules for habitat monitoring are FSVEg, which includes FIA, its GIS environment, FSVEg Spatial, and Rangeland Inventory and Monitoring. The Inventory and Mapping module is also relevant for its potential vegetation context.

For monitoring habitat in riparian areas, the National Riparian Monitoring Protocol is under development for the Western United States (USDA Forest Service, in press). In addition, the *Riparian Methods Technical Guide* provides summaries of a variety of methods for mapping, monitoring, and inventorying riparian vegetation. The guide is intended to introduce resource managers to remote sensing methods that can be used to fulfill a variety of riparian business needs. The guide also will include links to other information about riparian assessment and will be located with the *Rangelands Methods Technical Guide* as part of the Landscape Toolbox (<http://www.landscapetoolbox.org/>).

FSVEg

The best source for plot- and stand-level information at the local scale, especially in forested ecosystems, is FSVEg. This application stores plot data collected under the CSE protocol, as well as strategic grid data, insect and disease study data, FIA data, and remeasured permanent growth plot data.

CSE protocols for stand and compartment examinations include standards for collecting stand, plot, tree, surface cover, understory vegetation, and down wood data (USDA Forest Service 2010b, available within the Forest Service Web intranet environment at <http://fsweb.nris.fs.fed.us/products/FSVEg/documentation.shtml>). CSE also contains data codes, portable data recorder software, forms, reports, and export programs. See chapter 9 for additional information about the corporate data structure of NRM.

Data and associated reports in FSVEg can be extremely valuable for monitoring wildlife habitat because most forest-related habitat attributes are either measured directly using the CSE protocol or are available as derived attributes in FSVEg. Therefore, the primary questions are whether CSE data were collected across the local area of interest for the emphasis species and whether the data are sufficiently current to use as the basis of a monitoring program. If existing CSE data are inadequate to meet monitoring objectives, use the CSE protocol to collect new data or augment whatever CSE data are available.

FIA

A second source of plot data is FIA, which is the continuous forest inventory on all land ownerships in the United States. The current quasisystematic sampling design is based on a hexagonal grid across the United States, with each hexagon containing approximately 6,000 ac, with a measurement cycle of 5 years in the Eastern United States and 10 years in the Western United States, implemented under a rotating panel design (chapter 3, section 3.3.3).

The inventory involves the following three phases. Phase 1 (P1) entails stratification of estimation units (e.g., counties) to increase the precision of sample estimates. P2 is comprised of ground plots that occur at an intensity of roughly 1 plot/6,000 ac. P3 plots are a 1/16 subset of P2 plots. Technicians collect additional data in P3 plots on forest health indicators, such as down wood, understory vegetation, soils, lichens, ozone, and tree crowns. In some FIA regions, however, all vegetation types, including shrublands and grasslands, are sampled using the FIA P2 plot grid. This All Condition Inventory (ACI) creates P2 plot grid coverage of forested and nonforested sites. While the ACI is not yet a national approach, there is potential to implement this inventory on a national basis.

FIA data offer great utility for estimating or deriving wildlife habitat attributes. Table 4.3 describes habitat attributes addressed in this chapter that are available, or can be calculated, from FIA data. When constructing wildlife-habitat-relationships models from FIA data, these models can be applied across large landscapes (e.g., Zielinski et al. 2006, 2010). FIA data are stored in FSveg and are also available on the FIA Web site (<http://fia.fs.fed.us>), two sites where data are organized by State with each file containing all levels of data (tree-level data, condition-level data, etc.) and a set of derived variables (e.g., tree volume).

The FIA program also includes valuable tools that generate tabular and spatial summaries based on user-defined inputs (accessible at <http://fia.fs.fed.us/tools-data/default.asp>). These tools include the following applications.

- EVALIDator—available either as a Web-based tool or as a downloadable Microsoft Access database. Analyses can be conducted for any State, and reports can be created for nearly 100 different attributes. In addition, spatial and attribute filters can be applied to customize the output to meet the user's needs (Miles 2009).
- FIDO—a Web-based reporting tool that creates tables and maps from user-defined areas of interest and survey years. Nearly 50 standard reports are available, or the user can develop customized queries. The results can be displayed in several output formats (Wilson and Ibes 2005).

There are four important caveats for using FIA data. First, Federal law mandates that FIA plot locations remain undisclosed to the public. Thus, plot locations (e.g., latitude and longitude) of publicly available data sets are approximated and do not represent the true locations of the plots. Although the rules vary by FIA unit, all plot locations are “fuzzed”

(up to 1 mile), and a proportion of locations on private lands are swapped with other locations. Any fuzzed and swapped locations always remain within the original county, however. Approximate plot locations or even simple tabular data may be sufficient for monitoring habitats of emphasis species or for monitoring specific habitat attributes, such as snag density. The effect on analyses depends on the spatial resolution and the use of the data (McRoberts et al. 2005). For analyses requiring exact plot locations, FIA has established a spatial data services center (SDS). This facilitates linking FIA plot data with spatial information while keeping plot locations confidential. To learn more about SDS, visit http://www.fs.fed.us/ne/fia/spatial/index_ss.html.

Second, with 1 plot/6,000 ac for P2 plots and 1 plot/96,000 ac for P3 plots, a local-scale analysis might contain only one to two plots, which is insufficient for an analysis of habitat data for monitoring. Therefore, FIA data are best used for analyses at broad scales (regional or subregional), although they can also be useful for forest-scale applications, such as prioritizing habitat by broad vegetation type. Some regions increase the regional sample of FIA plots through grid intensification, in which additional plots are sampled between the normal FIA grid spacing. The regions collect data under the FIA protocol or a modified CSE protocol to combine the original FIA sample with the local sample for a seamless analysis. Exploring existing FIA data will demonstrate the variability of the attributes of interest and will help determine how many additional plots are needed. Consult your regional Forest Service office to determine whether grid intensification has occurred in your area. If not, use data from the FIA plots that fall in your analysis area, but acquire new data using either the FIA protocol or a modified CSE to obtain a sufficient sample to meet monitoring needs.

Third, FIA is primarily a forest inventory. Although some programs sample nonforested vegetation (ACI was addressed previously), the plots are selected based on stratification at a national scale of forest/nonforest vegetation types. FIA sampling therefore does not generally extend into nonforested vegetation.

Fourth, the Forest Service does not sample FIA plots annually. As such, FIA data are best suited for long-term monitoring. If a habitat monitoring program requires information on rapid vegetation response at fine spatial scales, extant FIA data will likely not be useful. Advantages still exist to collecting new data using FIA protocols, however. Local results can be directly compared with and potentially applied to the larger spatiotemporal domain in which FIA excels, if this strategy is followed (e.g., Zielinski et al. 2006).

FSVeg Spatial

FSVeg Spatial provides an environment for displaying and analyzing vegetation attributes in a GIS environment. This application uses a polygon approach and is strongly recommended as a standardized, Agency-supported vegetation mapping environment at the local scale. Polygons can be populated with a variety of data sources. For example, in the Forest Service Pacific Northwest Region, raster data from satellite imagery for mid-scale mapping are summarized and used to populate FSVeg Spatial polygons for some

local planning units. Polygons are also often developed from legacy stand examination polygon data layers. Forests nationwide are gradually implementing this application. A limitation of the application is that only National Forest System lands are mapped.

Rangeland Inventory and Monitoring

While this application provides methods for sampling all life forms, the primary emphasis focuses on sampling nonforested vegetation, including shrublands and grasslands because there are more methods available for these vegetation types. In addition, the methods, analysis, and geospatial tools in this application meet a different set of sampling objectives than those in CSE (FSVeg). Rangeland Inventory and Monitoring includes protocols, such as visual macroplot, line intercept, and cover/frequency for sampling vegetation; these applications will be useful when the CSE protocol does not meet inventory and monitoring information needs. Line intercept is currently supported by a protocol in the NRM (see <http://fsweb.nris.fs.fed.us>). Go to http://fsweb.nris.fs.fed.us/products/Rangeland_Inventory_Monitoring/index.shtml for a full list of methods and associated field guides available in this application. In the past, acquiring existing data for nonforested vegetation types was challenging because the Forest Service has collected data less consistently in these ecosystems. All Forest Service regions are now collecting data within some of the nonforested areas, however.

4.4.2 Data-Collection Methods for Field-Sampled Data

The section that follows describes commonly used methods of field data collection to sample the vegetation attributes described in this chapter. We assume decisions about organization, placement, and intensity of field plots or transects have already been carefully made before the collection of new data begins (chapter 3). The methods described in the following section are located in NRM (section 4.4.1). Details about using these methods for particular vegetation attributes are presented in sections 4.3.1 and 4.3.2. Consult Elzinga et al. (1998) and Herrick et al. (2005) for more specific information on a wide range of field-sampling methods for the plot, quadrat, line intercept, and point methods that follow.

Plots and Quadrats

Plots and quadrats are area-sampling methods because they have two-dimensional area (length and width or radius and diameter). Fixed-area plots are typically large enough to walk within the boundaries. In general, plot size is a function of vegetation size, spacing, and pattern, regardless of life form, but may vary by vegetation type (i.e., the dominant vegetation). For forested vegetation, 1/5-ac plots are common, whereas in shrublands, 1/10-ac plots are often used. In herbaceous vegetation (e.g., grasslands and wet meadows), 1/24-ac (or smaller) plots are commonly used. Plot shapes vary, but shape is typically circular in most upland vegetation and rectangular in riparian vegetation.

When estimating cover in fixed-area plots, the sampler usually walks the plot to avoid viewing the vegetation at an oblique angle from the plot center, which results in an

overestimation of cover. Estimating plant abundance in large, fixed-area plots lacks adequate precision and repeatability through time and among different observers, but may be sufficiently repeatable for monitoring broad changes in vegetation cover (e.g., by life form).

Quadrats are smaller than fixed-area plots and can be viewed from one point, usually standing and looking directly down on the vegetation. Because of their smaller size and the position of the sampler, measurements from quadrats are more precise and more accurate than those from fixed-area plots; they are also more repeatable through time and among different samplers. Using small quadrats reduces the number of items encountered, as well as the search time. The appropriate number of quadrats to be sampled, the number of lines (if quadrats are placed along lines), and the size, spacing, and shape of quadrats are functions of the size, pattern, and spacing of the vegetation.

Multiple quadrats also can be nested within a fixed-area plot, such that tree or large shrub cover and density are assessed in the large plot, and herbaceous and small shrub/subshrub cover and density are assessed in the quadrats. Currently, protocols in NRM support visual macroplot and cover/frequency methods (<http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml>).

Line Intercept

In line intercept, the sampling plane is one-dimensional. When sampling, a line or transect is drawn between two points; all objects of interest that intercept the line are counted and/or measured. Transects can be positioned at any height (determined by the dimensions of the sampling plane), depending on the item being sampled (e.g., shrub cover and ground cover). In general, the line is approximated using a tape that is suspended above the vegetation or laid flat on the ground. For many attributes, transects provide very repeatable measurements and are therefore good choices for monitoring. This method is most often used to measure **cover (canopy or foliar)** of shrubs, grasses, and herbs (Canfield 1941; see Shrubs and Herbaceous Vegetation, section 4.3.2) or to count items that intersect the line, such as down wood by size class (section 4.3.2). Line intercept is commonly used to estimate cover in nonforested ecosystems, but it is also used in forested systems to measure understory shrub cover.

Multiple lines can be oriented perpendicular to a baseline, forming a large square or rectangular macroplot, which is the sampling unit. Another approach is to arrange the lines as spokes within a large circular macroplot and start the intercept measurements an appropriate distance (e.g., 1 to 5 ft) from the center of the plot to avoid oversampling of vegetation at the plot center. Intercept of either canopy, foliar, or **basal cover** of vegetation is measured and summed along each line, and average cover is then calculated across all transects for the entire macroplot. This method is most appropriate for shrubs (typically less than 5-ft tall) or vegetation with well-defined canopies, such as matted forbs or subshrubs (Elzinga 1998).

A hybrid of the plot and line intercept methods is the belt or strip transect, which is essentially a long linear rectangle. Strip transects have the advantage of sampling a much larger area than a line transect and are therefore best used if the object of interest is scarce yet easy to detect. Strip and belt transects are poor choices for common objects, however, because the strip functions as a long, narrow plot. As such, this approach has a very large edge-to-area ratio, requiring multiple boundary decisions (i.e., in or out) along the plot edge.

We also recommend the variable strip transect, which is most useful in measuring tree boles. Using this approach, an observer walks a transect looking for trees of interest. When spotted, the observer walks forward until the tree is perpendicular to the transect and then uses a prism or Relaskop to determine whether the tree is tallied. Advantages of this approach are that for large-diameter trees, plot size is huge (transect length by limiting distance) and prisms and Relaskops, combined with limiting distance tables, allow for highly repeatable counts with minimum time spent measuring distances. Because of the large plot area, variable transects are well suited for counting rare trees, such as large-diameter snags.

Point Methods

The point intercept method is commonly used to measure cover, including foliar and basal vegetation cover and ground cover (e.g., bare ground, moss, rock, and litter). Because points are essentially dimensionless, this method is considered the least biased and most repeatable for determining cover (Bonham 1989, Elzinga et al. 1998). If the point intercepts the item being measured, such as basal vegetation, it is tallied. Determine the percentage composition by cover for each category (e.g., species, life form) by dividing the number of points within a category by the total number of points and multiplying by 100.

In typical low-statured herbaceous vegetation, points are usually identified using a sharp rigid object, such as a range pin or a ballpoint pen. Equal-sized points are used for consecutive measurements and documented in the project metadata. Points can be organized along lines (line intercept; Herrick et al. 2005), in point frames, or in quadrats (intercept recorded on quadrat corners). A point frame typically yields more repeatable results because the angle of intercept is fixed. Typically, the pin is placed perpendicular to the ground surface. In grasslands dominated by fine-leaved rhizomatous species, however, an oblique angle can be used (Elzinga et al. 1998). Because the point-intercept method samples the least amount of area within a sampling unit, it may be necessary to sample many points to obtain an adequate sample for estimating cover.

Herrick et al. (2005) present a variety of options to supplement the basic line-point intercept method, such as recording height on a subset of the points. The resulting dataset can be used to assess structural complexity (see canopy complexity, section 4.3.2). Point intercept is appropriate for trend monitoring because it is repeatable through time and among users. Detailed metadata documentation (e.g., sampling rules about maximum gap for foliar cover, side of tape read, and overlap) is critical for consistency in measurements, however.

4.4.3 Guidelines for Using Field-Sampled Data

For any given monitoring program, using existing field-sampled data depends on the spatial extent of the monitoring program and the desired level of precision in monitoring results. For broad-scale monitoring, we recommend P2 and P3 FIA data because (1) the sampling design provides a statistically valid, spatially balanced sample; (2) the data are collected through a stringent, documented protocol; and (3) the data are free and readily available through NRM. Although a national forest of approximately 1 million ac has 100 to 200 P2 plots, field-data collection normally occurs on only forested P2 plots. On many western national forests, this practice can substantially reduce the amount of information available for forested areas. Further reductions occur when only a subsample of forested P2 plots meets habitat requirements for the emphasis species, such as all P2 plots in mixed conifer, late seral forests. As a result, there will likely be insufficient data to obtain the desired standard errors for monitoring and the grid must be intensified within the vegetation types of interest while maintaining a spatially balanced sample.

If there are too few P2 plots within an analysis area, collect data on existing and new plots using the FIA protocol or a modified CSE to combine new data with existing data for a seamless analysis. The choice of whether to use FIA or CSE data depends on what protocol is locally available and the approach used by the applicable Forest Service region. Three Forest Service regions (Pacific Northwest, Pacific Southwest, and Northern) have intensified the FIA grid through specific regional protocols. Contact the regional FIA coordinator to learn more about the regional grid and to obtain assistance with accessing and using the data.

Midscale monitoring programs can also take advantage of FIA data but will need to intensify the grid to increase sample size, reduce variance, and achieve the desired precision for the monitoring objectives. Midscale monitoring programs can also use CSE data; they can be augmented using the existing data stored in the Ecosystem Inventory and Monitoring application to further describe additional vegetation characteristics. Again, the choice of whether to use CSE or FIA protocols depends on which protocol is being implemented on a local or regional basis.

Because of the small spatial extent of local monitoring programs, it is rare that existing data are available for the area of interest. Therefore, the standard approach will be to collect new data for all or most of the identified habitat attributes. To the extent possible, use CSE or FIA protocols to collect new data; augment these protocols using methods from the Vegetation Inventory and Monitoring application of NRM (e.g., line intercept, cover/frequency) if the sampling objective requires additional data.

When using existing local data, carefully evaluate the sampling design under which the data were collected. If collected for a specific project or specific area, the data may not be representative of the area of interest to be monitored and might not meet statistical standards for randomized or unbiased sampling. These data are purposive or convenience sampled, and although they may have served a purpose for a past objective, they can

cause statistical problems if they become the basis of a new monitoring program (Anderson 2001). It is also important to ensure that the sampling unit is clearly defined and that subsamples are not confused with samples (see chapter 3, section 3.3.3).

4.5 Existing Protocols and Sources of Remotely Sensed Data

The Forest Service and other land and resource management agencies use a wide variety of remotely sensed data sources that may be useful in wildlife habitat monitoring programs. These sources include traditional aerial photography, moderate to very high-resolution digital satellite imagery, and active systems, such as radar and LIDAR (tables 4.2 and 4.10). The data can be acquired from either airborne or spaceborne platforms and can be either in photographic or digital form. The Forest Service and other Federal agencies have acquired and archived these data types regularly for decades.

As with field-sampled data (section 4.4), we recommend using existing remotely sensed data when possible, rather than collecting new data. The Forest Service Geodata Clearinghouse provides access to numerous raster and vector data sources as well as existing maps and other tools (<http://svinetfc4.fs.fed.us>). A variety of spatial data sets, primarily but not solely derived from remote-sensing methods, are maintained by the Forest Service and described in the National GIS Data Dictionary (table 4.11). Availability of layers varies by land management unit and many data sets are available on public-facing Web sites in addition to internal Forest Service intranet sites. Other sites that offer free downloads of spatial data layers for a variety of land ownerships include the following:

- The U.S. Geological Survey (USGS) National Map site (<http://nationalmap.gov/>), which provides public access to high quality geospatial data for a wide variety of thematic areas, such as geology, climate, ecoregion boundaries, transportation networks, ownership, Breeding Bird Survey routes, and locations of nonnative species.
- The National Atlas (<http://nationalatlas.gov/>), a U.S. Government Web site that offers on-demand mapmaking, enables users to create maps from a large number of data layers. The Web site includes data layers from the ranges of bat species in the United States to water features, such as streams, lakes, and dams.
- LANDFIRE (Landscape Fire and Resource Management Planning Tools Project), an interagency project to map vegetation, fire, and fuel characteristics across the United States (<http://www.landfire.gov/index.php>; Rollins and Frame 2006). The Forest Service wildland fire management programs and the U.S. Department of the Interior share this project. The goal of LANDFIRE is to produce a comprehensive, consistent, and scientifically credible suite of spatial data layers for the entire United States. Data products are 30-m (98-ft) spatial resolution raster data sets, which vary in accuracy by geography, product, and scale of use. The LANDFIRE National component includes more than 20 mapping products, many of which are pertinent to habitat mapping and

monitoring. The existing vegetation type map uses ecological systems, a midscale vegetation classification system between fine-grained ecological communities and coarse-grained ecoregions, to map vegetation across the United States (Comer et al. 2003; tables 4.5 and 4.6). Other map layers include environmental site potential, a potential vegetation layer, existing vegetation cover and height by life form and class, and historical fire regimes. An additional resource for habitat monitoring is the LANDFIRE reference database, which includes thousands of records of plot data used to generate the mapping products. For those interested in better understanding LANDFIRE products and their potential use in habitat monitoring, an online training course is available (<https://www.conservationgateway.org/ExternalLinks/Pages/landfire-training.aspx>).

- The National Elevation Dataset (NED) (<http://ned.usgs.gov/>), which merges the highest resolution, best-quality elevation data available across the United States into a seamless raster format. The NED provides coverage of the entire United States, including Hawaii, Alaska, and the island territories. These layers can be used to

Table 4.10.—*Characteristics of commonly available satellite imagery applicable in wildlife habitat monitoring (adapted from Brewer et al. 2005). Brewer et al. (2011a) provided a more complete and current list of Earth resource satellite sensors.*

Sensors (by recommended scale)	Swath/footprint	Spatial resolution	Revisit time	Image availability
Broad scale				
AVHRR	2,600 km	1 km/4 km	Daily ^a	1978 to present
MODIS	2,300 km	250 m, 500 m, 1 km	Daily	2000 to present
Mid scale				
Landsat MSS	185 km	80 m	16 days	1972 to 1992
Landsat TM	185 km	15-m B/W and 30-m multispectral	16 days	1982 to 2012
Landsat ETM+	185 km	30 m	16 days	1999 to present
ASTER	60 km	15 to 90 m	16 days	1999 to present
Local scale				
WorldView-2	16.4 km	0.5-m B/W and 1.8-m multispectral (8 bands)	1 to 7 days	2009 to present
QuickBird	16.5 km	0.6-m B/W and 2.5-m multispectral	1 to 3 days	2001 to present
IKONOS	11 km	1-m B/W and 4-m multispectral	1 to 3 days	1999 to present
SPOT	60 km	10-m B/W and 20-m multispectral	1 to 3 days	1986 to present
	80 km	5-m B/W		2002 to present

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer. AVHRR = Advanced Very High Resolution Radiometer. B/W = Black and white (also referred to as panchromatic). IKONOS = From the Greek word eikon, or "image." km = kilometer. Landsat ETM+ = Landsat 7 Enhanced Thematic Mapper Plus; note that, beginning in 2003, a permanent scan line corrector failure occurred, resulting in a loss of about 22 percent of the data (along edges) in scenes from this satellite. Landsat MSS = Multispectral Scanner. Landsat TM = Landsat 5 Thematic Mapper. m = meter. MODIS = Moderate-resolution Imaging Spectroradiometer. SPOT = Satellite Pour l'Observation de la Terre (System for the Observation of the Earth), developed by the French.

^a Weekly or biweekly composited data are most often downloaded for use.

Table 4.11.—Example themes and feature classes with potential application in wildlife habitat monitoring, as described in the Forest Service National GIS Data Dictionary (http://fsweb.datamgt.fs.fed.us/current_data_dictionary/index.shtml).

Theme	Example feature classes or layers	Description	Example habitat attribute or disturbance agent/process	Associated national application or references
Activities	ActivityLine, ActivityPoint, ActivityPolygon, ProjectArea	Four feature classes describe the spatial location of completed ground-disturbing activities (e.g., fire line construction, fuel removal, fence construction, weed treatments, recreation improvements) within or near an administrative unit.	Noxious weed distribution, timber harvest, trail locations	Forest Service Activity Tracking System (FACTS v.1.2; http://fsweb.ftcol.wo.fs.fed.us/fs/facts/index.shtml)
Ecomap Sections_2007	Climate, Ecomap provinces, Ecomap sections, soil sections	Includes polygons for ecological provinces and sections within the conterminous United States. This data set contains regional geographic delineations for analysis of ecological relationships across ecological units.	Ecological province, soils	http://fsgeodata.fs.fed.us/other_resources/ecosubregions.php
Fire management	Fire history, WUI	Points represent start locations for fires and polygons represent final mapped wildfire perimeter. Data are maintained at the forest/district level to track area affected by fire. WUI: the line, area, or zone when structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels; includes size of area and fire management zone identification.	Burned habitat, exurban development in the WUI	FIRESTAT, Reporting for National Fire Plan
Geology	geologic map unit (GeologyMapUnitsOrder2)	Polygon-based layer of geologic map units; polygons are delineated based on geologic characteristics and classifications. Includes NRM published feature classes for geology; includes all map unit orders for geologic map unit in NRM, point feature classes for site bedrock, and site surficial materials. Feature class polygons are attributed with stratigraphy, lithology, geomorphology, and descriptive text.	Local geologic unit (e.g., relevant for burrowing mammals)	NRM Terra
RMU	Key area, unit, subunit	Land units that support the management of rangeland needs and mapping. Includes a variety of land unit polygons (e.g., allotment, exclosure, and general resource area).	Grazing allotment boundaries, pastures, implementation monitoring boundaries	FSM 2200, http://fsweb.nrm.fs.fed.us/products/infra/
Recreation	RecreationSitePoint, RecreationSitePolygon, WildernessRecManagement Polygon	Spatial location of recreation sites (e.g., campgrounds, trailheads, boat launches) and recreational opportunity spectrum areas within or in close proximity to an administrative unit and wilderness recreation management areas within a federally designated wilderness.	Developed recreation sites (e.g., for calculating recreation site density)	FSH 2330, FSH 2340, FSM 2320; http://fsweb.nrm.fs.fed.us/products/infra/
Invasive species and TESP	InvasivePlantAll, InvasivePlantCurrent, TESP OccurrenceAll	Published data provide occurrence and infestation information at a national extent.	Extent of invasive plants within a monitoring area (e.g., sage-grouse habitat), locations of sensitive plants	http://fsweb.nris.fs.fed.us/products/TESP_Invasive_Species/index.shtml
Transportation	Road, trail, travel management area	Spatial location of roads and trails within or in close proximity to an administrative unit.	Road and trail density	http://basenet.fs.fed.us/ , http://fsweb.r6.fs.fed.us/eng/travel_routes/user_board/

Table 4.11.—Example themes and feature classes with potential application in wildlife habitat monitoring, as described in the Forest Service National GIS Data Dictionary (http://fsweb.datamgt.fs.fed.us/current_data_dictionary/index.shtml) (continued).

Theme	Example feature classes or layers	Description	Example habitat attribute or disturbance agent/process	Associated national application or references
Vegetation	EV, PNV	EV is the plant community, or floristic composition and vegetation structure, occurring at a given location at the current time; PNV refers to the plant community that would be established if all successional sequences were completed without human interference under the present environmental conditions, including those created by humans. PNV is a useful tool to stratify the landscape into basic units of land capability.	EV, PNV	NRM; Warbington 2011
Water	NHD, hydrologic units	Feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the Nation's surface water drainage system. Provides a national framework for assigning reach addresses to water-related entities, such as industrial discharges, fish habitat areas, wild and scenic rivers. NHD data is available to each forest or to a Forest Service region by navigating to the EDW Production database.	Streams, rivers, aquatic features; watershed boundaries (e.g., to establish ecologically based monitoring boundaries)	http://datagateway.nrcs.usda.gov/
Fish and wildlife	Wildlife sites, fish and wildlife observation	Terrestrial wildlife sites and the most recent visits to those sites; combines attributes of the point and polygon site layers from the NRM Wildlife application into a single polygon geodatabase feature class; locations of observations of aquatic and terrestrial wildlife.	Wildlife occurrence (to establish monitoring boundaries, habitat sampling sites, validate habitat models)	http://fsweb.nris.fs.fed.us/products/Wildlife/index.shtml

EDW = Enterprise Data Warehouse. EV = Existing vegetation. FACTS = Forest Service Activity Tracking System. FSH = Forest Service Handbook. FSM = Forest Service Manual. GIS = Geographic Information System. NHD = National Hydrography Dataset. NRM = Natural Resource Manager. PNV = potential natural vegetation. RMU = rangeland management unit. TESP = Threatened, Endangered, and Sensitive Plants. WUI = wildland urban interface.

derive topographic variables, such as slope, aspect, or topographic complexity, which is an important habitat attribute for species, such as bighorn sheep (*Ovis canadensis*) or pronghorn (*Antilocapra americana*).

- The Geospatial Data Gateway maintained by USDA Natural Resources Conservation Service (<http://datagateway.nrcs.usda.gov/>) provides a variety of natural resources and environmental data for downloading, such as soils, orthoimagery, and census data. Users can select a geographic location to see what data are available for that area or search by theme.
- USGS has satellite imagery available at <http://earthexplorer.usgs.gov/>.
- Some individual States have collated spatial data within State boundaries. For small-scale monitoring these sites provide easy data access to multiple data layers already edge-joined across the State and having a common projection. See <http://nris.mt.gov/gis/> for an excellent example relevant to monitoring in Montana.

Check with your local remote sensing specialist for new applications because remote sensing is a dynamic field, and new data sources frequently become available. Remember, any map is simply a model of actual conditions and will contain error. The Image Classification (section 4.5.2) section addresses why a **classification accuracy** assessment is important and why you need to always look for the accuracy assessment associated with any map product considered for a habitat monitoring effort.

4.5.1 Types of Remotely Sensed Data

Aerial Photography

Aerial photography offers opportunities to monitor a variety of habitat attributes, particularly at a local scale. Most national forests and grasslands have collected aerial photographs at 1:24,000, 1:15,840, or 1:12,000 scales since the 1950s and sometimes back to the 1930s. The Forest Service continues to acquire aerial photography over most local management units every 10 years. This rich archive of information can be useful for retrospective analysis and is likely one of the best current information sources about vegetation and land cover. Archived aerial photographs can be digitized and analyzed using methods commonly used in analysis of satellite imagery, offering new information for use in habitat and other monitoring (Morgan et al. 2010).

The Farm Service Agency Aerial Photography Field Office, colocated with the Forest Service Remote Sensing Applications Center (RSAC) in Salt Lake City, UT, is the archival storage location for all aerial photography negatives acquired by any Federal or cooperating State agency since 1954. Users can purchase the archived imagery as hard-copy prints or digital scans. Photography and negatives acquired before 1954 are stored in the National Archives.

Several national programs provide aerial photography covering the lower 48 States. One example is the National Agriculture Imagery Program, which acquires imagery

during the agricultural growing seasons in the continental United States and provides digital orthographic photography within 1 year of acquisition. NAIP imagery is typically 1- or 2-m (3- or 6-ft) spatial resolution and is useful for identifying a variety of forest and range vegetation attributes, in addition to houses, roads, and other anthropogenic features (chapter 7). NAIP is a digital product and is available as county mosaics or 7.5-min quarter quads at <http://www.apfo.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai-or>. (See sidebar for other national aerial photography programs.) Available since 2001 and 2002, NAIP imagery is recorded annually, and is fast becoming a commonly used data source for a wide range of natural resource applications.

Light Detection and Ranging (LIDAR)

Laser altimetry, or light detection and ranging (LIDAR), is a more recent geospatial data source providing information about the three-dimensional structure of terrestrial and aquatic ecosystems (Lefsky et al. 2002, Vierling et al. 2008). LIDAR follows the same principle as sonar or radar in that a signal, in this case, a laser beam (in the visible, ultra-violet, or near infrared range), projects from a source either downward from an aircraft or upward from a source located at a set distance above the ground. As with a laser range finder, the beam bounces off solid objects that it encounters (e.g., vegetation, rocks, soil) and the elapsed time indicates the distance between the source and the object. After being collected, the LIDAR data can be separated into bare earth and canopy layers creating a three-dimensional portrayal of the site (Lefsky et al. 2002).

LIDAR can be superior to aerial photos for obtaining estimates of many habitat attributes in forests with highly variable canopy structure. Using LIDAR processing software, measurements can be made of canopy cover, tree height, crown diameter, understory canopy cover layers height, and stand density. From these measurements, users can estimate basal area, biomass, and other canopy measurements. Vierling et al. (2008) provide numerous examples of how LIDAR data are useful for wildlife habitat studies, especially when investigating species that use vertical forest structure.

Farm Service Agency Programs

In addition to the Forest Service programs, several U.S. Department of Agriculture, Farm Service Agency programs provide useful aerial photo data spanning more than 30 years (implemented with the Forest Service as a cooperating agency). These programs include the following:

- National High Altitude Photography (NHAP) program, which started in 1978 when several Federal agencies combined their funds and knowledge to provide consistent and systematic aerial photography (1:80,000 to 1:60,000) coverage for the United States.
- National Aerial Photography Program (NAPP), which began in 1987 as a replacement for NHAP with the objective of acquiring complete and uniform photo coverage (1:40,000) of the conterminous 48 States over a 5- to 7-year cycle.
- National Digital Orthophoto Program (NDOP), which has the objective of providing complete coverage of the United States and its territories and possessions, maintained and updated every 3 to 10 years. (Note: This program uses NAPP photography when available.)

Two obstacles currently hinder widespread application of LIDAR; the high volume of data obtained and the cost of data acquisition, processing, and analysis (Laes et al. 2006). The large volume of data points requires adequate storage capacity and data summarization involves skills that are not widely available. Recent studies, however, have demonstrated that costs and accuracy of LIDAR compared with traditional stand exams can be similar for measuring vegetation structure, and LIDAR can provide information across a much larger area (Hummel et al. 2011). LIDAR data sets are becoming increasingly available, and a consortium of Federal and State agencies provide reduced costs to member agencies. Regional remote sensing specialists typically have information about acquisition and cost of LIDAR products, which can help in decisions about using these data for habitat monitoring. Mitchell et al. (2012) provide guidance on LIDAR project considerations, data acquisition and processing, required software, products (e.g., canopy height and percentage canopy cover), and application of LIDAR products. Also visit the RSAC Web site dedicated to LIDAR, which describes training, sources of available LIDAR data, and LIDAR software tools (<http://fswb.rsac.fs.fed.us/lidar/>).

Satellite Imagery

Table 4.10 summarizes available sources of digital satellite imagery. Although many sources of satellite imagery are available, with new satellites and sensors added regularly, data from the Landsat program represent the most extensive continuous and consistent archive of Earth imagery. Multispectral satellite imagery records the visible and near infrared portions of the electromagnetic spectrum. Photosynthetic vegetation is dark in visible wavelengths and very bright in NIR wavelengths, making multispectral remote sensing a particularly effective tool for distinguishing photosynthetic vegetation relative to all other Earth surface materials (Lillesand and Kiefer 2000).

Landsat data archived by the USGS represent a valuable source of historical Earth observation data. The USGS EROS data center has now made the entire Landsat data record available at no cost (<http://glovis.usgs.gov/>).

4.5.2 Guidelines for Using Remotely Sensed Data

This section provides a brief overview of approaches for using remotely sensed data, including how these data are typically extracted and how they relate to attributes of interest for wildlife habitat monitoring. For a more detailed description and discussion of these systems and principles, refer to Brewer et al. (2011b), Campbell (1987), Jensen (1996), and Lillesand and Kiefer (2000).

Whether using aerial photographs or satellite imagery, always document the image source, image-processing techniques, scale, and map accuracy (Glenn and Ripple 2004). Valid comparisons of habitat attributes among years using data obtained from remotely sensed sources require thorough documentation of these source characteristics. It is also important to match the monitoring information needs with the scale and type of remotely sensed data.

Whether in photographic or digital form, remotely sensed data can be used similarly. After the monitoring information needs and the image data source have been matched appropriately, information from remotely sensed data is derived by using three general analytical approaches—image interpretation, image classification, and image sampling. Image interpretation involves systematically examining image data and identifying attributes, such as canopy cover or tree height through interpretation of elements, such as image tone and texture (see Brewer et al. 2011b and Lillesand and Kiefer 2000 for further description). Image classification involves categorizing pixels into prescribed classes, such as vegetation types. Image sampling involves selecting, measuring, or recording a sample using aerial photographs or satellite imagery. In the following section, we present more detail on approaches that are especially pertinent to habitat monitoring, specifically image classification and image sampling.

Image Classification

Image classification is the process of categorizing pixels or polygons into land-cover classes or themes (Lillesand and Kiefer 2000). The resulting classification can be binary (e.g., habitat or not habitat) or complex (e.g., existing vegetation composition and structure). Five general analytical processes describe most image classification schemes. All have some applicability to wildlife habitat classification. Classification methods include unsupervised, supervised, an unsupervised-supervised hybrid, ancillary data hybrid classification, and change-detection methods (Brewer et al. 2011b). We do not include specific examples of these analytical processes; however, all of these approaches have been used to produce wildlife habitat-related map products.

Change-detection classifications are increasingly used for monitoring, especially at broad scales. Change detection compares the spectral values of two or more images obtained at different time points at the same geographic location. This method can evaluate changes in the size or shapes of vegetation patches, changes in the width or character of linear features, changes in vegetation type or species composition, changes in condition of a single vegetation type, or changes in timing or extent of seasonal processes (Kennedy et al. 2009). Lu et al. (2004) and Coppin et al. (2004) provide detailed reviews and address change detection methods. Kennedy et al. (2009) describe the four main steps of a change detection analysis and address practical considerations that arise at each step.

A classified image is simply a model and will contain errors because of a variety of factors. Similarities in color or texture at coarse resolutions, for example, may lead to difficulties in differentiating between deciduous tree species. Also, national classification systems have a finite number of classes that can be used efficiently, so some species may not be represented in a given region or landscape. Estimates of more broadly defined vegetation types will often have high accuracy relative to individual species classifications. Bradley and Fleishman (2008) describe the utility of vegetation-based remotely sensed

products beyond land cover maps, such as greenness indices and leaf area index. Not only are these measures useful for species distribution and habitat modeling, but they also are useful for offering wide spatial and temporal coverage (table 4.10).

It is important to assess the quality of thematic maps and quantify the error in a meaningful way, a process known as classification accuracy assessment (Foody 2002, Lillesand and Kiefer 2000). The assessment can be done for one or more purposes; for instance, to estimate either overall accuracy, the accuracy in mapping a specific class, or accuracy in area measurements (Foody 2002). Accuracy assessments generally require a comparison with field-sampled data, but the purpose of the accuracy assessment must be clear to ensure that the field samples include the desired properties (Lark 1995). Foody (2002) provides an overview of classification accuracy assessment approaches. Foody (2009) provides a deeper understanding of the sample size of field plots needed to make classification accuracy assessments.

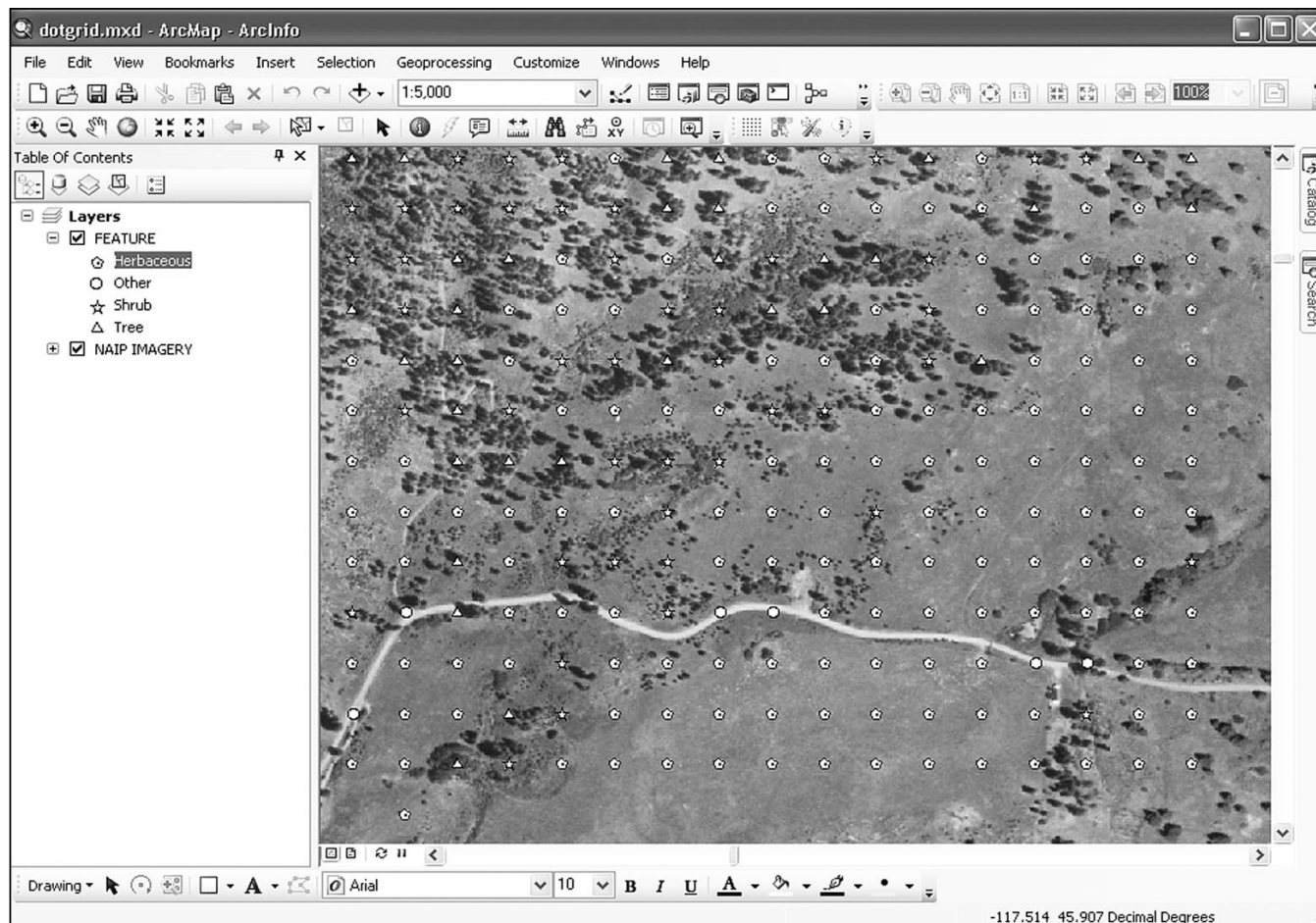
Image Sampling

Direct Image Sampling. Direct image sampling is the process of randomly selecting a discrete set of points or areas from an image to characterize the entire image or an attribute of interest. An example is dot grid sampling, which can be used to estimate canopy cover or to estimate the proportion of the image occupied by different vegetation types. Use the Digital Mylar Image Sampler tool (<http://fsweb.geotraining.fs.fed.us/tutorials/digmylar/>) or other standard GIS tools in ArcGIS software (figure 4.3) to conduct dot grid sampling in a GIS framework. In addition to dot grids, the Digital Mylar Image Sampler tool offers a variety of templates for estimating vegetation cover attributes from high resolution, digital imagery sources. Use of digital dot grids has become commonplace because of the availability of high-resolution digital imagery (e.g., NAIP).

Dot grid sampling can be part of a multistage sample design that includes field data collection, or it can be a surrogate for field data collection. Maersperger et al. (2004) successfully tested techniques for monitoring shrub cover in sagebrush communities. Hamilton et al. (2004) used dot grid overlays on digital photos in conjunction with SPOT satellite imagery in a multistage inventory of pine (*Pinus* spp.) mortality.

Nearest Neighbor Imputation. Nearest neighbor **imputation** is a type of image sampling that uses a set of tools to create a spatial data layer of vegetation and other attributes by using sample data to estimate values for unsampled locations. It typically combines field-sampled data, remotely sensed images, and other environmental attributes, such as elevation and precipitation. Imputation is a process of assigning attribute values to each individual pixel or polygon within an area of interest based on attribute values at one to several field-sampled units. Each unsurveyed unit (target unit) is compared with the field-sampled units (reference units), and is then assigned the attribute values of the reference unit(s) most similar to it.

Figure 4.3.—Example of dot grid sampling with the Digital Mylar Image Sampler tool.



NAIP = National Agriculture Imagery Program.

To create new data layers using nearest neighbor methods, an individual who is knowledgeable about such methods can extract a set of vegetation habitat attributes from field-sampled data and create a spatial depiction of wildlife habitat across the entire area of interest. Most wildlife habitat monitoring teams will need substantial assistance with these techniques for a variety of reasons. Nearest neighbor methods are a current focus of research and are changing rapidly; therefore, consult with specialists to ensure use of the latest and most appropriate approaches. For example, researchers are currently exploring ways to incorporate LIDAR data when developing imputed map layers. Nearest neighbor algorithms are complex and require intense computing time. Software systems for automating the data management, modeling, and analysis required for developing nearest neighbor maps are increasingly available, but still evolving. Finally, if FIA plots are used as reference units, the user must meet certain standards and criteria to obtain exact plot locations because of the issue of plot confidentiality (section 4.4.1).

Researchers have developed several different nearest neighbor methods, using various distance measures (e.g., Euclidean, Mahalanobis) and algorithms. For Forest Service applications, these methods include k -nearest neighbor (k -NN; McRoberts et al. 2002),

gradient nearest neighbor (GNN; Ohmann and Gregory 2002), most similar neighbor (MSN; Crookston et al. 2002, Moeur and Stage 1995), and random forest (Breiman 2001). The term k -NN is sometimes used generically for all nearest neighbor methods, with the letter k representing using more than one reference unit for imputation. Random forest is actually a classification algorithm that was later adapted for imputation by Crookston and Finley (2008). Hudak et al. (2008) provide an overview and comparison of nearest neighbor methods.

Theoretically, nearest neighbor imputation can be used to model nearly any set of vegetation and abiotic attributes (Legendre and Legendre 1998, McCune and Grace 2002, Pielou 1984), although most imputation to date is of forest vegetation attributes because most reference units are forested. Among many examples, researchers have used GNN to map old-growth forest structure (Ohmann et al. 2007) and to model stand density, canopy cover, basal area, tree quadratic mean diameter, stand age, and tree species richness (Ohmann and Gregory 2002). Other researchers have used MSN to model canopy cover, basal area, stand density index, stand height, tree quadratic mean diameter, and total cubic foot volume (Crookston et al. 2002, Moeur and Stage 1995).

Fortunately, the availability of existing imputed map layers is increasing, so it may not be necessary to create new maps. For example, the Pacific Northwest Research Station, in collaboration with Oregon State University (Landscape Ecology Modeling, Mapping, and Analysis team [LEMMA]), has developed imputed maps for several projects, available at <http://www.fsl.orst.edu/lemma>. The Northern Research Station has developed an atlas of forest resources using GNN, FIA, and MODIS vegetation index data that will soon be available. A national pilot study for nearest neighbor imputation has produced several map products, available at <http://blue.for.msu.edu/NAFIS>.

INFORMS, a Forest Service decision-support framework (<http://fsweb.nris.fs.fed.us/products/INFORMS/index.shtml>), imputes forest stand attributes using CSE data as reference units to impute tree lists for unsurveyed stands. The original imputation method for INFORMS was MSN, but users now have options for using other nearest neighbor methods through the software package *yaImpute* (Crookston and Finley 2008). Imputation is only part of the decision support framework; INFORMS is a stand growth simulator with localized growth simulation formulas written for different geographic areas.

The reliability of imputed vegetation maps is contingent on the quality of the data used to develop them. Reference plots must be randomly selected and of sufficient number to represent the full range of ecological conditions within the area of inference. At mid-scales and broad scales, the Forest Service primarily uses FIA data as reference units because the data are collected under a systematic random sampling design and thereby avoid sampling bias. Other sources of reference units are regionally intensified FIA grids, such as the CVS in the Pacific Northwest. Adding LIDAR-derived metrics as an additional source of predictor variables improves imputation accuracy (Hudak et al. 2006, 2008; Maltamo et al. 2006), and this technology can be expected to be more widely used as LIDAR becomes more affordable.

Although nearest neighbor imputation provides a powerful tool for producing spatial depictions of wildlife habitat, these mapped products are modeled, not measured, which results in several sources of potential error at different stages in the modeling process (chapter 3). Current research focuses on improving the ability to map and measure changes in vegetation attributes through time. Although accuracy may continue to remain an issue at fine scales and for short time periods, imputed images can generally be used at mid-scales to broad scales and for time periods that exceed 10 years. Moreover, one can use imputed maps to characterize current conditions, monitor progress toward a desired condition, or ensure that habitat amount remains above a predefined threshold. In these contexts, nearest neighbor imputation can serve as a valuable set of tools for wildlife habitat monitoring.

Image-Based Stratification. Image-based stratification uses imagery and other geospatial data to reduce the variance of the attributes of interest by partitioning the population into homogenous strata. This process is often used to improve the statistical or operational efficiency of a sample (i.e., to improve the sample error of the estimate with a given number of field plots or to achieve a given level of sampling error with fewer field plots). Aldrich (1979) documents using image-based stratification to improve estimates of commercial forest land. McRoberts et al. (2006) provide a summary of FIA post-stratification procedures.

One example of image-based stratification is the Nevada Photo Inventory Project, a pilot effort conducted by Interior West FIA to explore potential gains in efficiency by combining photo-based samples with FIA field-sampled data (Frescino et al. 2009). This general analytical approach has been applied to remote-sensing-based sampling of resources other than forests, such as riparian area estimation (Blackard et al. 2008, Ruefenacht et al. 2005).

Image Counts and Observations. The simplest form of image sampling is to count items of interest. Within the Forest Service, counts include buildings and other structures (see chapter 7 for an example of housing density), water developments, transportation systems, recreation sites (authorized and unauthorized), wildlife use areas, and potential wildlife use areas, such as caves and mines for bats. If the count cannot be automated, owing to the need for human interpretation, generate a random sample of search areas to make inferences regarding the total number within the area of interest. The ability to count features within the image data requires consistent interpretation of the features of interest.

4.6 Conclusions

In this chapter, we present a discrete set of vegetation attributes that, based on experience and literature review, provide useful measures for monitoring habitat for a variety of wildlife species. Although the user will inevitably want to modify these attributes and add new ones, we encourage readers to use standard data-collection methods for all selected attributes. Monitoring by its nature requires remeasurement, and nonstandard methods

will be much more difficult to duplicate in the future. Even more important, interpretation of detected trends requires comparison with trends in other areas. Nonstandard methodologies greatly hamper data comparisons across time and space. In addition, standardized approaches from multiple sources in general are more defensible (they are usually tested and published) and efficient (they have been used repeatedly and tailored to maximize efficiency). Consequently, these methods are more likely to persist through time. Consistent monitoring approaches and data sets that persist for many years are relatively scarce, but they greatly contribute to species conservation.

When applying existing models to monitor habitat, it is important to determine how the vegetation data used for model construction were collected, and to carefully match those methods in subsequent data collection for monitoring. For this reason, we have sought to separate and define closely related terms throughout this chapter, as well as indicate where these differences are important in a monitoring context. For example, canopy cover is not equivalent to canopy closure (section 4.3.2), and which attribute is most appropriate must be distinguished in data collection for monitoring.

In an age of reduced fiscal and personnel resources, along with an emphasis on landscape-level assessments, standardization and consistency in methods and measurements are paramount. Developing cost-effective, standardized wildlife monitoring, whether based on highly individualized habitat models or a suite of selected vegetation attributes, is a daunting challenge. We hope that the methods and resources highlighted in this chapter will help build standardized approaches for monitoring vegetation attributes as part of a wildlife habitat monitoring program. The need for timely, consistent, accurate, and meaningful collection of vegetation data, and its application to monitor wildlife habitat across large areas, is greater than ever.
